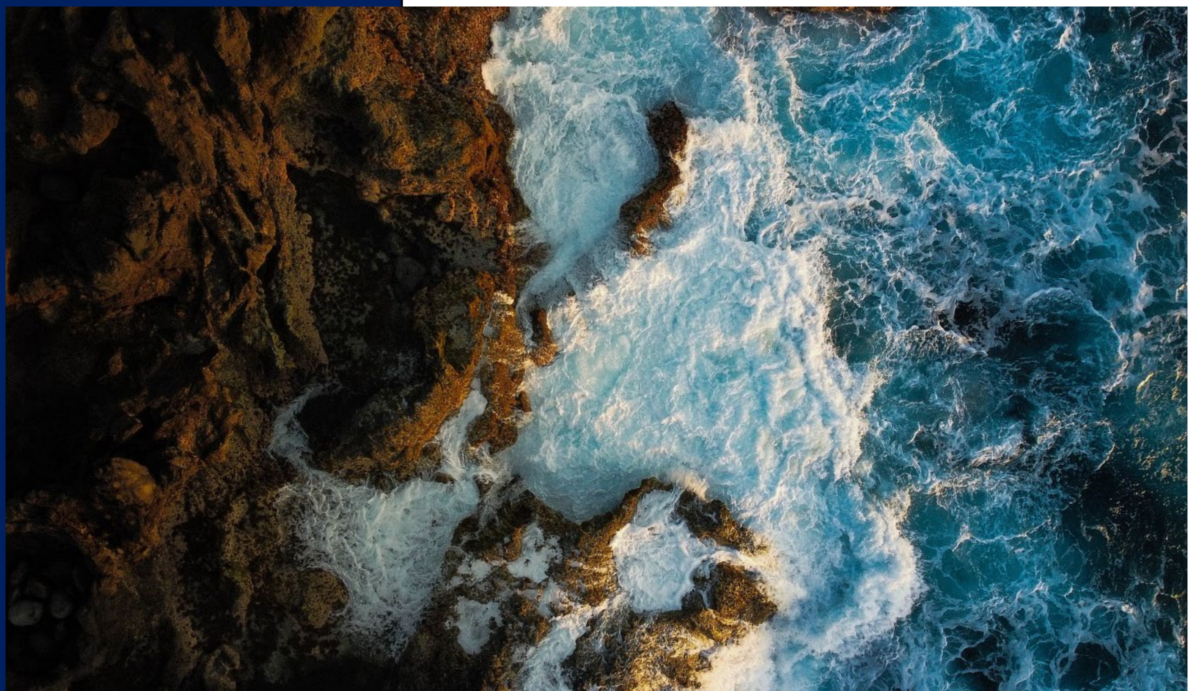

Identification and Assessment of Data Gaps for the Marine Spatial Plan

A Compilation of Expert Feedback

By

Mai Aoki

For the

Shorelands and Environmental Assistance Program

Washington State Department of Ecology

Olympia, Washington

January 2025, Publication 24-06-029

DEPARTMENT OF ECOLOGY
State of Washington

Publication Information

This document is available on the Department of Ecology's website at:
https://apps.ecology.wa.gov/publications/summarypages/2406029.html

Cover photo credit

- Romain Huet, April 1, 2023: Pixabay

Contact Information

Shorelands and Environmental Assistance Program

P.O. Box 47600
Olympia, WA 98504-7600
Phone: 360-407-6000
Website[1]**:** Washington State Department of Ecology

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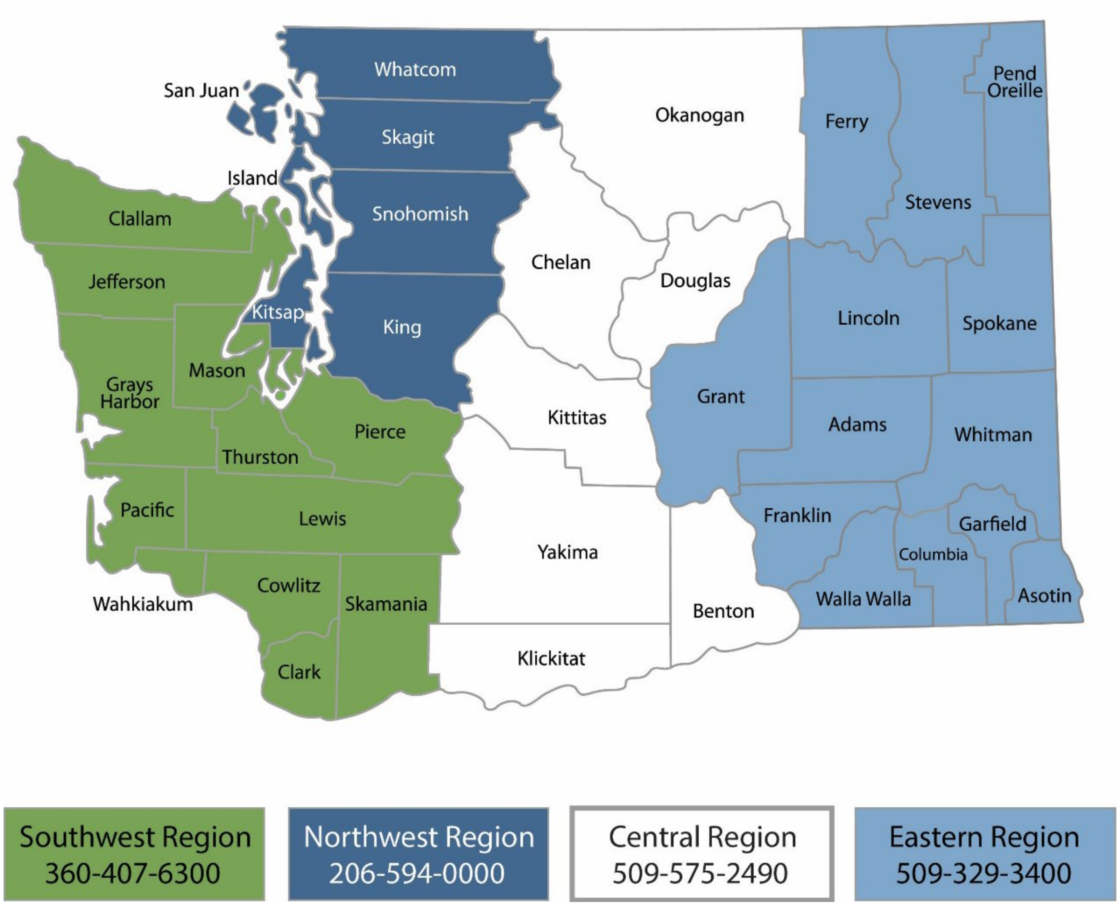
Department of Ecology's Regional Offices

Map of Counties Served



Region	Counties served	Mailing Address	Phone
Southwest	Clallam, Clark, Cowlitz, Grays Harbor, Jefferson, Mason, Lewis, Pacific, Pierce, Skamania, Thurston, Wahkiakum	PO Box 47775 Olympia, WA 98504	360-407-6300
Northwest	Island, King, Kitsap, San Juan, Skagit, Snohomish, Whatcom	PO Box 330316 Shoreline, WA 98133	206-594-0000
Central	Benton, Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima	1250 W Alder St Union Gap, WA 98903	509-575-2490
Eastern	Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman	4601 N Monroe Spokane, WA 99205	509-329-3400
Headquarters	Across Washington	PO Box 46700 Olympia, WA 98504	360-407-6000

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Acknowledgements

The authors of this report thank the following people for their contribution to this study:

- Andrew Leising, NOAA-SWFSC
- Aspen Ellis, University of California, Santa Cruz
- Ben Donatelle, Recreation and Conservation Office
- Burke Hales, Oregon State University
- Casey Clark, Washington Department of Fish and Wildlife
- Christina Fahy, NOAA Fisheries West Coast Region
- Cinde Donoghue, Washington State Department of Ecology
- Curt Whitmire, NWFSC, NOAA
- Daniel Studt, NOAA Fisheries West Coast Region
- Dany Burgess, Washington State Department of Ecology
- David Huff, NOAA
- Dayv Lowry, NOAA Fisheries, West Coast Region Protected Resource Division
- Dr. Amanda Newsom, Washington Department of Fish and Wildlife
- H.T. Harvey & Associates Ecological Consulting
- Ian Miller, Washington Sea Grant
- Ian Taylor, NOA Northwest Fisheries Science Center
- James W. Murray, School of Oceanography, University of Washington
- Jamey Selleck, Natural Resources Consultants
- Jason Cope, NOAA
- Jeffery Leirness, CSS Inc. and NOAA National Centers for Coastal Ocean Science
- Jeffrey Moore, NOAA Southwest Fisheries Science Center
- Jeffrey Seminoff, NOAA Southwest Fisheries Science Center
- Jennifer Hagen, Quileute Tribe
- Jennifer Ruesink, University of Washington
- Jesse Schultz, Washington Department of Fish and Wildlife
- Julie Ann Koehlinger, Hoh Indian Tribe
- Karma Norman, Northwest Fisheries Science Center
- Katie Wrubel, Olympic Coast National Marine Sanctuary
- Katy Davis, Washington Department of Fish and Wildlife
- Kelly Andrews, NOAA/NMFS/Northwest Fisheries Science Center
- Kendall Valentine, University of Washington
- Kevin Decker, Washington Sea Grant
- Larissa Pfleeger, Shoalwater Bay Tribe
- LCDR John Macdonald Robertson, US Coast Guard
- Leif Anderson, NOAA Fisheries
- Lewis Barnett, NOAA
- Liz Schotman, Washington Regional Manager, Surfrider Foundation
- Lynne Barre, NOAA Fisheries
- Makah Tribe
- Meg Chadsey, Washington Sea Grant
- Megan Dethier, University of Washington
- Melissa Miner, University of California, Santa Cruz and MARINe
- Ole Shelton, NOAA
- Parker MacCready, University of Washington

- Quinault Indian Nation
- Raymond Wendel, Washington Department of Fish and Wildlife
- Scott Pearson, Washington Department of Fish and Wildlife
- Shallin Busch, NOAA Fisheries
- Stephanie Jolivette, Department of Archaeology & Historic Preservation
- Steven Bogard, NOAA Southwest Fisheries Science Center
- Sydney Hanson, Department of Archaeology & Historic Preservation
- Tammy Russell, Scripps Institution of Oceanography
- Washington Coastal Marine Advisory Council
- Washington Department of Fish and Wildlife
- Washington Department of Fish and Wildlife
- Washington State Recreation and Conservation Office
- Whitney Roberts, Washington Department of Fish and Wildlife

Various other experts participated in this process. Sincere gratitude is extended to all contributors for their willingness to share their valuable knowledge, insights, and expertise. Their engagement in these meaningful discussions was instrumental in shaping the outcomes of this effort.

Special thanks to the following staff from the Washington State Department of Ecology for their assistance in the development of this report:

- Casey Dennehy
- Heather Rogers
- Henry Bell
- Jay Krienitz
- Noah Linck
- Olivia Zimmerman
- Teressa Pucylowski
- Vania Beard

Executive Summary

The Washington Marine Spatial Plan (MSP), adopted in 2018, provides a framework to manage new ocean uses in Washington's Pacific waters. It also offers essential baseline information and spatial analyses to support the evaluation of proposed projects. However, due to evolving socioeconomic, ecological conditions, and marine resource management priorities, much of the MSP data is outdated and has limitations in quality and accuracy.

To address this issue, in 2020, the Washington State Department of Ecology (Ecology) convened an effort to identify priority topics and data gaps by engaging state and federal agencies, Tribes, researchers, and resource managers.

Building on this effort, this project assessed data gaps critical for policy compliance, decision-making on new ocean uses, and mitigating conflicts with existing uses. Interviews with 114 experts from state and federal agencies, academic institutions, and organizations, along with input from the Washington Coastal Marine Advisory Council (WCMAC) and technical staff from five coastal Tribes, contributed to the evaluation of 533 data gaps across 34 topics. These gaps were categorized into general, offshore wind, and offshore aquaculture data gaps. Expert feedback also led to the identification of "Key Data Gaps" for each topic.

This report is a detailed compilation of expert feedback for each data gap. It seeks to serve as a tool to assess the current landscape of existing knowledge and guide future research initiatives for ocean management. The next step is to develop a strategy to address data gaps.

Introduction

Background

The Washington Marine Spatial Plan

In 2010, the Washington State Legislature enacted a marine planning law, Marine Waters Planning and Management ([RCW 43.372](RCW 43.372)), to integrate coastal decision making and ecosystem-based management. This law authorized the state to create and use a marine spatial plan "to guide state agencies and local governments when exercising jurisdiction over proposed uses and activities" in state waters. RCW 43.372.005(3).

The Washington Marine Spatial Plan (MSP) was developed and adopted by the state in 2018. The MSP implements a proactive planning strategy and a coordinated decision-making process for addressing new ocean use development in Washington's Pacific waters, such as offshore renewable energy or offshore aquaculture. The MSP also guides state agencies and local governments in evaluating the effects of such proposed projects, and provides various data to help inform these decisions, in the form of maps, spatial analyses, and baseline information.

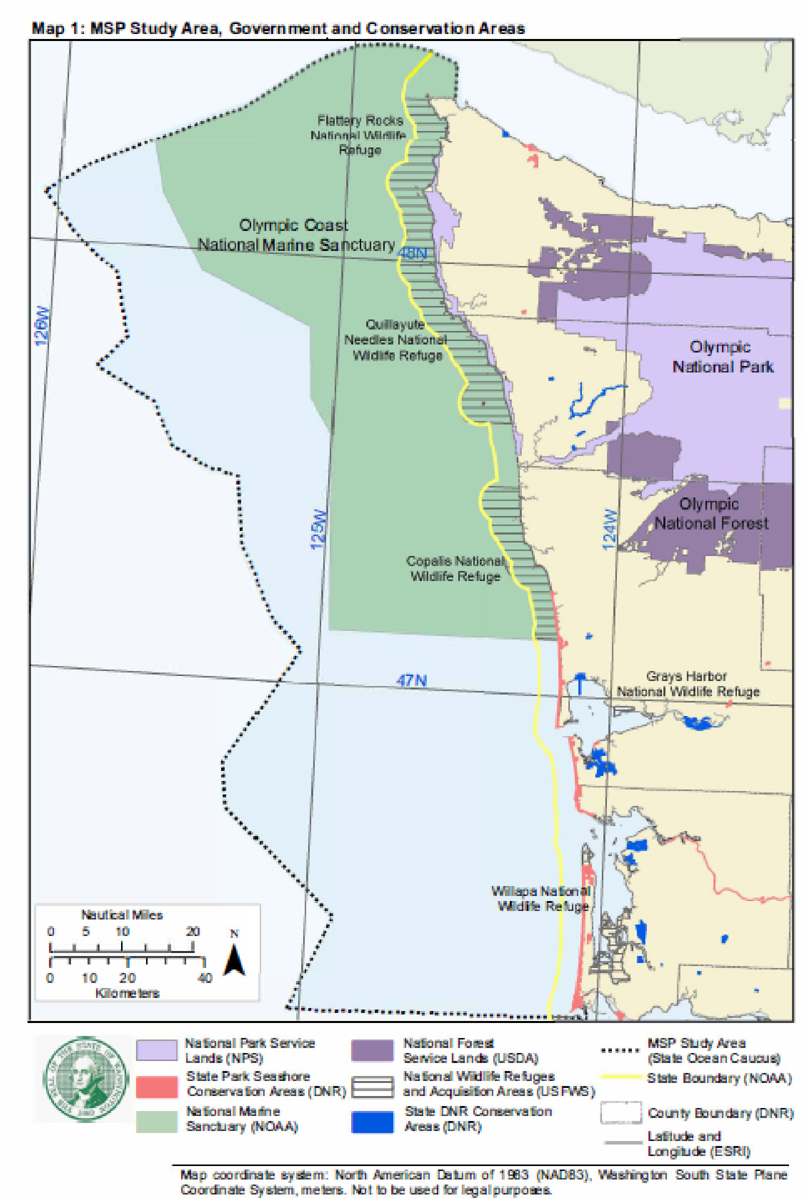


Figure 1. MSP Study Area and government and conservation areas

The MSP applies to a "Study Area" (Study Area), a geographic area that encompasses the marine waters of the Pacific Ocean along Washington's coastline. This boundary stretches from the intertidal zone to the continental slope, with depths reaching up to 700 fathoms (4,200 feet) and extending 35 to 55 nautical miles offshore. It includes both state waters (0-3 nm) and federal waters beyond 3 nm. It spans from Cape Flattery at the north of the Olympic Peninsula to Cape Disappointment at the mouth of the Columbia River and includes the estuaries of Grays Harbor and Willapa Bay. The Study Area was selected for its high intensity and density of existing coastal uses, its ecological significance to Washington's coastal zone, and its ability to maximize the use of existing data and information. Additionally, the Study Area was based on the expected locations for potential new federal activities and their foreseeable effects on the state's coastal uses and resources.

Despite the boundaries of the Study Area, the MSP incorporates data and information that extend beyond this area. Many of the uses and resources along Washington's Pacific coast are interconnected with activities, infrastructure, or communities located outside the MSP Study Area. Data beyond the Study Area is included to provide a comprehensive overview of existing activities and resources in Washington, their significance to coastal communities and the state, and future trends.

Enforceable Policies

In addition to providing data and information regarding resources and existing uses, the MSP also established two new enforceable policies: Important, Sensitive, and Unique areas (ISUs) and Fisheries Use Protection Standards (FUPS).

An enforceable policy refers to "State policies which are legally binding through constitutional provisions, laws, regulations, land use plans, ordinances, or judicial or administrative decisions, by which a State exerts control over private and public land and water uses and natural resources in the coastal zone." 16 U.S.C. § 1453(6a). Under the federal Coastal Zone Management Act (CZMA), the "federal consistency" provision mandates that federal actions, both within and outside the coastal zone, must be consistent with the enforceable policies of a state's federally-approved Coastal Zone Management Program (CZMP) if they have reasonably foreseeable effects on any coastal use (land or water) or natural resource. Federal actions encompass those requiring federal licenses or permits, as well as activities or projects conducted by federal agencies.

The enforceable policies of Washington's CZMP include provisions from the following state laws and their implementing regulations:

Table 1. State laws and their purpose

LAW	PURPOSE
Shoreline Management Act (SMA)	Consistent with the overall best interest of the state and the people generally, to preserve the public's opportunity to enjoy the physical and aesthetic qualities of natural shorelines of the state to the greatest extent feasible. (RCW 90.58.020)

LAW	PURPOSE
State Environmental Policy Act (SEPA)	To promote efforts which will prevent or eliminate damage to the environment and biosphere, stimulate the health and welfare of human beings, and better understand the ecological systems and natural resources important to the state and nation. (RCW 43.21C.010)
Water Pollution Control Act and Water Quality Standards	To retain and secure high quality for all waters of the state and prevent and control the pollution of state waters. (RCW 90.48.010)
Washinton Clean Air Act	To preserve, protect, and enhance the air quality for current and future generations. (RCW 70A.15.1005)
Ocean Resource Management Act (ORMA)	To protect the state's coastal waters, seabed, and shorelines while recognizing the importance of existing ocean and marine-based industries and activities. (RCW 43.143.005)
WA MSP	The MSP contains two enforceable policies: ISUs and FUPS. ISUs established standards to maintain areas with high conservation value, high historic value, or key infrastructure and to protect them from adverse effects of offshore development, while allowing existing compatible uses. FUPS protects fisheries from adverse effects of new ocean uses, including avoiding and minimizing social and economic effects to fishing. (MSP Sections 4.3.3 and 4.6.3)

The Washington Coastal Zone Management Program Enforceable Policies[2] provides additional information regarding the federally-approved enforceable policies of Washington's CZMP.

Described in the next section, these enforceable policies significantly influenced the data gaps that were selected for this data gap assessment effort.

Efforts to update the MSP

The MSP data have limitations in quality and accuracy and differ in terms of collection methods, timing, duration, and measurement frequency. Additionally, while some features of the Washington coast and ocean are stable, others are more dynamic and can change significantly year to year. Unfortunately, many datasets lack long-term monitoring, which is essential for capturing the variability of dynamic resources. To address these gaps, statistical models are often used. However, changing conditions may result in future patterns that differ from those indicated by current datasets.

While external organizations may have updated some of the information contained in the MSP, much of the data and information remains unchanged since the MSP's adoption. This,

[2] https://apps.ecology.wa.gov/publications/documents/2006013.pdf

combined with changing socioeconomic and ecological conditions, evolving priorities for marine resource management, and discussion around potential new ocean uses, highlighted the need for the state to reassess its data and research needs related to marine spatial planning. In response, in 2020, the Washington State Department of Ecology (Ecology) executed a data assessment effort (2020 MSP Data Assessment). The 2020 MSP Data Assessment surveyed Washington state and federal agencies, Tribes, researchers, academics, resource managers, and other interested parties to reevaluate the information contained in the MSP and identify and prioritize data and research needs. Participants prioritized a total of 106 topics and identified numerous data gaps, including those relating to offshore wind and offshore finfish aquaculture.

Purpose and Method

This project aimed to build upon the 2020 MSP Data Assessment. It undertook an in-depth review of specific data gaps, focusing on those critical for decision-making, evaluating potential new ocean uses, ensuring compliance and consistency with enforceable policies, and minimizing conflicts associated with existing ocean uses.

The information collected through this process is intended to serve as a tool to assess the current landscape of existing knowledge and guide future research initiatives that promote sustainable ocean management practices and facilitate effective responses to ongoing and emerging challenges. The next step is to develop a comprehensive strategy to address these identified data gaps.

Topic selection

This project reviewed data gaps from topics that were identified during the 2020 MSP Data Assessment. However, due to constraints in time and resources, not all topics were used. Topics identified as having higher priority, as well as those that were broader and encompassed other narrower topics, were selected. Additionally, new topics were incorporated based on the recommendations provided by project participants. A total of 34 topics were selected for this project. These topics were organized into five categories:

Table 2. List of topics in each category

BIOLOGY

Albacore tuna	Marine mammals
Benthic invertebrates	Pacific Whiting
Birds	Salmon
Corals and sponges	Sea turtles
Forage fish	Invasive species and pests: Plants
Groundfish	Invasive species and pests: Animals

ECOLOGY

Coastal estuaries	Rocky shores
Kelp and eelgrass	Sandy beaches and shoreline
Protected areas	Seafloor

OCEANOGRAPHY

California Current Ecosystem	Marine debris
Climate variability	Marine sediment
Currents, eddies, and plumes	Ocean acidification
Harmful Algal Blooms	Upwelling
Low dissolved oxygen events	

SOCIOECONOMIC

Aquaculture	Research
Commercial fisheries	Shipping, transportation, and navigation
Recreational fisheries	

CULTURE

Culturally or historically significant sites	Recreation and tourism

Four other topics were initially identified for this effort. However, due to a lack of sufficient feedback, these topics were removed. They are recommended for consideration in future endeavors to assess data gaps. These topics are:

Pacific Sardine	Aesthetic values
Public services, utilities, and energy	Community culture

Data gap selection

Data gaps were selected from the 2020 MSP Data Assessment, with a focus on those critical for decision-making, evaluating potential new ocean uses, ensuring compliance with enforceable policies, and minimizing conflicts related to ocean use. For example, data gaps related to moral and legal obligations for protecting sites from offshore development were excluded. Additionally, new data gaps were incorporated based on expert feedback and relevant scholarly publications.

Within each topic, the selected data gaps were organized into three categories: general data gaps, data gaps pertaining to offshore wind, and data gaps associated with offshore aquaculture. While the offshore aquaculture-related data gaps for the 2020 MSP Data Assessment focused on finfish, this project broadened the scope to include all potential forms of offshore aquaculture, encompassing shellfish, finfish, and kelp.

Interviewing subject matter experts

Acknowledging that not all data gaps identified in the 2020 MSP Data Assessment were reviewed by subject matter experts and that some research progress has occurred since then, this project aimed to engage experts from various agencies and organizations to further identify and assess these data gaps. Experts were identified through networking efforts and resources such as state and federal agency websites and university faculty directories.

For each expert, the following questions were asked:

- Is this a data gap? What is known and unknown regarding this data gap?
- Are there data gaps that are missing?

The process of collecting feedback relied on the availability and willingness of experts to participate. For each topic, at least three experts were consulted to provide their insights and perspectives. This approach was designed to capture a broad range of viewpoints, enhancing the assessment of data gaps and contributing to a more comprehensive and robust evaluation process. Notes were taken during the interviews and subsequently shared with the interviewees. Their review and revision of the notes were requested to ensure their feedback was captured accurately.

Through this process, the list of data gaps was refined; data gaps were added, rephrased, consolidated, or removed. To note, while this list aims to highlight data gaps of concern and interest, it is important to recognize that this list is not exhaustive. Existing gaps may evolve as research progresses and new data gaps may emerge. Ongoing collaboration with researchers and interested parties is encouraged to reassess existing gaps, identify new data gaps that may emerge, and better understand the present research landscape.

In addition to providing feedback, experts were also asked to rank the data gaps within each topic. As this project's assessment of data gaps was preliminary, a specific criterion to rank the gaps was not provided. Rather, the experts conveyed why they believed a specific data gap was of a higher interest than another. This elevated certain data gaps and resulted in a list of "Key Data Gaps." This ranking process is further discussed in the next section. Lastly, recommendations for resources and additional experts to consult were requested.

It is important to point out that the assessment of each data gap is based on the professional opinions of the experts consulted. This project did not independently verify the feedback collected from the experts. As such, readers should be aware that the views expressed are not necessarily representative of the views of the Washington State Department of Ecology and may differ from other sources or perspectives. There may be disagreements regarding the interpretations or conclusions drawn. While not formally fact-checked, the expertise of these participating individuals has been invaluable in offering insights into the current state of knowledge on various topics. Their perspectives have contributed to a deeper understanding of existing knowledge, illuminated key areas of uncertainty, and highlighted topics that may require further research or investigation. These expert opinions are intended to guide and inform ongoing discussions and future efforts, rather than serve as definitive or conclusive statements. Consequently, readers should be mindful of the context and limitations of the feedback as they review this report.

Identifying "key data gaps" and compiling collected data

Given the large number of identified data gaps, experts were asked to rank the gaps within each topic based on their level of importance. The final ranking for each data gap was determined by calculating the average score. The top six data gaps were designated as the "key data gaps." In cases of tied scores, either five or seven data gaps were selected.

Due to time constraints or limited expertise, not all experts ranked every data gap. Additionally, the limitations of using an average-based ranking system are acknowledged. Personal interests and values can influence rankings and there are also inherent shortcomings in calculating an average. Averages are sensitive to outliers which can skew results, and they fail to capture the variability or consensus among participants. They also imply each participant's score holds equal weight. For example, if only one participant ranked a specific data gap, this participant's score receives a greater weight in the "final" ranking.

Table 3. Sample of participant scores and calculation of average score

DATA GAP	PARTICIPANT 1	PARTICIPANT 2	AVERAGE
A	1	3	2
B		1	1
C	2	2	2
D	3	4	3.5

Hence, while averages offer a useful summary, there is a need to interpret them within their subjective limitations.

The purpose of creating a more focused list of data gaps by identifying the 'Key Data Gaps' is to serve as a starting point to explore future research initiatives. Assessing the overall feasibility of each data gap will be a vital next step. The data gaps ultimately selected for future research efforts must be achievable within the constraints of available funding, resource, and expertise. This assessment will require consideration of a range of factors such as the associated costs, the expected duration of the research projects, the necessary resources required to conduct the studies, and the availability of qualified researchers. This selection should also not be interpreted as being definitive. The rank of a data gap may shift as research and technological advancements progress and new data gaps emerge.

Once interviews for a given topic were completed, the feedback was compiled and shared with each participant for a final review. This process gave experts an opportunity to make any necessary adjustments to their feedback, review the data gaps identified subsequent to their interviews, and re-rank them as appropriate.

WCMAC

With a refined and narrowed list of data gaps in hand, feedback from the Washington Coastal Marine Advisory Council (WCMAC) was sought.

WCMAC was established in 2013 to serve as a forum for ocean policy, planning, and management issues on the state's Pacific coast. Representing diverse interests and entities, WCMAC provides recommendations to the state on the management of ocean resources and uses. Within the WCMAC is the Offshore Wind Technical Committee (OSW TC) that was formed in 2022 to advise and provide recommendations on technical issues relating to offshore wind.

Recognizing the expertise of the WCMAC members, a presentation was made to the OSW TC in January 2023 to introduce the project. The initial plan involved having WCMAC members assess data gaps before other subject matter experts conducted their own assessments. However, during a data gap evaluation for biological topics on February 21, 2023, the WCMAC members expressed challenges in providing feedback on topics outside their areas of expertise. As a result, the process was adjusted to first gather feedback from subject matter experts, then return to the WCMAC once the data gaps were refined and a more focused list was available for review. Additional presentations were made to the OSW TC in July and October 2023 to provide general updates.

On February 14, 2024, a presentation was given to the full WCMAC and a request for volunteers was made for feedback on the "Key Data Gaps." Interested members were contacted via email and invited to complete a survey to indicate the topics they wished to provide feedback. Five members responded to the survey, and three topics were assigned to each member without overlap, thereby maximizing the number of topics reviewed by WCMAC members. Interviews were conducted in the following months, and the notes taken during these interviews were shared with the interviewees to confirm the accuracy of their feedback. Feedback from WCMAC members is available for the following topics:

Climate variability

California Current Ecosystem

Coastal estuaries

Commercial fisheries

Forage fish

Groundfish

Kelp and eelgrass

Marine debris

Ocean Acidification

Protected areas

Recreation and tourism

Salmon

Shoreline: Sandy beaches

Seafloor

Upwelling

Coastal Tribes

The invaluable knowledge possessed by Tribes is widely acknowledged. To facilitate collaboration in evaluating known and unknown information, five coastal Tribes were contacted: the Hoh Indian Tribe, the Makah Tribe, the Quileute Tribe, the Quinault Indian Nation, and the Shoalwater Bay Indian Tribe. Due to the project's limited time frame and the importance of incorporating Traditional Knowledge, it was determined that a comprehensive assessment of each identified data gap and the identification of additional gaps within the project's timeline would be unfeasible. Consequently, a general assessment of the data gap topics was requested. Detailed information regarding their feedback can be found in "Section II: Coastal Tribes" of this report.

Report format

This report is organized into eight chapters: Introduction, Coastal Tribes, Biology, Ecology, Oceanography, Socioeconomics, Culture, and Conclusion. With the exception to the Introduction, Conclusion, and the Coastal Tribes chapters, the five remaining chapters are organized as follows:

List of data gaps: This list provides the data gaps that were identified and assessed.

Background: This section summarizes relevant information contained in the MSP.

Key data gaps: This section identifies the top six data gaps that, on average, were ranked the highest by the experts. Where applicable, the data gaps are categorized into three groups: general data gaps, offshore wind data gaps, offshore aquaculture data gaps. For each data gap, the following is provided:

- Summary of feedback: Expert feedback was compiled and summarized for each identified data gap. Notably, some feedback applied to multiple data gaps. To accommodate the assumption that a reader may choose to only review the feedback for specific gaps, the feedback was repeated where applicable.
- Additionally, all identifying information of the experts who provided feedback was removed from these summaries. This decision to present their feedback anonymously was made to encourage a more open and honest dialogue among participants. By removing the pressure of attribution, the aim was to make participants feel more comfortable sharing their thoughts and opinions, leading to more candid responses. Without anonymity, experts might have felt compelled to limit their remarks or fact-check every comment, which would have required significant time and resources and substantially prolonged the process.
- Feedback on importance: A summary is provided on the reasons why the experts regarded the data gap to be more significant than others. Not all experts provided a rationale; thus, a summary was prepared based on the justifications that were available.
- WCMAC: When applicable, feedback from a WCMAC member is provided.

Other Data Gaps: This section contains the remaining data gaps. These data gaps are also organized by general data gaps, offshore wind data gaps, and offshore aquaculture data gaps. Similar to the “Key Data Gaps,” a summary of expert feedback is provided for each data gap. These summaries also omit any identifying information about the participating experts.

Resources: A table is provided to present resources relevant to the identified data gaps. The table contains information on the resource name, access link, type of resource, and a brief description.

Coastal Tribes

Technical staff from the Hoh Indian Tribe, the Makah Tribe, the Quileute Tribe, the Quinault Indian Nation, and the Shoalwater Bay Indian Tribe were invited to preliminarily review the project and data gap topics that were selected for this project. Through emails and for some, one to three virtual meetings, various tribal staff participated and offered feedback at different levels of detail. Conversations focused on a general assessment of the project structure and topics and recommendations of publicly available resources were shared. Specific data gaps were not reviewed. A summary of each Tribe's feedback is provided below. **These summaries are based solely on meeting notes and are provided for information purposes only. They should not be construed as representing the official viewpoints, beliefs, or positions of any Tribe government. Readers are encouraged to engage directly with tribal governments for accurate and comprehensive understanding of their perspectives and concerns.**

The feedback Tribes provided will be considered to inform the development of a strategy to address data gaps which will aim to bring together western science and Traditional Knowledge. If a Tribe expresses interest, we look forward to exploring meaningful ways to work together to develop a strategy that ensures research initiatives align with tribal priorities, benefit indigenous communities, and uphold the integrity of indigenous data. We are committed to the principle of data sovereignty, recognizing it as a right of indigenous people to govern their data collection and control their data in ways that align with their values, traditions, and aspirations. Please note that the meetings described above were intended solely for discussion purposes and are not indicative of a Tribe's approval of Ecology's plan to develop a strategy to address data gaps or agreement to participate in those conversations.

Hoh Indian Tribe

There were three data gap topics that stood out:

Table 4. Topics of interest for the Hoh Indian Tribe and corresponding comments

TOPIC	COMMENT
Forage fish	There was a recognition on the general lack of forage fish data. Of particular concern was the limited data regarding smelt, a species of value to the Hoh Tribe. Despite their importance, information on smelt populations is lacking. Over time, smelt abundance has fluctuated between good and poor years and without an oral history documenting these changes in smelt runs, establishing a time series of smelt data would be valuable.
Hypoxia	The observation of an increase in hypoxic events, ranging from localized occurrences to widespread phenomena, has elevated concerns. Along the coast, a considerable number of instruments are deployed to monitor various ocean parameters; however, gaps exist and necessitate gathering comprehensive information on hypoxic conditions. Collecting this data to better understand the timing, frequency, and extent of hypoxic events are crucial for effective management.

TOPIC	COMMENT
Nearshore data	There is a substantial gap in understanding coastal dynamics. Data needs were identified for the nearshore zone, extending up to 15 kilometers from the shore. Observations in the nearshore zone reveal a complex interaction of factors and of particular interest is the movement of water between onshore and offshore areas and its impact on marine life.

In addition, there was a recommendation to review the comment letter the National Marine Fisheries Service submitted to BOEM on June 28, 2022, in response to the commercial leasing for wind energy development on the Outer Continental Shelf offshore Oregon (Docket No. BOEM-2022-0009). This letter identified information BOEM should collect when assessing offshore wind activities in Oregon. Represented as covering many of the questions Tribes generally had, in particular, concerns for the need for baseline data and the effect offshore wind activities will have on upwelling were shared.

Makah Tribe

Staff from the Makah Tribe expressed an interest in data gap topics relating to:

Table 5. List of topics of interest for the Makah Tribe

TOPIC		
Groundfish	Climate variability	Oceanographic processes
Seabirds	Currents	Fisheries
Marine mammals	Upwelling	Vessel activities

During a Makah Ocean Policy Work Group meeting, Ecology was invited to discuss this data gaps identification and assessment project. The Makah Tribe's Vice Chairman and staff stated they had additional needs prior to further engagement on this matter and recommended review of the Makah Ocean Policy document. Ecology will continue to collaborate with the Makah Tribe to discuss science, data gaps, and ocean policy management as capacity allows. Acknowledging and respecting their tribal sovereignty and capacity, Ecology remains committed to working in partnership with the Tribe.

Quileute Tribe

Communications did not involve identifying specific data gap topics of interest. However, a discussion regarding data gaps concerning Washington's Marine Spatial Plan was deemed useful, particularly since elements of the data catalog and data viewer were used for their work. A suggestion was made to provide updates on this effort through a meeting format, inviting pertinent staff from other Tribes to participate.

Quinault Indian Nation

Interest and comments were expressed for several data gap topics which are provided below:

Table 6. Topics of interest for the Quinault Indian Nation and corresponding comments

TOPIC	COMMENT
Benthic invertebrate species	There are interests in a study on intertidal communities including long-term trends in species abundance and distribution. Additionally, an independent review of data gaps on Dungeness crabs is needed, including their habitat preferences and life-stage vulnerability to physical and chemical stressors. Pacific Razor clams are also a culturally important species to the Quinault Indian Nation (QIN) and vulnerable to various stressors at both larval and juvenile-adult stages of their life cycles. Their habitat is limited on the WA coast.
Groundfish	Recommend including an independent review of data gaps on black cod. Recommend habitat suitability be estimated for numerous culturally and economically important species including sablefish, halibut, lingcod, Sebastes spp., Etc.
Kelp and eelgrass	There is a significant difference between these two areas. On the outer coast. Eelgrass is not prevalent in high energy coastal nearshore areas. Found primarily in embayments where it acts as important habitat for crab, salmonids, and others. Kelp is an important habitat maker on the outer coast where it can get established. Tribal knowledge keepers recall that kelp was much more prevalent in the past and extended beyond Destruction Island to offshore of the sandy beach areas from Pt. Grenville south.
Rocky shores	The QIN reservation is in a transition zone where sandy beaches end and shift to rocky shores. There are very erosive shorelines that change dramatically season to season based on ocean activity. Because of this, the tidepools at Pt. Grenville are important source/sinks for intertidal organisms that have few suitable anchoring spots south until the Columbia River mouth area. The tidepools there may act as an important connection to the tidepools in the north that allow genetic flow of species along the entire WA coast. This may be more suitable for an Intertidal Invertebrates section – same with razor clams.

TOPIC	COMMENT
Habitat identification	There was a general interest in advancing efforts aimed at identifying habitats. The QIN was engaged in a habitat framework project which used the Coastal and Marine Ecological Classification Standard (CMECS) to analyze and characterize marine habitats. This project was transferred to the Northwest Indian Fisheries Commission. QIN is also contracting with researchers to develop habitat suitability indices for important species project into the future using IPCC climate change scenarios.
Water column	There is an interest in conducting studies of the water column. Water column data is critical to both climate/ecosystem monitoring and to responsible fisheries management. Not just studies but there is also interest in augmenting QIN's ability to collect water column monitoring data.
Climate variability	Key piece to collect good information on basic physical and oceanographic variables. Data collection and monitoring is key to this for QIN to defend and sustainably manage its treaty resources.
Upwelling	There are interests in understanding where upwelling is the strongest and better comprehending primary and secondary productivity. Two resources were recommended. The first is the NANOOS Visualization System's Data Explorer, an application where various monitoring assets can be viewed. The second is a new high frequency radar placed on the outer coast by Westport. This radar monitors the transport of surface waters and allows tracking of boats, people, marine spills, plankton, and crab megalope. Quinault also uses NOAA's upwelling indices[3] for various species monitoring/forecasting.
Low dissolved oxygen	There are questions on the co-occurrence of low dissolved oxygen with other stressors and whether refugia exists from these stressors. There are efforts to study what happens if there is high temperature and low DO or low pH. Refugia from these stressors will be key. Are they available with seasonal events that have been getting longer? And what are the primary areas affected by seasonal hypoxia events?
Fisheries	This topic should be divided into tribal and non-tribal categories and should include recreational and subsistence fishing.
Public services, utilities, and energy	There is interest in studies related to offshore wind.

[3] https://oceanview.pfeg.noaa.gov/products/upwelling/dnld

TOPIC	COMMENT
Culture	Treaty rights are significant. The State of WA is a co-manager on treaty fisheries and the federal government is the trustee of treaty resources and is responsible for maintaining access and sustainability. Particularly in the context of offshore wind and aquaculture, assessment of impacts to treaty rights by, for example, displacement of effort will be crucial. Among other potential impacts.

Shoalwater Bay Indian Tribe

Interest and comments were expressed for several data gap topics which are provided below:

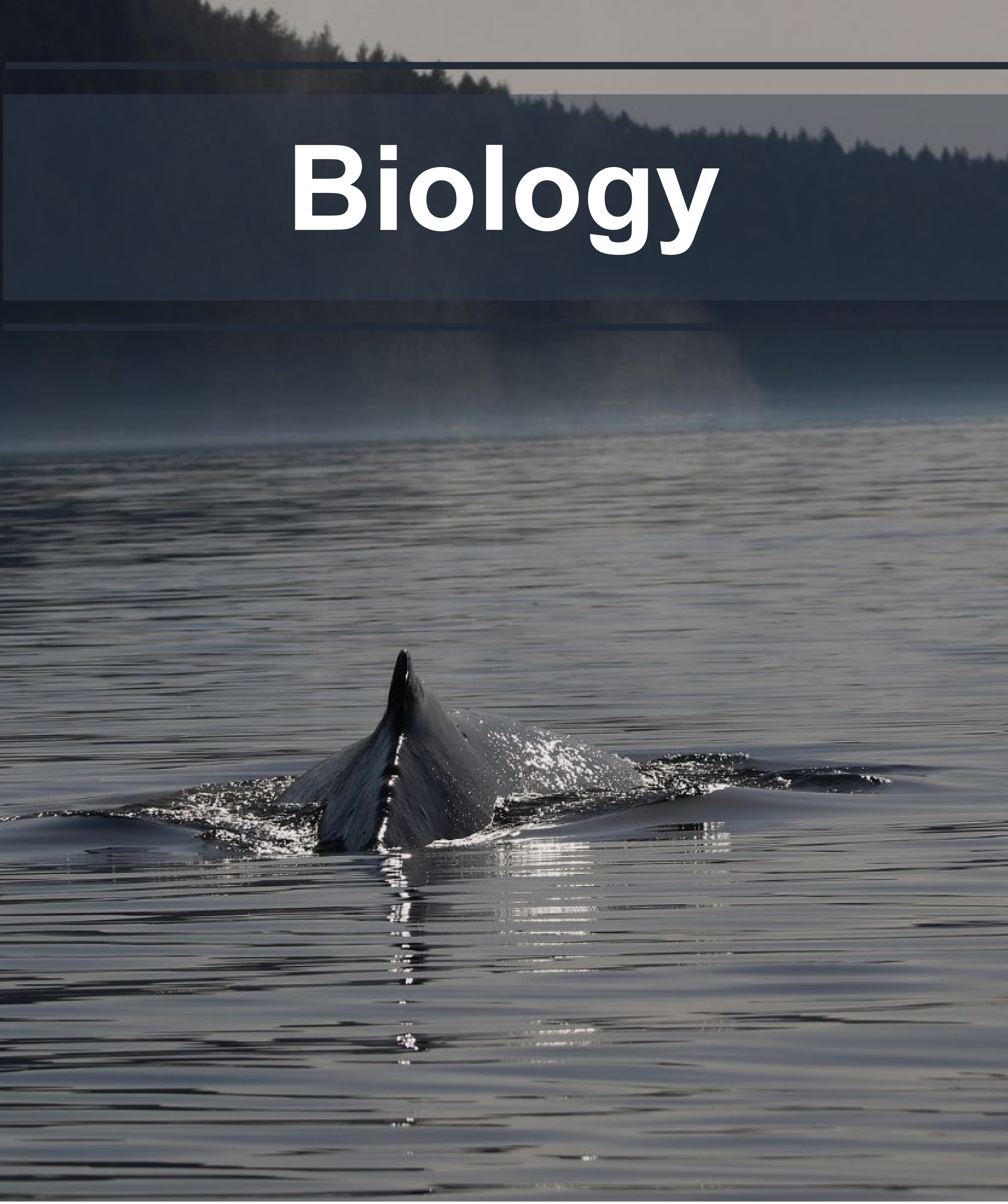
Table 7. Topics of interest for the Shoalwater Bay Indian Tribe and corresponding comments

TOPIC	COMMENT
Invasive species and pest species	There are interests in: 1) studying the effect of increased vessel activity from offshore activities on the abundance and distribution of invasive and pest species; and 2) collecting current and sea water temperature data to better predict the influx of these species.
Seabirds, shorebirds, and waterfowl	Coastal restoration work for the habitat of two protected species, the Western Snowy Plover and the Streaked Horned Lark, is ongoing. A Motus Wildlife Tracking System[4] tower is situated in Tokeland, WA.
Sandy Beaches and shoreline	There is ongoing work to address shoreline issues with Oregon State University and the Washington State Department of Ecology such as the Graveyard Spit Restoration and Resilience project and the Shoalwater Bay Dune Restoration project. There is interest in building capacity to monitor the shoreline and perform annual surveys.
Coastal estuaries	Interest expressed.
Kelp and eelgrass	There is interest in mapping native and non-native species.
Rocky shores	There is interest in mapping and identifying areas for Olympia oyster restoration.
Seafloor	There is interest in collecting bathymetry data.
Protected areas[5]	Interest expressed.

[4] The Motus Wildlife Tracking System uses automated radio telemetry to track individuals of various bird, bat, and insect species with high temporal and geographic precision. https://motus.org/

[5] The term "Protected Areas" includes Critical Habitat Areas, Important Sensitive and Unique Areas, Essential Fish Habitat, and Ecologically Important Areas.

TOPIC	COMMENT
Harmful algal bloom	Interest expressed. Follow shellfish biotoxin data.
Climate variability	There is interest in installing a wave buoy to monitor wave height, swell duration, and timing of wave height to support the Tribe's resilience planning efforts.
Marine debris	There is an interest in updating the Geographic Response Plan by incorporation locations for installing oil spill booms.
Marine sediment	Interest expressed.
Aquaculture	Interest expressed. Commercial aquaculture operations are established on tribal beds, with certain sites used for cold storage purposes.
Commercial fisheries	Interest expressed. There is an individual within the Tribe that holds a commercial crabbing license.
Recreational fisheries	Interest expressed. There are general concerns with their recreational fisheries which include challenges arising from European Green Crabs.
Historically or culturally significant Sites	Interest expressed. For a Tribe that has predominantly lived on the water, the effect of sea level rise and erosion on their culture and community are significant concerns.


Biology

Albacore Tuna

Key Data Gaps

General Data Gaps

- Abundance, distribution, health, and trend of albacore tuna
- Susceptibility of albacore tuna to pathogens and virus

Offshore Wind Data Gaps

- Effect of physical structures of offshore wind on albacore tuna
- Effect of electromagnetic fields from offshore wind cables on albacore tuna

Offshore Wind and Aquaculture Data Gaps

- Effect of offshore wind or aquaculture on the migration of albacore tuna

Other Data Gaps

Offshore Wind Data Gaps

- Effect of offshore wind on spawning and growth of albacore tuna
- Effect of noise and vibrations from offshore wind on albacore tuna
- Effect of light from offshore wind on albacore tuna

Offshore Aquaculture Data Gaps

- Effect of offshore aquaculture on the competition, predation, and other interactions involving albacore tuna
- Effect of waste products and chemicals from offshore aquaculture on albacore tuna
- Effect of offshore aquaculture on early marine survival of albacore tuna
- Effect of disease from offshore aquaculture on albacore tuna
- Effect of fish escapements from offshore aquaculture on albacore tuna

Background

Albacore tuna are highly migratory species and are seasonal visitors to the MSP Study Area. Like other pelagic fish species, they face various pressures, including fishing, pollution, and climate variations. These variations involve upwelling, influence from source waters, and El Niño/La Niña events and their effects on prey availability and habitat.

The Pacific Fishery Management Council (PFMC) manages the albacore tuna fishery through the Highly Migratory Species Fishery Management Plan. Regulation of the fishery is minimal due to the stock's extensive migration, international agreements, and stock assessments. It remains one of the few West Coast fisheries open to new fishers. Local and West Coast-based vessels harvest albacore tuna off Washington using troll and/or pole and line ("bait boat") methods. Canadian vessels also operate in United States (US) waters and land catches in Washington under a treaty between the US and Canada. Management of albacore tuna involves coordination with the Inter-American Tropical Tuna Commission and the Western and Central Pacific Fisheries Commission, reflecting the interests of numerous nations with fishing stakes in the Pacific Ocean.

Commercial and recreational catches in the albacore tuna fishery primarily occur beyond the 700-fathom boundary of the MSP Study Area during the summer and fall when the fish migrate to the West Coast. While most fishing takes place outside the Study Area, it's most common within 30 to 50 nautical miles offshore, sometimes closer to 20 nautical miles. Commercially, it's the most participated fishery sector along the Washington coast, with 221 to 338 unique vessels landing in Washington ports annually, generating landings ranging from 10 to 18.6 million lbs. and ex-vessel values ranging from $11.3 to $28.2 million between 2004 and 2014. Recreational activity averaged 4,328 trips annually from 2004 to 2013, with a notable increase in private vessel trips in 2013 to 7,056 trips.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to albacore tuna:

General data gaps

- Abundance, distribution, health, and trend of albacore tuna
- Susceptibility of albacore tuna to pathogens and virus

Abundance, distribution, health, and trend of albacore tuna. There is limited information on the abundance, distribution, health, or trend of albacore tuna. However, some data are available. For instance, biomass and recruitment estimates can be found in stock assessments conducted by the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC), the Inter-American Tropical Tuna Commission (IATTC), and the California Current Integrated Ecosystem Assessment's (CCIEA) Ecosystem Status Report. The Albacore Working Group (ALBWG) of the ISC regularly conducts stock assessments of North Pacific albacore tuna to estimate population parameters, summarize stock status, and provide scientific advice on conservation needs for fisheries managers. According to the latest assessment, North Pacific albacore tuna stocks are generally considered stable, with only minor changes observed from 2020 to 2023 compared to the 2014-2017 assessments. Tagging studies are ongoing to improve understanding of tuna movements and migrations, though this area could benefit from further research. Additionally, concerns remain about the impacts of illegal, unreported, and unregulated (IUU) fishing outside the US Exclusive Economic Zone (EEZ).

NOAA's Southwest Fisheries Science Center has developed species distribution maps for albacore tuna using available data. The NOAA Stock SMART website offers information on stock status, management, assessment, and resource trends, including data on stock abundance, fishing mortality, and recruitment trends. The most recent record for albacore tuna in the North Pacific Ocean was updated on October 24, 2023, and is based on the ISC's 2020 stock assessment.

Feedback on importance: There is a need for improved information on the movements of albacore tuna, as well as a better understanding of the impacts of IUU fishing.

Susceptibility of albacore tuna to pathogens and virus. Outside of aquaculture settings, there is a lack of awareness regarding pathogen concerns associated with albacore tuna.

Feedback on importance: No specific feedback provided.

Offshore wind data gaps

- Effect of physical structures of offshore wind on albacore tuna
- Effect of electromagnetic fields from offshore wind cables on albacore tuna
- Effect of offshore wind on the migration of albacore tuna

Effect of physical structures of offshore wind on albacore tuna. The potential effect of offshore wind structures on albacore tuna is uncertain. The effect of structures will depend on whether the wind farms alter the water column properties or if cables and foundations alter surface qualities enough to affect tuna. These effects will depend on the length of the structures and the type of foundation used to keep them afloat. As highly migratory species, tuna may only need to navigate around these structures. However, some tuna species are known to be attracted to structures. While it is unclear whether offshore wind structures will function as a fish aggregating device (FAD), they may attract tuna to the area.

Feedback on importance: An assessment of the effects of offshore wind structures should include a thorough examination of how these structures may impact access to fishing grounds for the albacore tuna fishery.

Effect of electromagnetic fields from offshore wind cables on albacore tuna. The effect of electromagnetic fields (EMF) is unknown across species. There is no rich literature on EMF for any specific species.

Feedback on importance: No specific feedback provided.

Offshore wind and aquaculture data gap

- Effect of offshore wind or aquaculture on the migration of albacore tuna

Effect of offshore wind or aquaculture on the migration of albacore tuna. This is a data gap. Albacore tuna is known to pursue optimal water temperatures. For both offshore wind and offshore aquaculture, any migration impacts are expected to be limited to a local scale and unlikely to have a population-level effect. However, the effect of offshore wind farms on tuna migration may shift depending on the scale of oceanographic impacts they cause.

Feedback on importance: No specific feedback provided.

Other Data Gaps

The following are the remaining data gaps:

Offshore wind data gaps

- Effect of offshore wind on spawning and growth of albacore tuna
- Effect of noise and vibrations from offshore wind on albacore tuna
- Effect of light from offshore wind on albacore tuna

Effect of offshore wind on spawning and growth of albacore tuna. Because albacore tuna spawning occurs in tropical and subtropical waters outside US EEZ, offshore wind is unlikely to have any direct effects on spawning or larvae. However, if spawning were to occur in areas with offshore wind facilities, tuna larvae (as well as all other larvae) could suffer adverse effects due to changes in hydrodynamics.

Effect of noise and vibrations from offshore wind on albacore tuna. Noise and vibrations from offshore wind operations may affect tuna. Fishers have reported disturbances to feeding schools caused by vessels in the area. Assessing the effects of sound on tuna is challenging, as they do not adapt well to captivity, making it difficult to study their hearing capabilities under controlled conditions.

Effect of light from offshore wind on albacore tuna. The effect of light on tuna is not well understood. Albacore tuna inhabit a wide range of ocean depths, and their behavior can vary significantly depending on activities such as foraging. Light from offshore wind structures may attract or repel tuna. If it leads to fish aggregation, it may influence predator-prey dynamics within wind farm areas. However, any impact is unlikely to have a significant effect on overall tuna population levels.

Offshore aquaculture data gaps

- Effect of offshore aquaculture on the competition, predation, and other interactions involving albacore tuna
- Effect of waste products and chemicals from offshore aquaculture on albacore tuna
- Effect of offshore aquaculture on early marine survival of albacore tuna
- Effect of disease from offshore aquaculture on albacore tuna
- Effect of fish escapements from offshore aquaculture on albacore tuna

Effect of offshore aquaculture on the competition, predation, and other interactions involving albacore tuna. If offshore aquaculture operations were to raise tuna, concerns would arise regarding the quantity and origin of the feed used. If a different species were farmed, the impact on tuna would depend on the species being cultivated. For example, if offshore aquaculture focused on groundfish—species more closely associated with the seafloor—the potential effects on albacore tuna would likely be less significant.

Effect of waste products and chemicals from offshore aquaculture on albacore tuna. The bioaccumulation of waste products and chemicals from offshore aquaculture would pose a concern for albacore tuna. As these substances accumulate in the marine environment, they may alter water column properties, resulting in higher levels of toxins and pollutants. These changes could negatively impact the availability of prey, which in turn could affect the health and behavior of tuna.

Effect of offshore aquaculture on early marine survival of albacore tuna. The effect of offshore aquaculture on the early marine survival of albacore tuna will vary depending on the location of tuna spawning. Larvae are highly sensitive to environmental changes and stressors. However, as these facilities are likely to be situated closer to the shore and farther from spawning grounds, significant concerns are unlikely to arise.

Effect of disease from offshore aquaculture on albacore tuna. Offshore aquaculture may cause the transmission of pathogens from farmed species to wild albacore tuna populations. However, current understanding of how these diseases may transfer to tuna remains limited.

Effect of fish escapements from offshore aquaculture on albacore tuna. Limited information is available on the effect of fish escapements on albacore tuna. This effect would vary depending on the species involved. Key concerns would include the spread of pathogens from farmed species and competition for resources.

Resources

Table 8. Resources relevant to albacore tuna.

NAME	ACCESS	TYPE	DESCRIPTION
Changes to the structure and function of an albacore fishery reveal shifting social-ecological realities for Pacific Northwest fishermen	https://onlinelibrary.wiley.com/doi/10.1111/faf.12519	Published article	Examines changes in Pacific Northwest fishermen's harvest portfolios over 35 years, focusing on the albacore troll and pole-and-line fishery. Recent social-ecological shifts impacted different segments of fishing fleets unevenly.
Dynamic Habitat Use of Albacore and their Primary Prey Species in the California Current System	https://repository.library.noaa.gov/view/noaa/37600/noaa_37600_DS1.pdf	Published article	Analyzes how juvenile albacore in the CCS use their environment, particularly their overlap with four forage species' habitats. Results suggest varying associations between albacore and different forage species, shedding light on foraging strategies and prey-switching behavior.
ISC: Stock Assessment of Albacore Tuna in the North Pacific Ocean in 2020	https://apps-st.fisheries.noaa.gov/sis/docServlet?fileAction=download&fileId=6255	Report	Presents the findings of the 2020 assessment of north Pacific albacore tuna.
ISC: Stock Assessment Report 2023	https://isc.fra.go.jp/working_groups/albacore.html	Report	Presents the findings of the 2023 assessment of north Pacific albacore tuna, offering scientific advice on stock status and conservation for fisheries managements. The assessment uses recent fishery data up to 2021, employing a length-based, age- and sex-structured integrated statistical stock assessment model.

NAME	ACCESS	TYPE	DESCRIPTION
NOAA: Stock SMART	https://apps-st.fisheries.noaa.gov/stocksmart?stockname=Albacore%20-%20North%20Pacific&stockid=11682	Website	Provides information on Stock Status, Management, Assessment, and Resource Trends. It offers various applications enabling users to search, view, compare, and download assessment results for stocks managed by NOAA Fisheries.

Benthic Invertebrates

Key Data Gaps

General Data Gaps

- Abundance, distribution, health, and trend of benthic invertebrates
- Food web interactions of benthic invertebrates
- Neashore sampling of benthic invertebrates
- The effect of climate change on benthic invertebrates
- Connectivity of benthic invertebrates across regions

Offshore Aquaculture Data Gaps

- Effect of offshore aquaculture on competition, predation, and other interactions involving benthic invertebrates

Other Data Gaps

General Data Gaps

- Recruitment, settlement, and spawn timing data of benthic invertebrates
- Natural mortality of benthic invertebrates
- Tissue sampling of benthic invertebrates for contaminants
- Recovery of benthic invertebrates from physical disturbance
- What compromises the benthic invertebrate community at the deep sea

Offshore Wind Data Gaps

- Effect of offshore wind structures on benthic invertebrates
- Potential for offshore wind to attract non-native species and its subsequent effect on benthic invertebrates
- Effect of electromagnetic fields from offshore wind on benthic invertebrates
- Effect of offshore wind on ocean transport of larval and juveniles stages of benthic invertebrates
- Effect of light from offshore wind on benthic invertebrates
- Effect of noise and vibrations from offshore wind on benthic invertebrates

Offshore Aquaculture Data Gaps

- Effect of waste products and chemicals from offshore aquaculture on benthic invertebrates
- Effect of offshore aquaculture on early marine survival of benthic invertebrates
- Effect of disease from offshore aquaculture on benthic invertebrates
- Effect of fish escapements from offshore aquaculture on benthic invertebrates
- Effect of offshore aquaculture on the distribution of benthic invertebrates
- Effect of offshore aquaculture structure on benthic invertebrates
- Effect of physical disturbance during harvesting for offshore aquaculture on benthic invertebrates

Background

The MSP's discussion of benthic invertebrates focuses on their habitat and the ecological role they play with some information on their natural and human-induced stressors. This information is summarized below.

a. Habitats

Seafloor: The seafloor habitat includes diverse environments such as soft/mixed substrates, rocky/mixed substrates, and biogenic habitats featuring deep-sea corals, sponges, and anemones, attracting fish and invertebrates.

Benthic invertebrates play crucial roles in this ecosystem, particularly deposit feeders like amphipods, isopods, crustaceans, snails, sea cucumbers, worms, polychaetes, sea slugs, and hermit crabs. These organisms feed on detritus on the seafloor and form essential links in the food web, serving as prey for groundfish species, including economically important species such as Dover Sole and Pacific Halibut. Other notable benthic invertebrates include bivalves, corals, sea urchins, and sea stars, which contribute significantly to the diets of flatfish and rockfish. This habitat is also important for species like Dungeness Crab, Pink Shrimp, and Spot Prawns that are commercially harvested.

Environmental stressors like low dissolved oxygen events (hypoxia and anoxia) pose significant threats to seafloor habitats. These events can stress or kill benthic invertebrates unable to escape low-oxygen conditions, potentially disrupting the seafloor food web and affecting the groundfish assemblage. In 2006, hypoxic conditions were severe enough to cause widespread fish and invertebrate mortality along the Washington and Oregon coasts. The severity and extent of hypoxia events are expected to increase in the future, which could further impact these ecosystems.

Rocky Shores: Rocky shores have various substrates, tidal elevation gradient, productivity, and local physical disturbances. Suspension-feeding benthic invertebrates like barnacles, mussels, sponges, tubeworms, and tunicates thrive in this habitat, influencing nutrient levels and serving as food for predators. Grazing invertebrates such as snails, limpets, chitons, and crustaceans feed on microalgae, macroalgae, and detritus, occupying specific vertical zones within the intertidal area. Predators within rocky shore habitat include the ochre sea star (*Pisaster ochraceus*), whelks, anemones, worms, and crabs. The vertical distribution limits for each species depend on their resilience to physical factors such as desiccation and temperature, as well as other variables including competition and predation.

In particular, the ochre sea star is a keystone species crucial for maintaining rocky shore diversity. However, sea star wasting disease has severely impacted its populations, altering community composition and hindering recovery. Monitoring revealed high mortality rates in 2014, with continued wasting observed in 2015.

Sandy Beaches: Sandy intertidal beach habitats are shaped by factors such as sediment deposition, wave energy, beach slope, upwelling, and climatic variability. The structure of these beaches, characterized by zonation, grain size, wave energy, and moisture content, significantly influences community composition. In Washington, dissipative beaches are thought to support a greater diversity of microhabitats than intermediate and reflective beaches, which have steeper slopes, coarser sands, and less surf activity.

Organic matter transported by waves and currents, including detritus and macrophytes like kelps, supports a rich food web and provides habitat for beach-dwelling organisms. Primary producers like surf zone phytoplankton and benthic diatoms thrive in sandy habitats. Macrofauna in these habitats include crustaceans (shrimp, crabs, amphipods), polychaetes, snails, and isopods, which are distributed across tidal elevations. Notably, the razor clam is a key invertebrate on Washington's sandy beaches, supporting recreational digging activities and contributing to coastal economies through nutrient recycling and the promotion of primary production. Sandy beaches also host crustacean scavengers, terrestrial arthropods, and various meio- and microfaunal invertebrates, although the dynamics of these communities are less well studied in Washington.

Coastal Estuaries: Coastal estuaries, such as Willapa Bay and Grays Harbor, are vital semi-enclosed ecosystems where rivers meet the ocean. They support a wide range of marine and terrestrial species at various life stages and are interconnected with freshwater, terrestrial, and marine processes. These habitats serve as essential nursery grounds and provide numerous ecosystem services. Invertebrates, including insect larvae, amphipods, polychaetes, and burrowing shrimp, are abundant. Estuaries also host commercially and ecologically important shellfish, such as the Olympia oyster, Pacific oyster, Manila clam, and Dungeness crab. These ecosystems play a critical role in the life cycles of many species, offering shelter and ample food sources for juvenile stages.

Biogenic habitats, such as eelgrass beds and oyster reefs, are common in these estuaries, providing structural complexity and serving as primary producers within the food web. Eelgrass supports a diverse community of epiphytes, microalgae, macroalgae, and invertebrates, which adhere to its leaves and serve as prey for fish and marine birds. This habitat is essential for several economically important species at various life stages, including Dungeness crab, Pacific herring, salmonids, shrimp, and flatfish.

Oysters create complex biogenic habitats in the lower intertidal and subtidal zones, supporting diverse communities of fish and invertebrates within oyster shell accumulations. Oysters also play critical roles in ecosystem functions by circulating and clarifying water, reducing hypoxia, and filtering nutrients. Historically, Willapa Bay supported significant populations of Olympia oysters in the low intertidal and shallow subtidal zones. However, overharvesting and habitat loss led to the commercial extinction of Olympia oysters by 1930. Recovery efforts have been challenged by the removal of shell accumulations, which are vital for Olympia oyster larvae, and the expansion of eelgrass beds.

b. Other stressors

Various stressors apply to benthic invertebrates such as predation, invasive species, climate change, and existing human activities.

Predation: Various predators in marine ecosystems target invertebrates as a significant part of their diets, including groundfish, marine mammals, shorebirds, and seabirds.

Invasive species: Spanning diseases, parasites, plants, invertebrates, and vertebrates, invasive species are present along Washington's coast across diverse habitats. These species enter the ecosystem through various pathways such as ballast water discharge, packaging materials, fouling on aquaculture shipments, release from the aquarium trade, recreational boating, and floating debris.

Climate change: Climate change is expected to impact various habitats and species. For example, for seafloor and deep-water habitats, climate change is expected to affect deep-sea corals which rely on aragonite for their skeletons. Declines in coral ecosystems could adversely affect fish and invertebrates dependent on them. Additionally, shellfish face challenges like slower growth, thinner shells, and increased mortality due to ocean acidification.

Human activities: Various existing human uses affect invertebrates such as fisheries, recreation, tourism, aquaculture, transportation, and navigation. For example, mining operations like sand and gravel dredging can directly remove immobile and slow-moving benthic species, disrupting their communities. Recovery times vary widely; studies show biomass and abundance can recover within months to over two years post-dredging, with diversity recovery taking longer. Changes in community composition depend on specific predator-prey relationships and dredging timing.

Additionally, sand transmission pipelines can crush benthic invertebrates, with storm movements exacerbating the impact if pipelines are unsecured. Hard-bottom habitats are most affected, while soft-bottom habitats tend to recover more quickly after pipeline removal. Mining can also create seafloor pits that accumulate fine materials, reducing oxygen levels and altering benthic community composition. Increased turbidity and sediment deposition may further impact benthic invertebrates. These effects are of greatest concern to coral reefs, hard bottom habitats, and spawning areas. The effects of noise from these activities on benthic invertebrates are also poorly understood.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to the benthic invertebrates:

General data gaps

- Abundance, distribution, health, and trend of benthic invertebrates
- Food web interactions of benthic invertebrates
- Nearshore sampling of benthic invertebrates
- The effect of climate change on benthic invertebrates
- Connectivity of benthic invertebrates across regions

Abundance, distribution, health, and trend of benthic invertebrates. There are significant spatial gaps in the understanding of abundance, distribution, health, and trend of benthic invertebrates, with much of the information being better developed for harvested and managed species. Survey efforts are primarily focused on fisheries management areas, leaving large portions of the coastline unexamined. Although efforts are underway to refine distribution models, substantial gaps remain in understanding abundance, distribution, and long-term recovery trends.

Figure 2. A close up of a purple sea urchin.

In many areas of Puget Sound and along the nearshore of the outer coast, including Willapa Bay and Grays Harbor, comprehensive site-specific data on both infauna and surface benthic invertebrates are available. The Olympic Coast National Marine Sanctuary (OCNMS) and Olympic National Park also provide valuable information. Surveys[6] on algae and invertebrates in the subtidal zones of the northern outer coast have been conducted and may still be ongoing. In 2003, the Environmental Protection Agency's (EPA) Regional Environmental Monitoring and Assessment Program (REMAP) surveyed coastal areas such as Willapa Bay, Grays Harbor, and Neah Bay. This initiative sampled benthic invertebrates across Washington and Oregon, with summary reports available in the "Ecological Condition of the Estuaries of Oregon and Washington[7]."

There is a significant data gap concerning non-managed species. For instance, substantial knowledge exists about mussels and currently, with the sunflower sea star being a species of concern, there are annual surveys conducted to monitor its recovery and status. These surveys track trends in species abundance. Research on sea star wasting disease and efforts to monitor and characterize the rocky intertidal community provide some data on benthic invertebrate assemblages. However, substantial data gaps remain, particularly along the coast, and the status of these gaps on the shelf remains is unclear. For example, the offshore distribution, population dynamics, and role of razor clams in intertidal recruitment are still unknown. Routine surveys and mapping of benthic communities would be instrumental in addressing these gaps.

However, along the Olympic coast, there is a comprehensive understanding of the distribution of habitats both mobile and sessile benthic invertebrate communities inhabit. Approximately 96% to 97% of the environment consists of unconsolidated and soft sediments. The remaining 3% to 5% is composed of hard-bottom habitats, which can host deep-sea corals, sponges, and other biogenic structures vulnerable to disturbances such as trawling, deep-sea wind farm installations, and submarine cables. Ongoing mapping and interpretation efforts may adjust these percentages. High-relief hard habitats, although less common, exhibit considerable variability in species composition and are particularly sensitive to disturbances that could lead to irreversible impacts.

[6] https://link.springer.com/article/10.1007/s00442-018-4263-7

[7] https://archive.epa.gov/emap/archive-emap/web/pdf/cemapfinal.pdf

Feedback on importance: It is essential to understand the existing conditions before assessing the potential impacts of any activity.

Food web interactions of benthic invertebrates. There is a significant data gap regarding food web interactions along the coast and in Puget Sound. The understanding of these interactions varies depending on the species involved. For example, active studies are examining the feeding preferences of invasive species, such as the European Green Crab, and how these introduced species are influencing local food webs. The diets of various invertebrates, including filter feeders, scavengers, and fish-eating anemones, are crucial for understanding ecosystem dynamics.

Research on species interactions and their connections within the broader food web is limited. Fish stomach content analyses occasionally identify some invertebrates, but no comprehensive studies have been conducted. Efforts to classify invertebrates have been made, but their interactions within and across the food web remain poorly understood. Year-round sampling provides a seasonal perspective on these interactions, with spring activity of the benthic community being particularly observable as they move into the water column. An example of the type of work conducted is available here: From the predictable to the unexpected: kelp forest and benthic invertebrate community dynamics following decades of sea otter expansion[8]. Additionally, the article "Estimates of the Direct Effect of Seawater pH on the Survival Rate of Species Groups in the California Current Ecosystem"[9] explores the impacts of ocean acidification (OA) on benthic communities and how these impacts cascade through food webs, potentially affecting species like Gray Whales that depend heavily on benthic invertebrates for food.

In particular, there are two areas that require further investigation: the impact of expanding sea otter populations on commercially and subsistence-harvested species, and the effect of the decline of sunflower sea stars on food web interactions and associated habitats.

Feedback on importance: Understanding the food web interactions of benthic invertebrates is crucial, as changes to prey populations can impact the entire system.

Nearshore sampling of benthic invertebrates. There are various nearshore sampling efforts for benthic invertebrates. For example, the state conducts several surveys in the nearshore environment, primarily focusing on subtidal areas while giving less attention to intertidal zones. There are also academic institutions studying nearshore conditions to track shifts in species distribution and the spread of diseases.

However, current sampling efforts have limitations. For example, the Washington Department of Natural Resources (DNR) conducts annual subtidal kelp surveys from Destruction Island to Neah Bay at only five locations. Additionally, NOAA's Dungeness crab monitoring begins at a depth of 55 meters, excluding nearshore areas. Fishery stock assessments also primarily focus further offshore. Tribal data supplements these fishery-independent assessments, as Tribes co-

[8] https://link.springer.com/article/10.1007/s00442-018-4263-7

[9] https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0160669

manage and track their catches. Including tribal catch data from nearshore areas is essential to complete the picture, as relying solely on offshore data would leave important gaps.

Feedback on importance: Assessing the potential impacts of any activity first requires establishing a baseline of the benthic community and understanding the current conditions.

The effect of climate change on benthic invertebrates. Climate change stressors have the potential to significantly impact communities and habitats on a large scale. Some of these changes will be unprecedented, with certain stressors occurring together in time and space for the first time. This convergence could result in unforeseen outcomes that may threaten the stability of ecosystems. However, research studying the effects of climate change on species is conducted in laboratory settings, and there is a critical need to replicate climate change conditions in the field. Additionally, while there are ongoing discussions focus on enhancing species resilience, influencing species behavior remains a complex challenge. Recommendations will be limited to habitat protection and measures to adapt to sea-level rise.

NOAA will publish the Climate Vulnerability Assessment for Olympic Coast National Marine Sanctuary[10], though the dissemination date is currently unavailable. This report will include a section dedicated to invertebrates, focusing on nine species, including Dungeness crabs, sunflower stars, and red and purple urchins, to assess their vulnerability and adaptive capacity in response to management measures and restoration efforts. The assessment highlights varying levels of available information, including confidence scores and identified data gaps. It addresses multiple oceanic changes, such as ocean acidification (OA), hypoxia, harmful algal blooms (HABs), upwelling, and stratification. However, many aspects remain uncertain, particularly the cumulative impacts of multiple stressors, their combined effect on species, and broader consequences for the food web. Biological thresholds, especially those related to OA and temperature changes, are not well understood. Hypoxia shows clearer sublethal impacts compared to other stressors, with increased occurrences along the outer coast.

In addition, a NOAA-funded project[11] is examining the effects of various environmental stressors on Dungeness crab and krill to assist managers and Tribes prepare for the expected impacts of climate change. This project, which began in September 2022 and is projected to conclude in August 2026, includes four main components: data synthesis, modeling, experimental validation linking lab findings to field conditions, and an evaluation of management strategies for the fishery. The project is guided by input from Dungeness crab fishery managers from Washington, Oregon, and California.

Other efforts are also addressing this data gap. Recent research indicates significant changes in nearshore areas, with expectations of accelerated changes further offshore in the future. These

[10] https://www.noaa.gov/information-technology/climate-vulnerability-assessment-for-olympic-coast-national-marine-sanctuary-id473

[11] https://coastalscience.noaa.gov/project/science-to-support-a-climate-ready-dungeness-crab-fishery-in-the-northern-california-current/

findings align with those of the Olympic Coast Ocean Acidification Vulnerability Assessment, led by Washington Sea Grant.[12]

Feedback on importance: This data gap is critical due to the significant uncertainty surrounding the effects of climate change on benthic invertebrates.

Connectivity of benthic invertebrates across regions. There is an interest in understanding the connectivity of benthic invertebrates between regions and how changes in California and Alaska may affect organisms in Washington. Key questions include how species composition varies, particularly in relation to specific habitat types across different regions. There is a focus on species of significance, such as Dungeness crabs and razor clams, ESA-listed or rarer species, and those with management or recovery implications.

Benthic communities exhibit considerable diversity, depending on substrate type and habitat availability. Understanding the extent of connectivity between distinct habitat areas is challenging, as the interconnections between different habitats are unclear. Many species, such as brachiopods, have wide distributions across the entire Pacific region. While a significant amount of connectivity can be inferred, the mechanisms behind this connectivity remain unknown. Additionally, some species exhibit limited movement and remain within specific areas throughout their lives. While these species may be disturbed or affected, the significance of connectivity may be less relevant if they are ubiquitous. Rare and unique species warrant attention, but those with widespread distributions may not require extensive study. Effective resource allocation is necessary to address these priorities.

Feedback on importance: No specific feedback provided.

Offshore aquaculture data gaps

- Effect of offshore aquaculture on competition, predation, and other interactions involving benthic invertebrates

Effect of offshore aquaculture on competition, predation, and other interactions involving benthic invertebrates. The impact of offshore aquaculture on benthic invertebrates largely depends on the species being cultivated, the design of the facility, and the scale of the installation. The potential outcomes can be positive, neutral, or negative, depending on these factors.

If cultivated species remain confined within pens, the effects on benthic invertebrates are less certain. However, benthic species may still respond to nutrient enrichment. Studies have extensively documented the effects of nutrient inputs on food webs, both in local contexts (such as Puget Sound) and internationally, particularly regarding nutrient contributions from fish pens. Benthic invertebrates have been observed to aggregate around floating cages, though the exact cause of this behavior—whether it involves feeding on waste products or responding to other cues—remains uncertain and may vary with depth.

[12] https://wsg.washington.edu/community-outreach/olympic-oa-rva/

Shifts in environmental conditions can also favor resilient species, known as "tolerant taxa," which may alter community composition. For instance, wastewater treatment outfalls often show fluctuations in species composition. Such shifts may result in a higher abundance of certain animals but a decrease in overall species diversity, potentially intensifying competition. Predation dynamics may also be influenced, as birds and marine mammals are known to feed on benthic invertebrates. If a crab predator is cultivated, local crab larvae could also become prey.

If cultivated species are released into the environment, an added concern is the potential for disease transmission from farmed species to wild populations.

Feedback on importance: This data gap is important because introducing physical structures can enhance the presence of encrusting organisms, attract predators, and alter community composition.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Recruitment, settlement, and spawn timing data of benthic invertebrates
- Natural mortality of benthic invertebrates
- Tissue sampling of benthic invertebrates for contaminants
- Recovery of benthic invertebrates from physical disturbance
- What compromises the benthic invertebrate community at the deep sea

Figure 3. A close up of a Pacific oyster

Recruitment, settlement, and spawn timing data of benthic invertebrates. There is an uneven understanding across different species. Significant focus has been placed on recruitment, settlement, and spawn timing data for highly managed species; however, this is more the exception than the rule. For example, there is over 20 years of population survey data for razor clams and nearly 10 years of condition index data. The condition index data includes standard measures such as dry and wet weight, length, width, sex, and a visual ranking of gonad maturity. Annual surveys of all five management beaches (Long Beach, Twin Harbors, Copalis, Mocrocks, and Kalaloch) are conducted during summer low tides. Recently published research[13]

[13] https://www.researchgate.net/publication/369884949_Using_the_Pumped_Area_Method_for_the_Assessment_of_Recreational_Razor_Clam_Siliqua_patula_Populations_in_Washington_State

in the “Journal of Shellfish Research” includes detailed information on clam lengths and numbers, which are used to estimate total recruit and pre-recruit clams for management purposes. Limited data on mole crab populations are also available.

Historical data for commercially harvested bivalves could potentially reveal overarching patterns in recruitment and success, though they show significant variability. Both the survey design and bivalve populations themselves vary spatially and temporally. Currently, there are no clear trends in recruitment and settlement, especially in the subtidal zone. Climate change, along with other indirect climatic factors, is expected to increase phenological shifts in the future, but little is known about how these changes will impact the ecosystem.

Particularly for the intertidal zone, the OCNMS and Olympic National Park (ONP) are involved in sampling efforts. The MARINe Network also monitors juvenile barnacles and maintains a long-term dataset.[14] The Department of Fish and Wildlife (DFW) records legal-sized clams and identify recruitment pulses for recruitment. Fisheries management uses recruitment data to regulate harvest rates and engage in negotiations with Tribes, all with the goal of ensuring sustainable fisheries. Additional insights may be gained from literature reviews, commercial industries, and research conducted by universities.

Natural mortality of benthic invertebrates. This data gap is species specific. Disease mortality is increasing in prevalence and impact. Sea star wasting disease continues to receive significant attention, with data typically gathered from intertidal and subtidal surveys. Sea stars are key predators of sea urchins, and understanding the dynamics resulting from their decline is critical. In addition to sea star wasting disease, a new epidemic affecting mussels from Oregon to Alaska, known as *Prymnesium parvum*, has emerged. There is also concern over eelgrass wasting disease in Puget Sound. Research in Willapa Bay is focused on understanding the interactions between eelgrass and oyster aquaculture, as well as their broader community effects. Additionally, new climate-related threats are expected to impact various species. Rising temperatures are believed to contribute to the emergence and spread of many diseases, although the specific causative agents remain unclear. The broader implications of disease on ecosystems are a significant concern.

Predation also contributes to mortality, with sea otters playing an increasingly influential role, particularly in the Destruction Island area where their populations are expanding. Sea otters are voracious predators of Dungeness crabs, urchins, and kelp crabs. Urchin barrens, though patchy, are on the rise, especially in the northern region near Tatoosh Island. Intertidal pools at monitoring sites along the western strait (Kydikabbit) show varying densities of urchins.

Efforts to enhance surveillance are underway in response to emerging needs. Funding from the Pacific Shellfish Institute and Oyster Growers Association at Grays Harbor has supported periodic testing for mortality events. However, there is often a delay between the occurrence of events and the receipt of samples and responses. One of the main challenges is sampling at a time when there is still viable tissue available for diagnostic analysis to understand the causative agents of diseases.

[14] https://marine.ucsc.edu/

Tissue sampling of benthic invertebrates for contaminants. There is interest in studying the tissues of benthic invertebrates to identify and analyze contaminants. The National Mussel Watch Program[15] and Sound Toxins[16] monitor contaminants, and the Department of Health (DOH) or Ecology may have further information. The National Centers for Coastal Ocean Science's (NCCOS) Coastal Pollution Data Explorer[17] provides 30 years of global contaminant data, but the Olympic Coast has limited sampling sites—one each at Tatoosh and Neah Bay—resulting in sparse information. Available data suggests that contaminant levels along the coast are lower compared to Puget Sound, which reduces the urgency for extensive research in this area. While certain sites, such as military locations and the Makah dump site (the only Superfund site adjacent to OCNMS), are known to release contaminants, overall contamination levels are believed to be relatively low. While a comprehensive investigation may not be necessary for this data gap, available data are limited. Furthermore, a significant gap exists regarding harmful algal toxins affecting invertebrates. Using mussels as indicators may not fully reflect the impact on other invertebrate species.

Recovery of benthic invertebrates from physical disturbance. Benthic communities are highly sensitive to even minor environmental changes, with sensitivity varying by species and recruitment-related factors. Depending on recruitment strategies, age to maturity, fecundity, and larval dispersal, some populations, like razor clams, can recover relatively quickly (within 1-2 years). For example, significant scouring events in estuaries may impact species, but those that do not reside deeply within the substrate can often recover through consistent larval recruitment. In contrast, Pacific oysters, which prefer hard substrates, are habitat limited. Once their habitat is lost, their populations may struggle to return to previous levels.

Due to high costs, surveys using remotely operated vehicles (ROVs) generally focus on exploring new areas rather than revisiting previously surveyed locations. As a result, direct evidence of disturbance is limited. Understanding of disturbance primarily comes from resource protection efforts and monitoring of permitted activities. There is particular interest in assessing the cumulative impacts of abandoned anchors, including how long they remain visible on the seafloor before becoming buried and obscured, and whether trawlers may disturb them.

A report from OCNMS focusing on the recovery of seabed-associated communities from the reburial of submarine cables in the northern part of the sanctuary is expected to be available in the coming months. The study examines how seafloor invertebrates and fish communities are responding to trenching and the exposure of cable segments. Sponges and other species have been observed utilizing the exposed cables as habitat. While the study is focused on one area of the Washington coast, its findings may provide insights relevant to other regions affected by trenching or cable disturbances. However, due to irregular survey intervals, there are still gaps in the available data.

What compromises the benthic invertebrate community at the deep sea. Climate impacts and physical disturbances are two major stressors affecting these environments. Survey data and

[15] https://coastalscience.noaa.gov/science-areas/pollution/mussel-watch/
[16] https://www.soundtoxins.org/
[17] https://experience.arcgis.com/experience/e5ae2ee667e640c99ed85834291e83b2/

reports are available from various entities. Changing ocean conditions, including hypoxia, ocean acidification (OA), marine heatwaves, and harmful algal blooms (HABs), exhibit spatial variability. Hypoxia and OA are more prevalent in the southern portion of the sanctuary, while HABs are concentrated near the origin of the Juan de Fuca eddy. While there is a solid understanding of individual disturbances, the cumulative and long-term impacts of these stressors remain unclear.

Physical disturbances primarily affect deep-sea communities, particularly slow-growing or immobile species, which are highly vulnerable to activities such as anchoring and bottom trawling. These disturbances can result in prolonged recovery times and irreparable damage to complex habitats. When considering development or other spatial uses, it is crucial to assess both areas affected by human disturbances and those impacted by natural stressors.

Offshore wind data gaps

- Effect of offshore wind structures on benthic invertebrates
- Potential for offshore wind to attract non-native species and its subsequent effect of benthic invertebrates
- Effect of electromagnetic fields from offshore wind on benthic invertebrates
- Effect of offshore wind on ocean transport of larval and juvenile stages of benthic invertebrates
- Effect of light from offshore wind on benthic invertebrates
- Effect of noise and vibrations from offshore wind on benthic invertebrates

Effect of offshore wind structures on benthic invertebrates. The effects of new structures have been observed, with such structures typically becoming colonized by various species. Recent geoduck studies from the past decade have shown that adding structure to soft habitats can increase invertebrate populations. Research on sea stars, moon snails, and larger invertebrates, including infauna, has also been conducted in similar contexts.

Structures can also influence species composition. For instance, pier pilings and new docks can provide suitable habitat for species like abalone. These structures offer a substrate for species that attach to hard surfaces, facilitating their growth and spread. Similar patterns have been noted with moorings, which require monthly cleaning due to fouling by encrusting organisms. While these structures may initially provide habitat, there is a risk that they could become ecological traps. Larval species may recruit to physical structures in areas that are unsuitable for their long-term habitat needs, potentially diverting them from their intended ecological niches. Additionally, the introduction of structures creates opportunities for the colonization of non-native species. For instance, the installation of oil and gas platforms in the Gulf of Mexico acted as a vector for the spread of invasive species. Similar phenomena have been documented around oil platforms, artificial reef structures, and research from the East Coast. Settlement plates in King County may offer insight into the effects of providing hard surfaces, as they have shown the presence of a few non-native species. This introduction of species may also alter the food web.

Community changes are expected with the introduction of hard structures. These structures create feeding halos for predators and attract colonizers that thrive on hard substrates. This clustering effect can extend into the surrounding natural environment.

The effect of offshore wind structures also depends on the placement and footprint of bottom-contact facilities. If these facilities occupy only a small portion of the available or utilized habitat, the potential impacts may be minimal. In Washington, many studies on invertebrates focus on their presence in specific areas and often do not track individual movements. While movement patterns are sometimes inferred from seasonal occurrences, the actual paths that animals take between locations are likely poorly understood for most, if not all, species. The scale of offshore wind development is also an important factor—whether it is concentrated in a few areas or more widespread.

Several other factors must also be considered to understand the effect of offshore wind structures. The impact of light blockage on invertebrates is still unclear, although salmon researchers have extensively studied the shading effects of overwater structures. Materials such as copper can also have detrimental effects on marine life. Additionally, it is important to understand how these structures influence oceanographic processes, including upwelling events. The potential loss of equipment from these structures could also lead to further complications, such as secondary entanglement.

Related to structures, the initial installation of offshore wind structures will disrupt habitats, potentially causing harm or destruction. For example, dredging projects have historically removed geoducks, effectively eliminating populations in the affected areas. It remains uncertain whether these species will resettle afterward. While the initial installation is expected to cause significant disruption, post-construction disturbances are anticipated to be minimal.

Little is known about the deeper water benthic community, although significant research has been conducted along the Oregon coast, which may be applicable to Washington waters. Specific studies on offshore wind activities are less prevalent, but the OCNMS may have contributed to research addressing these gaps. Additional resources may include the Washington Department of Fish and Wildlife (WDFW), which conducts monitoring on the outer coast, and groundfish fisheries off the Washington coast, which may have collected relevant video tow data.

Potential for offshore wind to attract non-native species and its subsequent effect on benthic invertebrates. This is a recognized risk. On the outer coast, the likelihood of encountering non-native species increases, particularly as water temperatures rise. Disturbing or clearing an area can create opportunities for both native and non-native species to thrive. The introduction of new structures can also promote settlement by either group. Historically, oil and gas platforms have been linked to the spread of invasive species. Hard substrates, such as cables and nearby platforms, can act as conduits for colonization and expansion. Further research is needed to better understand these dynamics.

Understanding the types of equipment used, their movement, and biosecurity practices is essential for managing biofouling. Ballast water from vessel activities, for example, presents a significant risk as a major vector for transporting larvae of non-native species. Ships often discharge ballast water before reaching port, potentially releasing viable larvae near offshore platforms. If these larvae settle, reproduce, and outcompete local species, they may become invasive. The level of risk depends on factors such as the origin of the ships and whether they follow ballast water exchange protocols. In contrast, the risk of introducing non-native species through bottom-contact elements, such as platform anchors, is generally low, unless specific vectors are involved in transporting individuals to those habitats.

Effect of electromagnetic fields from offshore wind on benthic invertebrates. The impacts of electromagnetic fields (EMF) are not well understood, and assessing their potential effects is challenging without detailed knowledge of proposed structures, especially given the differences between west coast proposals and existing east coast installations. Key uncertainties include the movement capabilities of mobile versus sessile invertebrates and their ability to avoid EMF sources, the effects on different habitats, potential changes to species migration pathways, and how species at varying distances from the source may be affected. Understanding the gradient of impact relative to distance is essential for predicting disturbances. Additionally, questions remain about whether EMF exposure will cause temporary or permanent damage to species and ecosystems.

There are also uncertainties about whether EMF exposure will cause temporary or permanent damage to species and ecosystems. However, low-level EMF has not been shown to pose significant problems and, in some cases, has even been found to attract invertebrates in other areas. At higher levels, EMF could potentially deter growth or influence behavior. Laboratory studies, for instance, have demonstrated varying levels of mortality in burrowing shrimp exposed to different intensities of electrical currents. The Pacific Northwest National Laboratory (PNNL) is conducting research to enhance the understanding of offshore renewable energy projects and develop effective monitoring tools. Assessments are planned at the Sequim lab, with a focus on both monitoring technologies and the effects of EMF.

Effect of offshore wind on ocean transport of larval and juvenile stages of benthic invertebrates. This data gap has not been studied. The placement of offshore wind structures has the potential to disrupt critical ocean flows, which could affect the transport of larvae during key settlement phases. However, predicting the consequences of changes in ocean currents is challenging, as the movement of larvae and juveniles with these currents is uncertain. The depth at which larvae are found—whether near the bottom or at the surface—could significantly influence how they are impacted by current shifts. Limited understanding of larval behavior and movement complicates the ability to assess these effects, which likely vary by species. For example, while crabs have extended larval phases, it is unclear how they may be transported by currents. This issue is likely to be more significant if large numbers of platforms are constructed in close proximity. Some resources may be helpful in addressing this data gap. Localized current models, such as those used by the Salish Sea Modeling Center[18], could provide insights into local current dynamics. Additionally, the Admiralty Inlet Pilot Tidal

[18] https://ssmc-uw.org/

Project[19], conducted in the 2000s, explored the potential impacts of turbine placement in Admiralty Inlet.

Upwelling, which is primarily driven by wind, may also be affected by offshore wind structures. If these structures alter wind patterns, they could reduce the strength and persistence of upwelling. While there is significant concern about these potential impacts, the full extent remains uncertain. It is inaccurate to assume there would be no effect. This is another notable data gap. Spawning success could be negatively impacted if infrastructure installation or disturbances reduce spawning stock density or act as physical barriers.

Moreover, larvae of non-native species may also be affected. Ballast water is a primary pathway for the spread of these species, and ships discharging ballast water at sea before reaching port may release viable larvae near offshore platforms.

Effect of light from offshore wind on benthic invertebrates. Depending on the species, adults may be attracted to or deterred by light, although this response is not well-studied. Light could potentially affect localized areas, particularly for sedentary benthic species. While benthic invertebrates, which are typically found in mud or darker environments, are generally less impacted by light, some effects are possible, as many species rely on moonlight as a spawning cue. The influence of light is likely more pronounced in other organism groups, especially those inhabiting the water column.

When considering the population-level impact of light, the greatest concern is likely with larval stages. Light may have a more significant effect during the juvenile and larval phases, as these stages typically reside in the water column. Light can attract larvae from various species, and the extent of light penetration depends on factors such as depth and water turbidity. If larvae aggregate around artificial light sources, it could alter predation rates, with predators potentially increasing their consumption of larvae. Similarly, adult invertebrates may be attracted to light, increasing their vulnerability to predation.

Existing research may offer some insights into these effects. For example, studies in Puget Sound have used light traps to attract larval crab stages, capturing a variety of species. Research on the impact of light on juvenile salmonids may also provide useful information regarding light's effect on marine organisms.

Effect of noise and vibrations from offshore wind on benthic invertebrates. Current research primarily focuses on how sound affects marine mammals, seabirds, and certain fish species, leaving a significant knowledge gap regarding its impact on invertebrates. The extent to which species located at varying distances can perceive these disturbances remains unclear. Understanding the gradient of impact and distance is essential for anticipating what qualifies as a disturbance for different species. Additionally, it is important to assess whether noise and vibrations cause immediate or temporary damage and whether affected species can recover from such impacts. The permanence of any potential damage is also a critical consideration.

[19] https://tethys.pnnl.gov/project-sites/admiralty-inlet-pilot-tidal-project

Existing knowledge regarding the effects of noise and vibrations on benthic invertebrates is limited. Available studies indicate that vibrations in sediment can reduce the densities of burrowing shrimp in Willapa Bay, while clams may retract their siphons and cease feeding. Excessive vibration-induced stress may also impact growth and reproductive capabilities. For offshore wind farms, localized impacts are expected during construction, including potential effects from cable hum and anchor lines. Interestingly, species such as plumose anemones often settle on anchor lines, which may add new settlement habitats to otherwise flat, muddy seabed areas. This effect will depend on facility placement. Over time, these activities could influence sediment density and composition. While there is a notable data gap concerning the effects of noise and vibrations on benthic invertebrates, the greater concern currently lies with the potential impacts on higher-level organisms.

Offshore aquaculture data gaps

- Effect of waste products and chemicals from offshore aquaculture on benthic invertebrates
- Effect of offshore aquaculture on early marine survival of benthic invertebrates
- Effect of disease from offshore aquaculture on benthic invertebrates
- Effect of fish escapements from offshore aquaculture on benthic invertebrates
- Effect of offshore aquaculture on the distribution of benthic invertebrates
- Effect of offshore aquaculture structure on benthic invertebrates
- Effect of physical disturbance during harvesting for offshore aquaculture on benthic invertebrates

Effect of waste products and chemicals from offshore aquaculture on benthic invertebrates. The effect of waste products and chemicals varies significantly based on the species being cultivated, the facility's design, the scale of the installation, and the specific type of waste or chemicals involved. These factors can either inhibit or stimulate growth and influence distribution patterns of benthic invertebrates.

A substantial increase in nutrients has the potential to transform entire ecosystems, altering community dynamics by providing more resources. This influx of nutrients can favor opportunistic species, allowing them to thrive, while sensitive species may decline. Species that are more tolerant of stress, known as tolerant taxa, are better able to endure challenging conditions compared to more sensitive taxa. As a result, shifts in community composition can occur in response to environmental changes. For example, at wastewater treatment outfalls, different species may experience spikes in abundance at various stations, with those capable of surviving the conditions dominating. This can lead to a high abundance of animals, but with reduced species diversity. The thresholds at which species are affected by nutrient changes remain unclear. However, the total organic carbon (TOC) ranges that different species can tolerate could provide some insight.

There is increasing concern about how offshore facilities might exacerbate hypoxia and other oceanic stressors. The impact depends on factors such as nutrient inputs, the type of waste produced, and whether the environment acts as a nutrient sink or can re-mineralize nutrients.

The introduction of excess nutrients can disrupt ecological processes, elevate respiration rates that worsen hypoxia, fuel harmful algal bloom (HAB) events, reduce oxygen availability, and negatively affect various species. This is especially concerning for less mobile animals like invertebrates, which are unable to move significant distances. Determining optimal nutrient levels that support growth without causing harm is essential and requires baseline data. Additionally, maintaining adequate dissolved oxygen levels is crucial when introducing large nutrient loads. Insights from research on multitrophic aquaculture systems may offer valuable guidance, as sea cucumbers can consume waste and seaweed aquaculture could help mitigate nutrient levels. The presence of harmful chemicals adds further complexity. While the specific harmful substances related to aquaculture operations are not well understood, excessive amounts of any substance can be harmful. Current research often focuses on physical stressors, such as copper.

Effect of offshore aquaculture on early marine survival of benthic invertebrates. There is a significant data gap regarding the impact of offshore aquaculture on the early marine survival of benthic invertebrates. Speculating on these effects is challenging, as they depend on numerous factors, including the species being cultivated, facility design, installation size, and the type of waste and nutrients added to the water. The outcomes also vary by benthic invertebrate species, with opportunistic species potentially thriving under certain conditions. The impact is further shaped by the duration and timing of larval release, which may occur in quick pulses or continuously throughout the year. Seasonal variations can also influence these effects. Early life stages are generally the most sensitive, and differences are expected between long-lived and short-lived species.

If the target species is suspended in the water column, there will be a concentration of fish mouths, increasing the likelihood of floating larvae being consumed. The extent of this predation pressure will depend on the diet of the target species. For example, if the target species primarily feed on benthic invertebrates, predation pressure on such organisms will likely increase. Additionally, it raises questions about whether the target species will consume larvae and what impact this consumption might have. It is worth considering whether fish feed could supplement their diet and reduce the predation on larvae.

Localized nutrient enrichment is likely to occur in areas with offshore aquaculture, potentially leading to plankton blooms in nutrient-scarce environments. While the availability of food may influence species recruitment, an influx of nutrients could also trigger hypoxia or HAB events and affect early marine survival. The impact depends on the nature and quantity of the nutrient release, how it disperses in local currents, and its subsequent dilution. While the effects of offshore aquaculture on metrics like aragonite and calcite saturation—important for species like sunflower sea stars—remain uncertain, there may be sublethal impacts. Certain species, such as Dungeness crabs, have pH thresholds that are crucial for shell development. Female crabs carrying eggs are unable to avoid exposures to low dissolved oxygen, ocean acidification (OA), or increased temperatures. Once larvae become mobile, they may avoid benthic areas affected by conditions like hypoxia, as surface waters generally have higher oxygen levels due to the air-sea interface. The study *Seasonality and Life History Complexity Determine*

Vulnerability of Dungeness Crab to Multiple Climate Stressors[20] investigates how various climate stressors impact different life stages of the Dungeness crab. This research primarily focuses on the effects of OA and hypoxia, given that species vary in their tolerance to oxygen levels and temperatures for optimal development.

While the optimal conditions for each life stage of Dungeness crab are well-understood, similar data is lacking for most other species due to a lack of comprehensive studies. As a result, lethal thresholds are not fully defined, and the potential sublethal impacts are even less understood. While the threshold for mortality can be identified, it is more difficult to determine the changes that may compromise survival without causing death. An organism may survive but lose its ability to reproduce or function effectively. The level of environmental alteration required to impair an organism's functionality remains unclear.

Effect of disease from offshore aquaculture on benthic invertebrates. Diseases have been a significant factor in major die-offs, with sea star wasting disease being a prominent example in recent events. Various diseases can affect marine species, and while aquaculture always carries the potential for disease introduction, the transferability of diseases between species is not well understood. In addition to diseases, the risks also include parasites and non-native strains that could spread. The impact of disease is largely influenced by the species being cultivated, facility design, the scale of the operation, and the location, particularly if the facility is near native benthic invertebrates or species at risk. Cultivating new species with poorly understood disease dynamics adds an additional layer of complexity.

Concentrating organisms in aquaculture facilities may exacerbate disease concerns. Diseases can evolve rapidly in high-density populations, leading to the emergence of new variants. Furthermore, certain waterborne diseases can vary in their transmissibility based on environmental conditions. For example, raising water temperatures in an aquaculture facility can increase the spread of diseases that thrive in warmer conditions. Similarly, changes in pH levels can influence the frequency of disease outbreaks, underscoring how environmental factors affect disease transmission in aquatic ecosystems. Although there is concern about these disease variants escaping from aquaculture facilities and affecting wild populations, documented instances of such events remain relatively few.

It is uncertain whether fish diseases can be transmitted to benthic invertebrates, but the likelihood increases with shellfish aquaculture. For example, isopods can parasitize fish, shrimp, and other crustaceans, while in abalone culture, a parasitic worm can settle on shells, causing severe deformities and hindering shell growth. More research is needed to better understand the risks associated with these parasites in aquaculture settings.

Effect of fish escapements from offshore aquaculture on benthic invertebrates. Currently, there is limited available information on the impacts of fish escapements from aquaculture facilities. The consequences of escapements vary significantly based on the species being cultivated, the design of the facility, and the overall scale of the operation. Each type of aquaculture presents unique considerations. There is a need to understand whether the

[20] https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2021AV000456

cultivated species will feed, interact, or potentially transmit diseases to benthic invertebrates. Some cultivated species may carry diseases that can spread to others.

Escapement scenarios differ depending on whether the species involved are native or non-native. When cultivating native species such as kelp or abalone, there are considerations regarding genetic impacts. Introducing cultivated individuals into existing populations can potentially influence genetic diversity. Breeding with wild populations could lead to genetic mixing, which may have negative consequences for the genetic integrity of wild populations. In the case of non-native species, there is concern about their escape into natural environments, where they could prey on benthic species or compete with native species for resources. An example of such concern was observed with Atlantic salmon escapements impacting Pacific salmon populations.

Effect of offshore aquaculture on the distribution of benthic invertebrates. The effect of offshore aquaculture on the distribution of benthic invertebrates will be largely influenced by the species being cultivated, the design of the facility, and the size of the installation. Localized effects are expected, depending on the scale of the aquaculture facilities, and baseline data will be essential for assessing any changes. The distribution of mobile invertebrates may be affected. For example, Dungeness crabs, due to their mobility and opportunistic behavior, may be found beneath aquaculture facilities. Similarly, sea urchins may migrate to these areas to graze on waste products or take advantage of nutrient enrichment, though this remains speculative. The effect on distribution is less significant for low-mobility invertebrates or those with broad habitat preferences. In comparison to Dungeness crabs or sea urchins, most invertebrates are less mobile and less likely to shift their distribution in response to offshore aquaculture.

Effect of offshore aquaculture structure on benthic invertebrates. The implications of aquaculture vary depending on the type of operation. Net pens for finfish, shellfish aquaculture, and kelp/mariculture will each have unique structural dynamics, locations, and potential effects on surrounding species. Impacts are expected to be generally more pronounced during the installation of the facility, with the construction of the physical structure causing greater disruptions. Once operational, concerns such as light, shading, and spatial occupation tend to be less significant.

Aquaculture installations can provide additional substrate for habitat formation. However, species like mussels that attach to surfaces may contribute to biofouling, which poses risks to both infrastructure integrity and equipment functionality. For example, the failure of the Cypress Island facility was partly due to inadequate biofouling maintenance, which led to system breakdowns. Biofouling on equipment can create operational challenges and increase the risk of failure.

Aquaculture structures can also create shade, which may influence species and alter community dynamics. Changes in light availability can affect species interactions, such as those between kelp and other organisms. Keystone species like kelp, which depend on light for growth, may struggle to thrive in shaded conditions, potentially disrupting the entire ecosystem. Reduced light levels could also inhibit phytoplankton growth, impacting filter-feeding species like clams. These changes have broader implications for the algal community and phytoplankton dynamics.

Effect of physical disturbance during harvesting for offshore aquaculture on benthic invertebrates. The impacts of aquaculture activities will vary depending on the species involved. Benthic communities are generally sensitive to even short-term disturbances, which raises concerns about their long-term response. The introduction of large machinery, for instance, can disrupt sediment and significantly affect the substrate. Substrate disturbance is a key factor influencing recovery time for affected areas. This concern is especially relevant in kelp mariculture, as kelp attaches to the substrate. However, kelp may not thrive if grown at too great a depth, as it relies on surface conditions for optimal growth.

The potential impacts of these activities largely depend on their management. The harvesting of finfish typically has minimal direct impact on surrounding habitats. However, a major concern is the discharge of fish waste into the ocean, particularly during cleaning processes, a practice commonly seen in fisheries like Pacific whiting. Ideally, such activities should be conducted outside the marine environment to minimize nutrient discharge.

In shellfish aquaculture, the use of yellow ropes for harvesting has raised concerns about marine debris. These ropes, if not properly managed, can contribute to the accumulation of debris in the ocean. Efforts are underway in some regions to assess the extent of debris originating from aquaculture operations.

Resources

Table 9. Resources relevant to benthic invertebrate species.

NAME	ACCESS	TYPE	DESCRIPTION
Ecological Condition of the Estuaries of Oregon and Washington	https://archive.epa.gov/emap/archive-emap/web/pdf/cemapfinal.pdf	Report	Describes the overall quality of estuaries in Oregon and Washington using data collected as part of the Western Environmental Monitoring and Assessment Program (EMAP).

NAME	ACCESS	TYPE	DESCRIPTION
Estimates of the Direct Effect of Seawater pH on the Survival Rate of Species Groups in the California Current Ecosystem	https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0160669	Published article	Presents a novel methodology for developing regionally specific estimates of species sensitivity to ocean acidification (OA) and applies this method to the California Current ecosystem.
Expedition Report: EX2301, 2023 Shakedown + EXPRESS West Coast Exploration	https://repository.library.noaa.gov/view/noaa/55891#tabs-2	Report	Presents the data collected by NOAA Ocean Exploration from April 13-27, 2023, from Portland, Oregon to Seattle, Washington.
From the predictable to the unexpected: kelp forest and benthic invertebrate community dynamics following decades of sea otter expansion	https://link.springer.com/article/10.1007/s00442-018-4263-7	Published article	Combines spatial and time-series data on sea otter abundance, canopy kelp area, and benthic invertebrate abundance across Washington State to analyze the changing impacts of sea otter reintroduction on kelp and kelp forest communities.
Multi-Agency Rocky Intertidal Network (MARINe)	https://marine.ucsc.edu/	Website	Provides data and information from research conducted at over 200 rocky intertidal monitoring sites.

NAME	ACCESS	TYPE	DESCRIPTION
National Mussel Watch Program	https://coastalscience.noaa.gov/science-areas/pollution/mussel-watch/	Website	Contains data, information, and publications relevant to the Program's monitoring of the status and trends of contaminants and biological stressors in the nation's coastal waters.
Nautilus Live Ocean Exploration Trust	https://nautiluslive.org/science/data-management	Website	Provides videos and data collected from various expeditions by the Exploration Vessel *Nautilus* and other vessels Ocean Exploration Trust charters.
NCCOS: Coastal Pollution Data Explorer	https://experience.arcgis.com/experience/e5ae2ee667e640c99ed85834291e83b2/	Database	An interactive, web-based interface that displays spatial and temporal trends in chemical, physical, biological, and toxicological data.
Olympic Coast NMS Dive Survey Data	https://www.webapps.nwfsc.noaa.gov/apex/f?p=158:1	Website	Provides data from multi-disciplinary surveys of kelp forests in OCNMS.
Salish Sea Modeling Center	https://ssmc-uw.org/	Website	Contains information on the Salish Sea Model and relevant research, projects, news, and publication.

NAME	ACCESS	TYPE	DESCRIPTION
Seasonality and Life History Complexity Determine Vulnerability of Dungeness Crab to Multiple Climate Stressors	https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2021AV000456	Published article	Assesses the vulnerability of Dungeness crabs to climate stressors using a combination of ocean, population, and larval transport models with ocean acidification, hypoxia, and warming.
Sound Toxins	https://www.soundtoxins.org/	Website	Contains tools and resources to monitor and warn about HAB events, aiming to minimize risks to human health and reduce economic losses.
The Sea Star Wasting Task Force	https://piscoweb.org/sea-star-wasting-task-force	Webpage	Contains information of the Sea Star Wasting Task Force and its strategic action plan to identify research and management priorities to address the sea star wasting syndrome.
Using the Pumped Area Method for the Assessment of Recreational Razor Clam, Siliqua patula Populations in Washington State	https://www.researchgate.net/publication/369884949_Using_the_Pumped_Area_Method_for_the_Assessment_of_Recreational_Razor_Clam_Siliqua_patula_Populations_in_Washington_State	Published article	Describes the Pumped Area Method used to estimate razor clam abundance, set harvest seasons, and ensure long-term population stability.

Birds

Key Data Gaps

General Data Gaps

- General status, abundance, distribution, and trend of birds
- Flight behavior of birds
- Forcing factors of birds

Offshore Wind Data Gaps

- Risk of collision of birds with offshore wind facilities
- Effect of offshore wind on migration paths of birds
- Effect of offshore wind on bird behavior

Other Data Gaps

General Data Gaps

- Migration of birds
- Monitoring method of birds
- Disease and pathogens of birds

Offshore Wind Data Gaps

- Effect of offshore wind on roosting, nesting habitat, and foraging areas of birds
- Effect of vibrations and noise from offshore wind on birds
- Effect of offshore wind to the population and population dynamics of birds
- Effect of light from offshore wind on birds
- Risk of displacement from offshore wind
- Monitoring method to study the effects of offshore wind on birds
- Acceptable level of change
- Effect of offshore wind structure on birds

Offshore Aquaculture Data Gaps

- Effect of chemicals from offshore aquaculture on birds
- Effect of disease transmission from offshore aquaculture on birds
- Effect of offshore aquaculture on the migration paths of birds
- Effect of offshore aquaculture on the behavior of birds
- Effect of offshore aquaculture on the roosting, nesting habitat, and foraging areas of birds
- Effect of offshore aquaculture on the population and population dynamics of birds
- Potential for offshore aquaculture to cause entanglement
- Risk of displacement of birds from offshore aquaculture
- Effect of offshore aquaculture structure on birds
- Effect of human intervention on birds

Background

The MSP Study Area is home to a diverse range of bird species, including seabirds, raptors, marsh birds, waterbirds, and shorebirds, which inhabit various environments such as sea stacks, rocky islands, cliffs, dunes, marshlands, estuaries, tidal flats, coastal beaches, and old-growth forests. Seabirds and shorebirds, in particular, concentrate along Washington's west coast. As part of the Pacific Flyway, Washington serves as a critical migratory route for millions of waterbirds, shorebirds, and raptors. Seabirds such as albatross and shearwaters travel long distances to forage in the offshore waters of the MSP Study Area. Estuaries within the region also provide vital habitat for both resident and migratory bird species. Additionally, five national wildlife refuges have been established within or near the MSP Study Area to protect land-based resources, including important nesting and foraging sites for birds. A summary of the specific types of bird species found in the area is provided below.

Seabirds: Seabirds found within the MSP Study Area include murres, puffins, albatrosses, fulmars, shearwaters, gulls, murrelets, cormorants, terns, and others.

Seabirds in the MSP Study Area show seasonal variations in habitat use, influenced by both physical and biological factors. Species such as the sooty shearwater migrate long distances to forage in these waters during the summer, while others breed on coastal islands like Tatoosh and Destruction Islands. Some seabirds forage far offshore over the continental shelf, while species like the common murre and marbled murrelet prefer nearshore environments. Diets vary by species, but primarily consist of fish, zooplankton, and crustaceans.

Seabird abundance and reproductive success are affected by oceanographic conditions, oil spills, disturbances at breeding colonies, fisheries bycatch, and predators. Unlike most seabirds that nest on offshore islands, the marbled murrelet nests in old-growth forests up to 55 miles inland in Washington. As a threatened species, they face habitat loss and poor foraging conditions at sea. Annual monitoring tracks their populations in Washington.

Seabirds serve as important indicators of ocean conditions due to their varied foraging behaviors across different habitats and trophic levels. However, monitoring these species can be challenging due to their diverse life histories and behaviors. Some seabird species are used as indicators for the health of other seabird populations. The National Centers for Coastal Ocean Science (NCCOS) models relative seabird density using environmental variables and survey data. Species were selected to represent different habitat types, including nearshore (marbled murrelet), pelagic (northern fulmar and black-footed albatross), and rare or declining species (pink-footed shearwater and tufted puffin). Estuary use was not mapped due to limited survey data.

Shorebirds: Shorebirds include species such as sandpipers, plovers, oystercatchers, avocets, and stilts. Shorebirds migrate long distances between wintering and breeding grounds, using coastal estuaries and wetlands as crucial stopover sites to rest and refuel for their journey to Arctic nesting grounds. They feed primarily on invertebrates in shallow waters and associated wetlands, mudflats, beaches, and other tidelands. Grays Harbor and Willapa Bay are vital stopover sites, especially for species like dunlin. Some, like the western snowy plover, breed locally on sandy beaches near the MSP Study Area, while black oystercatchers nest on rocky coasts and offshore islands. Human activities and coastal development have significantly impacted shorebird habitats, affecting both their stopover sites and nesting areas.

Figure 4. A great blue heron standing on a rock by the water.

Marsh birds: Examples of marsh birds in Washington include the great blue heron, marsh wren, great egret, and American bittern. Marsh birds broadly include birds that feed, nest, or use tidal or freshwater marshes. They are associated with estuaries such as Grays Harbor and Willapa Bay and exist throughout the MSP Study Area. Marsh birds are sensitive to human disturbances, leading to site abandonment due to wetland loss, development, logging, and intrusions.

Ducks and geese: Ducks and geese in the MSP Study Area include species such as black brant, greater scaup, green-winged teal, tundra swan, bufflehead, and Canada goose. Ducks and geese frequent protected shores, bays, and estuaries in Washington. During winter, these birds gather in large numbers and migrate northward or eastward to breed during summer. These birds feed by diving, dabbling, or foraging on the water's surface, consuming a variety of foods from mollusks to vegetation.

Raptors: Several species of raptors forage in areas within and adjacent to the MSP Study Area. Bald eagles and peregrine falcons forage and nest near the outer coast. Eagles primarily prey on seabirds, waterfowl, and salmon, while falcons target shorebirds, seabirds, ducks, and other birds.

Birds with special protection: Several bird species within and adjacent to the Study Area are afforded federal or state special protection, including seabirds, raptors, shorebirds, waterbirds, marsh birds, and terrestrial birds. Population declines are often linked to oceanographic changes affecting prey availability, habitat degradation or loss, pollution, oil spills, and predation. Harmful algal blooms (HABs) can also impact birds by contaminating their prey. Management efforts by national wildlife refuges, the Olympic Coast National Marine Sanctuary, WDFW, and DNR are focused on protecting and recovering these species in Washington.

Key data gaps

General data gaps

- General status, abundance, distribution, and trend of birds
- Flight behavior of birds
- Forcing factors of birds

General status, abundance, distribution, and trend of birds. Marine bird and mammal populations along the United States (US) West Coast are among the most extensively studied globally. Since the late 1970s and 1980s, the US Fish and Wildlife Service (FWS) and other organizations have developed a comprehensive understanding of their status, trends, and abundance through extensive survey efforts, particularly along the coasts of California (CA) and Oregon (OR), providing robust and recurring data. However, as survey efforts move northward, they become less frequent. While Washington (WA) also conducts seabird surveys, they are not as comprehensive as those in CA. Citizen birding groups play a crucial role in monitoring marine bird populations off the WA coast, and ongoing pelagic surveys are expected to be completed within two years. These surveys aim to collect vital data on distribution and abundance during the non-breeding season (fall/winter). Additionally, the Catalog of WA's Seabird Colonies will be updated in 2024.

The level of knowledge regarding the abundance, status, and trends varies widely. Some species receive more attention than others, often based on their listing status. Threatened and endangered species tend to have more robust data due to targeted data collection efforts. For example, collaborative studies with the US Navy are underway to monitor the marbled murrelet. While this prioritization is generally effective, there may be species in Washington State that deserve more focus but are not currently receiving adequate attention. Identifying priority species for vulnerability assessments is challenging, and there may be a need to update and refine state listings to ensure comprehensive coverage. Significant work is also being done on indicator species. In contrast, other groups, such as non-colonial species, those with inaccessible colonies, and cryptic species that are difficult to identify in the field, are particularly under-studied. Understanding these species is critical, especially if they are vulnerable.

Predicting trends for various species is difficult due to gaps in knowledge. Currently, there are no regular surveys in Washington State, aside from NOAA's periodic surveys conducted every 4 to 5 years, both onshore and offshore. As a result, there is a lack of detailed data to study finer-scale dynamics. Ideally, annual data collection would provide the most comprehensive insights, though a five-year interval is typically considered sufficient for effective monitoring.

Separately, data on land-based bird species may also be relevant, as some inadvertently venture offshore. During the fall, these species migrate southeastward and occasionally attempt to land on platforms closer to shore, marking episodic events along established migratory routes.

a. Distribution

For most species, habitats are well-established and consistent, supported by reliable colony records that are updated annually or biennially. However, there are other important species in the region that are less abundant and lack sufficient information. For example, knowledge of the distribution of the short-tailed albatross is limited to the broader Pacific OCS region. The lack of data prevents the creation of a detailed distribution map for this species and hampers accurate predictions of its habitat preferences in specific areas. Tracking data could offer valuable insights into their movements.

Data collection efforts primarily focus on the distribution of species, specifically their two-dimensional distribution, seasonality, and relative abundance. The available data on distribution is much more extensive than that for the East Coast, Europe, and other global regions. The availability of data largely depends on the ease of monitoring species. Ongoing monitoring efforts by various organizations, including the Washington Department of Fish and Wildlife (WDFW), FWS, and the US Geological Survey (USGS), contribute to the data pool. Much of this data comes from at-sea surveys, known as sea transects, which provide valuable insights into bird distribution over time, as well as their status and abundance.

Additionally, organized birding boat trips from Washington and cruises from California to British Columbia contribute important data from deep waters, especially during times when smaller boats may not operate effectively. The Coastal Observation and Seabird Survey Team (COASST) also monitors deceased birds on beaches, offering comprehensive insights into their distribution along coastlines. Tracking data also provides valuable information, especially for species that are rarely observed during standard bird surveys. One ongoing project is compiling the largest dataset on seabird communities in the California Current, spanning from the 1980s to 2018, to better understand spatial patterns.

Data collected from at-sea surveys, conducted from ships or aircraft with observers, and tagging efforts have been instrumental in supporting modeling projects and mapping species' use of specific areas. For instance, a comprehensive modeling project integrated 40 years of transect data from the Pacific Northwest into a common database, significantly enhancing the understanding of species distributions, particularly for those abundant enough for detailed modeling. Some modeling initiatives focus on predicting species distribution across the Bureau of Ocean Energy Management (BOEM) Pacific Outer Continental Shelf (OCS) region. Sufficient data has been used to establish the distribution of most bird species in the area.

Changes are occurring rapidly, affecting many species in diverse ways and locations. Birds are shifting their habitats, with movements observed from areas like the Galapagos and Alaska. For example, surveys in Southern California, repeated after 20 years, have shown significant changes in distribution over time. USGS is analyzing existing data on various species and their life history components. It is also investigating the effects of climate change across different scales, such as the “Blob” and warm water events, to better understand the broader ecological impacts on marine and terrestrial ecosystems. While efforts are underway to understand historical distribution, these efforts do not fully address how distribution has changed over time, representing a notable data gap. While localized efforts may address regional distribution changes, comprehensive regional assessments are less evident.

Despite significant data collection efforts, gaps remain, particularly for rare species that are challenging to detect during surveys. These species are difficult to assess for effective risk management due to their scarcity. Not only can certain rare species be excluded from current modeling efforts because of insufficient data, but modeling risks at specific sites can also be particularly challenging for listed species like the short-tailed albatross. Although the short-tailed albatross is gradually re-establishing its historical distribution, its rarity makes it difficult to gather data through transects. This data gap is crucial, particularly since the use of development areas by threatened species remains a primary concern. Collaborations with Oregon State University (OSU) are focused on telemetry work and re-evaluating data for various species.

There is also a gap in understanding the vertical distribution of birds. Collaborative initiatives with PNNL are working to validate thermal trackers for studying the use of vertical airspace.

Offshore distribution, especially off the coast of Washington, is also not well understood. While some believe there is a comprehensive understanding of offshore distribution, others note that data becomes sparser the farther offshore one goes. Data on the gradient from onshore to offshore areas is also limited, with current efforts relying on extrapolations from nearshore surveys. Additionally, capturing concentrated species use during short time periods, such as migration, remains difficult due to the challenges of monitoring these movements in surveys.

Figure 5. A sanderling on the beach.

b. Abundance

There is comprehensive information available on the abundance of seabirds in Washington. Studies have been conducted on the abundance and diversity of bird communities within and outside the Olympic Coast National Marine Sanctuary. Long-term monitoring sites throughout the state have contributed valuable data, with notable studies conducted at Tatoosh Island and Protection Island. Ongoing transect surveys off the Washington coast also aim to model seabird population densities. Collaborations with researchers and organizations engaged in similar studies further strengthen these efforts.

Understanding seabird population density—beyond their abundance and preferred habitats—is essential for accurate risk assessments. However, this remains a significant gap in current research. Flight height data, which provides insights into seabird volume that fluctuates seasonally and with wind patterns, could help address this gap by moving beyond basic 2D occurrence data. Unfortunately, such data is limited for Washington. Key resources include surveys led by the National Marine Fisheries Service (NMFS), such as the ORCAWALE (Oregon California Washington Line-transect Expedition) program and offshore surveys conducted every four years from 1993 to 2014. While these surveys were primarily designed to assess the abundance of offshore marine mammals, they also provided valuable foundational data for seabird density studies.

c. Status and trend

Seabirds in Washington are generally believed to be facing challenges, with most species showing a downward trend. This decline is driven by various factors, including habitat loss, climate change, and reduced access to food resources. However, the global decline in seabird populations underscores that this issue is not unique to Washington. Ongoing efforts to track these trends will require regular updates to monitor the effects of climate change and other environmental factors on seabird populations. For instance, the population of common murres in Alaska has significantly declined, with numbers halving to about 4 million birds over an eight-year period. While the cause of this decline was identified, the full scope of its impact has only recently become clear.

Feedback on importance: To effectively address existing gaps, more distribution data specific to Washington state species is needed, ensuring that important and vulnerable species are not overlooked. A particular challenge is identifying interannual variability. While data collected every five years can reveal trends and changes, annual data collection is ideal, as species distribution is closely linked to environmental conditions. Annual coastal surveys would provide valuable insights, but offshore surveys are costly. Collaborative efforts with the Olympic Coast National Marine Sanctuary (OCNMS) to develop offshore monitoring are underway, though further efforts are needed in the region to fully address these challenges.

Flight behavior of birds. Information on widely distributed species like the common murre and tufted puffin should be readily accessible, given the extent of existing research on these species. However, significant data gaps remain. More research is needed on how birds adjust their flight behavior and altitude in response to wind conditions, particularly for species in Washington, which have not been adequately studied in this regard. Studies of similar species can offer valuable insights. When a related species has been studied, it is assumed that those findings are applicable to Washington species. The vulnerability index has already applied comparable metrics to Washington species and identified the best available references. There is no need to start from scratch; existing resources can be effectively leveraged.

Feedback on importance: There is interest in conducting a Population Viability Analysis, focusing on factors such as flight height and speed.

Forcing factors of birds. While the general impact of environmental factors on species is understood, studying environmental forcing factors is essential, as climate change, for example, is expected to significantly influence migration, distribution, and species trends. Currently, efforts are ongoing to identify specific factors contributing to declines. For instance, researchers are examining changes in food availability due to shifts caused by marine heatwaves, which have forced birds to adjust their diets in response to altered prey availability.

More research is needed to fully understand the effects of forcing factors. This includes investigating the factors that drive population fluctuations or induce shifts in ecological dynamics. Bird behaviors, for example, vary during El Niño years, when warmer waters and weakened upwelling occur. The impact of anthropogenic activities on birds will also depend on environmental forces, such as prolonged shifts in sea surface temperatures driven by climate change. Understanding the influence of factors such as climate change, prey distribution, predation (e.g., by bald eagles), and habitat availability is crucial. It is important to consider whether forcing factors should be studied independently or within broader ecological contexts. While not necessarily a data gap in the strictest sense, this issue requires ongoing attention within the framework of evolving pressures on ecosystems.

Feedback on importance: There is growing interest in studying the various factors that influence bird health, abundance, distribution, and behavior.

Offshore wind data gaps

- Risk of collision of birds with offshore wind facilities
- Effect of offshore wind on migration paths of birds
- Effect of offshore wind on bird behavior

Risk of collision of birds with offshore wind facilities. Understanding the risks of bird collisions with offshore wind turbines and the variability of this risk among different species is crucial. To accurately assess this risk, three key probabilities must be considered:

Probability of being in the region: To assess the likelihood of birds being within offshore wind farms, data on species distribution, abundance, and diversity in relation to offshore wind energy locations is essential.

Probability of encountering an object: Many birds offshore of Washington are dynamic soarers, flying higher in strong winds. However, more detailed data on bird avoidance and collision risks are available primarily for nearshore areas, where birds typically fly lower and closer to the water's surface.

Currently, flight height data is limited and often relies on information from similar species within broader taxa, with the assessment based on general characteristics of these taxa. Improving data collection is vital as tracking studies progress and capacity increases. For example, ongoing efforts aim to better understand how petrels and albatrosses adjust their flight heights in response to wind speed. Other data gaps remain, such as the impact of environmental conditions on bird behavior (such as dive or flight patterns) and energy expenditure. Concerns also exist about birds being attracted to artificial lights at night. While some knowledge on visual cues is available, this data is only available for bird species studied in other regions. Adjusting lighting types could help mitigate this risk.

Probability of injury: The likelihood of collision with turbines depends on how birds use vertical airspace and their ability to detect turbine blades. While researchers have identified typical flight altitudes based on available data, uncertainty remains about how birds will respond to the presence of turbines. Some species are adept at navigating around structures, while others may struggle. Dynamic soarers, such as albatrosses, shearwaters, and petrels, are generally less maneuverable than flapping flight birds like gulls, terns, and murrelets. Literature on bird avoidance generally shows high avoidance rates (often exceeding 90%) across many species, but data availability is uneven, with no data currently available for species like shearwaters and albatrosses.

It is unclear how well soaring birds will be able to avoid turbines, and factors such as fatigue may affect their responsiveness. Additionally, it remains uncertain whether these birds will actively avoid, be attracted to, or collide with turbines. The lack of analogous data for these behaviors presents a significant gap in understanding. However, based on current knowledge, most species tend to avoid colliding with turbines by steering clear of wind farms. This avoidance, though, may increase the risk of displacement, which could pose a more significant concern. Understanding the risk of displacement is a key data gap that requires further investigation.

Effective monitoring will be essential to close these knowledge gaps, particularly offshore monitoring, which will require remote methods due to the logistical challenges and costs of working in offshore environments.

Collision risk modeling has been conducted for specific bird species. However, primarily due to data limitations, scaling this model to assess collision risk at the turbine level for all species presents a substantial challenge. There is a critical need for comprehensive data to develop effective risk models.

While the risk of collision with offshore wind remains a data gap, ongoing research is gradually providing more insights as additional wind turbines are deployed in ocean environments. Research efforts are expanding, particularly in Europe and the UK, and significant work is being done on bird collision, attraction, and avoidance behaviors related to offshore wind installations. Studies are being conducted at two scales:

Individual turbine level: This focuses on how fluctuations in currents, variations in water flow, and the attraction of birds like gulls and terns influence collision rates. It also examines whether adjusting the configuration of wind farms can reduce these collision risks.

Farm configuration level: This investigates how the layout of wind farms, in relation to surface currents and wind circulation patterns, affects bird behavior and the likelihood of collisions.

While it is important to consult regions where comprehensive studies have been conducted, there are limitations. Much of the offshore wind development to date has taken place in the North Sea and Atlantic regions of Europe. However, the bird species composition in Washington differs significantly from that in Europe. Similarly, although offshore wind projects are now being developed on the East Coast of the US, the species composition there also varies from the West Coast. In both Europe and the East Coast, research has primarily focused on flapping birds, which limits the relevance of these findings to understanding collision risks and avoidance behaviors for West Coast birds, where dynamic soarers are more common. Dynamic soarers are birds that use wind currents to gain altitude and cover long distances. [21] Not only do species differ from those studied at existing offshore wind sites, but some species in Washington also lack case studies or any relevant data. In addition to the insufficient assessment of risks to bird species off the coast of Washington, the specific risks associated with floating offshore wind installations remain unclear.

More recently, efforts to understand these risks have been actively pursued by several groups in California, particularly within the California Current Ecosystem (CCE). Some work in this area has been done through Environmental Impact Statements (EIS) and vulnerability assessments,

[21] https://www.ox.ac.uk/news/2022-06-01-researchers-show-dynamic-soaring-isn-t-just-albatrosses

which have covered 81 species so far and are expected to expand. These assessments not only evaluate vulnerability but also address uncertainties based on the available data, with confidence in findings being expressed based on current information. Similar assessments have been conducted worldwide, reflecting global interest in this issue. However, given the unique seabird communities and population abundances along the West Coast, a specific analysis tailored to Washington is essential.

Additionally, collisions with vessels could provide valuable insights. While vessel speed increases the risk of collision, seabirds are generally known to avoid ships. For instance, dynamic soarers have been observed adjusting their flight paths to steer clear of ships. Additionally, some seabirds exhibit behaviors such as sleeping on the wing and often wake up in time to prevent collisions.

Feedback on importance: Alongside displacement risk, understanding the risk of collision is key to understanding offshore wind effects. Relevant data already exists but addressing this data gap requires a dedicated study.

Effect of offshore wind on migration paths of birds. To assess the potential risks of offshore wind on migration, it is essential to link species distributions, abundance, and diversity to offshore wind energy locations. Evaluating migration risks includes assessing the potential for displacement. Displacement from their usual habitat could have widespread effects, affecting their ability to migrate, forage, and transit effectively.

Figure 6. A common loon in the water.

A direct impact of offshore wind could be the alteration of migration routes, while indirect effects may involve influencing population dynamics, including reproduction and mortality rates. Understanding both the direct and indirect effects is challenging.

The effect on migration will depend on several factors, including the species involved, their flight heights, the height of the wind farm, and the potential overlap with migration paths and wind development areas. Addressing this data gap requires research focused on displacement, particularly in relation to collision risks and avoidance behaviors.

Species' avoidance behaviors could potentially alter established migration routes. If a species is likely to avoid a wind farm, it is important to determine whether the farm is located within its migration path. If overlap occurs, further investigation is necessary to understand how this interaction may affect the species' migration patterns. The extent and specific implications of these effects are still uncertain and warrant further study.

The effect on migration will also depend on proximity to shore for certain species. Nearshore birds that migrate only a few hundred miles may be more susceptible to offshore wind impacts, though this remains uncertain. In contrast, species farther offshore, particularly those in the pelagic community that rely on wind to navigate, could be more directly affected. Areas with high offshore wind activity may attract these birds, potentially making it more challenging for them to avoid structures and possibly altering their migration paths. However, seabirds are resilient in many ways, and their responses remain uncertain.

The scale of offshore wind infrastructure will influence the potential impact on migration. While a single structure is unlikely to have a significant effect, a full build-out of offshore wind farms could alter existing patterns of area use, particularly for species that are highly avoidance-prone. Hence, while this is not currently a high-priority concern, it could become more significant with extensive development. Although smaller-scale offshore wind developments are less likely to directly affect migration patterns, they may displace local bird populations, which could impact nearby breeding species. Given the close relationship between food intake and energy expenditure for many species, these displacement effects could be substantial. Additionally, scattered wind farms in vast offshore waters are unlikely to pose significant threats, as these areas are typically productive and expansive. However, in more confined areas, such as Puget Sound, the effects could be more pronounced, particularly for waterfowl.

Research on this issue is ongoing within the broader context of the California Current ecosystem. However, limitations in the way transect data is collected could result in underestimations of migration patterns. Transect surveys capture birds at specific points in time and may not fully account for birds passing through an area in bursts, leading to inconsistent detection. For example, birds might be observed frequently for the first few days but then go undetected for several days, making transects less ideal for capturing these dynamic migration patterns. Efforts are also being made to address this data gap through Environmental Impact Statements (EIS).

To improve understanding, researchers are exploring radar monitoring and telemetry. For example, collaborations with USGS are investigating radar and acoustic technologies to track migration behavior through areas of interest, while telemetry data is being used to track bird movements and create a species distribution atlas for the offshore region. While GPS tags are effective for larger species, such as albatrosses, smaller birds require more delicate tagging methods. International initiatives like MOTUS in Canada are also contributing to this effort. The MOTUS network includes 25 receivers along the California coast, enabling cross-border tracking. A bird tagged in one location within the MOTUS network can be detected by all the network's towers. This allows, for instance, the mapping of a migratory pathway of a species first detected by a receiver in British Columbia and subsequently detected in Washington.

Research efforts outside Washington and the West Coast may be informative. Examining previous studies on the impacts of offshore wind energy in locations where it has already been implemented can provide valuable insights into potential effects. Europe has had offshore wind farms for a longer period than the US. Recent studies in the North Sea, for example, have shown how loons are avoiding areas with wind farms, which researchers have observed through changes in their distribution. This has implications across a range of impacts. Certain groups and families of birds on the US Pacific coast may exhibit similar responses as some species occur in both the US and Europe. It is also reasonable to hypothesize that there could be analogous responses among related species. Studies on species avoidance of other structures in Europe may also provide some insight.

Regarding potential indirect impacts, facilities on the East Coast have not been operational long enough to fully assess these effects. While general avoidance rates are understood, behavioral changes are typically observed only after the facilities are constructed, suggesting a lag effect. Furthermore, quantifying shifts in migration pathways and evaluating indirect impacts at the population level remains challenging. There is currently no comprehensive tool available to accurately measure these population-level effects.

Feedback on importance: Relevant data on the potential effects of offshore wind on bird migration already exists; however, closing this data gap would require a dedicated study. Investigating displacement risk could help address this gap.

Effect of offshore wind on bird behavior. Offshore wind development can have both direct and indirect effects on bird behavior, as well as broader population impacts. Direct effects include mortality and displacement during migration, transit, and foraging. While habitat loss is a known concern, understanding the full extent of collision mortality and displacement remains limited.

The effect on behavior will depend on the scale of the offshore wind infrastructure. Currently, two main types of studies are being conducted: one focuses on the individual turbine level, exploring interactions between the turbine structures and changes in circulation that may affect the feeding behaviors of surface-feeding birds and possibly some diving species. The second type of study examines the cumulative effects of multiple wind farm leases within a larger area, typically assessed at the 100 km scale.

The impact on feeding behavior depends on whether offshore wind structures are located within the typical foraging areas of bird species. The radius within which birds forage is often constrained by their proximity to breeding colonies. For example, if offshore wind installations force birds to travel greater distances from their colonies to access food sources for nesting chicks, this can lead to significant behavioral changes. The increased travel distance requires more energy for food collection, which may reduce the energy available for chick rearing and affect reproductive success. The proximity of offshore wind farms to colonies is a key factor in determining the extent of these impacts.

Species with higher avoidance rates may also experience shifts in foraging behavior and patterns, which could negatively affect their feeding and overall health. However, there is currently no evidence that changes in feeding behavior directly impact reproductive success or vital rates. Adding complexity to this issue, birds that exhibit avoidance behaviors typically do not nest along the coast but instead disperse to coastal environments after breeding.

Offshore wind structures may also attract birds. These structures could provide roosting habitats or function as artificial reefs, drawing benthic life that, in turn, attracts fish and birds. While the reef effect is well-established, where underwater structures enhance marine life and create better feeding opportunities, it remains unclear whether floating turbines will have a similar effect on bird attraction or foraging behavior. Birds may be drawn to fish species that congregate around offshore wind structures, potentially offering additional feeding opportunities. For instance, seabirds often travel long distances daily in search of food and are known to detect fishing vessels from afar, drawn by the availability of food. However, this attraction could increase collision risks for birds. Additionally, if located within a migration corridor, it is unclear whether birds will opportunistically stop to feed at the turbine or simply pass by without feeding, as they may not be actively searching for food during migration.

In addition to impacts on feeding, exposure to contamination can have intergenerational effects, influencing chick health and recruitment rates. Noise or disturbance from turbines located near colony sites could also potentially contribute to colony collapse. Other factors, such as climate change, must also be considered alongside the effects of offshore wind. These factors include coastal erosion, large-scale diseases, oil spills, long-term contamination, and pollution, all of which can affect food availability and habitat access for seabirds.

Figure 7. A snowy plover on a beach.

Feedback on importance: Addressing the risk of displacement could help fill the data gap regarding the effects of offshore wind on bird behavior. While relevant data already exists, a dedicated study would be required to fully assess this. For example, conducting a literature review on foraging distances would enable the calculation of a buffer zone that could help address potential impacts.

Other Data Gaps

General data gaps

- Migration of birds
- Monitoring method of birds
- Disease and pathogens of birds

Migration of birds. The migration of birds represents a critical data gap. However, relevant information is likely accessible due to frequent bird tagging and ongoing seabird monitoring efforts along the coast.

While significant progress has been made in understanding the general migration patterns of marine birds, including their locations and timings, there is limited understanding of year-specific patterns. Unless researchers are actively collecting data, currently, there is no systematic approach in place to track these patterns. This presents challenges in predicting distribution and migration. Multi-year heat maps (e.g., for sooty shearwaters in fall in Washington), assume static environmental conditions. The dynamic nature of environmental forces could alter migration patterns and affect distribution and population dynamics. Additionally, while historical averages provide a useful starting point, they may not accurately reflect current trends or specific locations.

Addressing this data gap also requires data on offshore and nearshore migration, such as for Aleutian cackling geese and Western snowy plovers. Existing records offer some information, but the frequency of offshore movements remains unclear. A better understanding of shorebird presence, densities, and environmental conditions is essential to address these gaps. Some species presumed to be coastal may face offshore risks.

Monitoring method of birds. This represents a significant data gap. The need for monitoring methods depends on the scale of the research question. For example, understanding how birds alter migration routes in response to environmental factors requires a comprehensive, integrated dataset collected through various methods and across multiple locations. On the other hand, assessing bird responses to a specific offshore wind platform may be achieved through remote technology alone. The International Cooperation for Animal Research Using Space (ICARUS) program[22], an extensive global tagging initiative, tracks a large number of birds, demonstrating that it is unnecessary to tag every individual bird or set up numerous observation stations.

Much of the data currently collected on birds comes from human observers. However, there remains a need for methods to monitor temporal and spatial data gaps in conditions where human observation is impractical or unavailable. For example, a thermal tracker could gather data during nighttime or foggy conditions, providing measurements of flight height and speed within its field of view.

Monitoring methods are generally standardized through agencies like the US Fish and Wildlife Service (USFWS) and the Department of Fish and Wildlife (DFW). However, further efforts to establish standardized protocols for describing research methods would be highly beneficial for future studies. The USFWS is currently working on standardizing methodologies and documentation practices for seabird studies in the Pacific region.

Disease and pathogens of birds. There is considerable concern regarding avian influenza, which appears to be an ongoing issue. Recently, a significant mortality event among Caspian terns in Puget Sound was linked to avian influenza. While the virus has not yet had a major impact in North America, it remains prevalent among colonial marine birds in other parts of the world. Strategies for addressing this emerging threat are still unclear, but there is a substantial amount of information available. Expertise on this matter does not solely reside within seabird specialists. Virologists are also actively researching this issue. Additionally, other researchers are studying a range of diseases and pathogens, including botulism, contaminants (which can lead to diseases and adverse health effects), and harmful algal blooms (HABs). In Alaska, for example, a bird mortality event was observed after the ingestion of a fish contaminated with HABs.

[22] https://www.icarus.mpg.de/en

Offshore wind data gaps

- Effect of the physical structures of offshore wind on albacore tuna
- Effect of offshore wind on roosting, nesting habitat, and foraging areas of birds
- Effect of vibrations and noise from offshore wind on birds
- Effect of offshore wind to the population and population dynamics of birds
- Effect of light from offshore wind on birds
- Risk of displacement from offshore wind
- Monitoring method to study the effects of offshore wind on birds
- Acceptable level of change
- Effect of offshore wind structure on birds

Effect of offshore wind on roosting, nesting habitat, and foraging areas of birds. Offshore wind developments may disrupt access to birds' traditional roosting, nesting, and foraging sites, with the extent of the impact varying by species. To fully assess the risks of offshore wind energy on these habitats, it is important to evaluate species distribution, abundance, and diversity in relation to offshore wind locations.

Roosting and nesting: Species that are known to be attracted for roosting or nesting include gulls and cormorants. Oil rigs may provide insight into potential impacts.

Anything affecting nesting would cause significant disturbance. The potential effect of wind energy on nesting areas is unknown. Species that exhibit flexibility in their nesting location from year to year may be more capable of adapting to these changes caused by offshore wind. In contrast, species with consistent site fidelity may struggle to adjust. However, given the offshore placement of turbines, it remains uncertain whether these species would venture that far offshore. Some birds may also choose to nest on the structure depending on the tradeoff between finding a new nesting place and the risk of turbine collisions. The effect of a new nesting habitat on species also requires additional research. While there aren't many coastal birds that nest on structures, some species, such as cormorants and larids (gulls and terns), do. Though there are occasional inconsistencies, there is good knowledge about nesting habitats and colony sites. Various groups are dedicated to monitoring colony sizes along the Pacific Coast which provide valuable information. If the structure is near a colony, there is a higher risk of offshore wind affecting roosting or nesting.

For roosting locations, the species typically attracted to such habitats are primarily coastal rather than offshore species. Gulls frequently utilize boats for roosting, as do boobies and migratory landbirds, particularly when they are forced offshore due to adverse weather conditions. This behavior is commonly observed on fishing vessels. If wind structures are positioned far offshore, coastal species, which are more likely to land on structures, would be less affected.

Forage areas: Birds may perceive wind platforms as potential landing sites or be attracted to them as foraging areas if the structures function as a fish aggregating device (FAD). Temporarily, fish stocks could increase due to enhanced habitat availability around the structures, attracting birds seeking feeding opportunities, much like their attraction to fishing vessels. Research has shown that seabirds foraging near Marine Protected Areas (MPAs) exhibit reduced effort due to the increased availability of fish within an accessible distance. The location of offshore wind farms could influence which seabird species can access these areas, affecting the likelihood of birds landing on the structures and potentially altering their foraging patterns. Different species are likely to respond in various ways, and the overall impact on the seabird community remains uncertain. While there is research on avoidance behaviors, less attention has been given to the aggregation effects.

Currently, however, there is limited data or understanding regarding whether turbines can function as effective artificial reefs. It's important to note that while the attraction of birds to these structures could provide foraging opportunities, it may also increase collision risks. On the other hand, if offshore wind farm structures displace birds from their usual foraging grounds to areas that are less energetically costly, this could have a beneficial impact.

Effect of vibrations and noise from offshore wind on birds. There is limited knowledge regarding the effects of vibrations and noise on birds, as these factors are typically considered to have a more significant impact on other species. Additionally, it is generally expected that noise and vibrations will have the least effect on birds compared to other activities associated with offshore wind energy development. While the full scope of their effects remains uncertain, understanding the impact of noise and vibrations from offshore wind activities on avian populations is considered a relatively low priority. Some evidence suggests that seabirds may be attracted to low-frequency sounds, though supporting data is scarce. Conversely, birds may find noise and vibrations disruptive or may gradually acclimate to these stimuli over time.

A specific concern has been raised regarding the potential impact of pile driving on marbled murrelets, though this issue is believed to be more relevant in nearshore settings than in offshore environments. Numerous studies are currently underway to investigate this concern.

Effect of offshore wind to the population and population dynamics of birds. To assess the effects of offshore wind on avian populations and population dynamics, it is essential to consider how these facilities may influence resource access, nesting and foraging site selection, and potential mortality. Habitat loss and its broader impacts on species are also of concern, requiring attention to both population-level and direct effects. Additionally, population effects may arise from factors such as collisions or displacement. Given the diversity among seabird species, predicting the impact of any single factor is challenging. However, if the risks of collision or displacement are low, offshore wind facilities may have minimal effect on population dynamics.

Factors such as flight height, geographical location, and distance from shore will help identify which species are likely to be affected. However, there is insufficient understanding of the age and status structure of seabird populations, including breeders, non-breeders, pre-breeders, and floaters that lack breeding space. Relying solely on colony counts may not provide a comprehensive picture.

While this effect is being studied in various contexts, there is limited information specific to offshore wind energy. Tools and modeling can help examine population dynamics, but translating displacement effects into changes in population trends can be complex. This data gap may be addressed by exploring related areas of research.

Effect of light from offshore wind on birds. Bird attraction to light is a significant concern, particularly in relation to seabird collision risks. Seabirds can be drawn to light sources, increasing the potential for collisions with ships, especially for species like storm petrels, which may experience "fallout" incidents near their nesting colonies. Currently, no offshore wind projects are located near seabird nesting areas, which helps mitigate this risk. Regulatory agencies can enforce measures to minimize fallout. Careful consideration must also be given to the type of lighting used on turbines. While offshore wind facilities are not expected to be extensively illuminated, bright lights may be necessary during nocturnal operations on ships or barges involved in offshore infrastructure installation. Many seabird species are attracted to such lights, similar to those used to illuminate human activities like coastal streetlights. Since many seabirds are nocturnal and return to their colonies at night, they may be drawn to lights, become disoriented, and face difficulties returning to their colony. This attraction can lead to diversion and collisions with structures. The impact of lighting on birds varies by species.

Aviation lighting can be implemented in ways that minimize impacts on birds, such as using specific colors and turning off unnecessary lights. When done correctly, these measures can significantly mitigate the risks. This is not so much a data gap as it is a crucial consideration in turbine light design. The potential effects on birds should be taken into account when making decisions about turbine lighting.

Extensive research has been conducted on the impact of light on birds, with notable studies carried out in Kauai, Hawaii. Findings from these studies provide insights into bird behavior, allowing for some assumptions to be made within the same taxa. Overall, evidence indicates that seabirds are attracted to light. Numerous studies have investigated seabird behavior both at colonies and on the water, examining interactions with various structures, including oil platforms and ships. Significant efforts have been made to mitigate the impacts of stationary structures through measures such as downward-pointing lights. Similarly, the use of red spectrum lights, as implemented on oil platforms in eastern Canada, has been extensively studied for its effectiveness in reducing seabird attraction. However, gaps remain in the data, particularly regarding the effects of light on specific species. Additionally, the impact of light on marine bird species in the context of wind energy development has not been extensively studied. It remains an active area of research.

Risk of displacement from offshore wind. Displacement may be more critical than collision, though its impacts remain difficult to fully understand. Assessing the effects of displacement requires examining both individual-level impacts, such as mortality or reproductive success, and population-level consequences. The response of birds is uncertain; for instance, they may either be attracted to fish around the turbines or avoid offshore wind structures entirely. Evaluating this risk is complex due to the many factors involved, as outlined in vulnerability indices. Focusing on the contributing factors, rather than fully understanding the phenomenon itself, is essential. Understanding whether displacement will negatively affect birds is one of the most significant data gaps. While tools exist to assess this effect, they are not perfect and depend on additional data.

With such a productive ocean, the significance of losing habitat space is likely negligible until approaching closer to the coast. Coastal projects are more likely to affect nearshore birds by restricting their habitat. Species like loons, which are commonly found in nearshore areas, and marbled murrelets could be more vulnerable to habitat loss. Beyond a few miles from the coast, these concerns are expected to diminish. In more distant offshore locations, the impact of losing a few square kilometers of habitat is less significant due to the high productivity of the California Current Ecosystem (CCE). The narrow and productive nature of the CCE suggests that offshore wind farms could function similarly to marine protected areas, with birds likely navigating through them rather than avoiding them. Unless turbines are situated over specific hotspots, displacement concerns in the expansive pelagic waters are expected to remain minimal.

Scale will also be a critical consideration when evaluating the interaction between bird habitats and offshore wind farms. If wind farms are distributed across the entire coastline, they could impact birds, but they are unlikely to cause the extirpation of a species. All the bird species found here are also present in other locations. For instance, scoters migrate south into the Pacific Northwest but breed in Alaska, Yukon, and other Northwestern Territories. These birds exhibit strong site fidelity, returning to specific locations. While such place attachment could affect parts of a population, there is no evidence suggesting this level of fidelity occurs on the outer coast where wind farms may be situated. It will be crucial to strategically place turbines to minimize impact while maximizing efficiency.

Assessing this risk will be challenging until wind infrastructure is established. Until then, informed estimations will have to guide planning. It will be crucial to investigate why birds use specific areas and to identify alternative habitats should certain areas become inaccessible due to wind energy developments. The main concern is translating evidence of displacement into measurable impacts on populations. Cumulative effects of displacement could also be significant, particularly if multiple facilities are sited in migratory paths or foraging areas crucial during breeding seasons. Existing research may offer valuable insights, as studies in Europe have examined displacement in certain species. In the North Sea, offshore wind farms created zones of unsuitable habitat, with some birds avoiding these areas while others adapted.

Monitoring method to study the effects of offshore wind on birds. Changes to current monitoring methods will be necessary due to the unique challenges posed by offshore wind areas. Transects may not be feasible in these regions, so alternative methods, such as aerial surveys, will be essential. Survey flights will also need to operate at higher altitudes to avoid turbines. Any newly developed monitoring approaches will need to be well-documented and standardized to ensure consistency. Other regions have already documented strategies for monitoring birds in offshore wind environments. In Europe, for example, radar is being used to track birds' responses to offshore wind facilities. This monitoring focuses on birds around foundation platforms rather than floating structures.

To improve species identification at the lowest possible taxonomic level, a thermal tracker could be mounted on a boat to actively track and increase the sample size of birds observed. Collaboration with PNNL is underway to develop an automated, 24/7, 3D thermal tracker capable of remotely monitoring seabird flight trajectories through thermal imagery. The tracker will identify birds within its field of view, and as more targets are detected, it is hoped that it can distinguish species at a more specific taxonomic level. This technology is still under development. The thermal tracker has been deployed to gather data at the scale of individual turbines, and there is interest in ensuring it functions effectively in all weather conditions. To address weather-related challenges, optical monitoring methods are also being explored. One proposal involves equipping lenses with windshield wipers. High-resolution optical cameras could also help with taxonomic identification.

Additionally, a LiDAR buoy was tested offshore, but power source failures during winter led to a lack of data. If the power source had remained operational, it is hoped that the buoy would have collected valuable data. There is ongoing interest in integrating this technology into a larger radar system to study bird reactions around wind farms at a broader scale.

Blade vibration technology is also being explored to detect strikes or collisions. The goal is to develop a comprehensive monitoring system. This initiative has just begun with a 5-year grant, and with a Technology Readiness Level (TRL) of 9, indicating readiness for deployment, the aim is to advance to TRL 6 within the next 5-10 years.

Acceptable level of change. There may be differing perspectives on what constitutes an acceptable level of change. Determining acceptable thresholds becomes even more uncertain when the changes have a detrimental impact. While seabird populations are currently in decline, they have not yet reached a critical threshold where the entire population is significantly affected. However, this decline could present challenges for wind energy development in the future.

A key consideration is whether changes induced by offshore wind activities are likely to affect population viability. While some mortality may result from these activities, other factors, such as fishing bycatch, could have a more significant impact. It is crucial to assess whether offshore wind activities alone could push bird populations past a tipping point, especially when compared to other sources of mortality. Effectively addressing the primary sources of mortality will be critical.

Population-level effects will also vary depending on the species. Seabirds are widely distributed offshore, and many come from different regions. K-selected seabird species, which produce fewer but higher-quality offspring, are especially sensitive to adult mortality. While occasional breeding failures and loss of offspring are expected, the survival of adults is crucial for maintaining population stability. In contrast, more abundant species may have higher tolerance thresholds for population impacts.

The extent of change also varies depending on the location of wind infrastructure development. Wind farms should not be sited near seabird colonies to avoid detrimental impacts. In Denmark, turbines positioned adjacent to a colony resulted in the death of several hundred terns. Most seabirds nesting in Washington typically fly close to the water surface, below the rotor sweep zone. If colonies are situated near an offshore wind facility, birds returning to their colonies may begin to fly at the height of their nesting sites. This poses a collision risk.

Understanding the impact on protected species is critical when assessing the effects of offshore activities on seabird populations. The Migratory Bird Treaty Act at the federal level prohibits the "take" of protected species, including harm or death. Exceeding certain thresholds, such as the death of three short-tailed albatrosses, a highly endangered species historically found nearshore in Washington, can trigger closures of activities like longline fishing in the Gulf of Alaska. Locally endangered species often operate within narrow margins for acceptable change; for example, only one tufted puffin chick fledged from Protection Island this year. Under the Endangered Species Act (ESA), once a species is listed, efforts focus on ensuring human-caused impacts do not pose extinction risks, with mitigation measures implemented accordingly. The listing of declining species also provides indirect protection for other animals in their habitat. Environmental assessments and permitting processes, governed by state laws, guide the evaluation of significant impacts and mitigation requirements. Agencies determine acceptable levels of impact during the permitting process, with variations depending on whether the species is state or federally listed. Determining what constitutes an acceptable impact involves input from non-governmental organizations and the use of population genetics models to estimate minimum viable population sizes.

Research is actively exploring tools to assess the extent of impacts and effective mitigation strategies. Models such as collision risk assessments estimate the number of birds likely to collide with turbines, while population viability analyses gauge how mortality could affect bird populations. Improvements may be made elsewhere to account for the negative impacts of wind farms.

Effect of offshore wind structure on birds. Seabird responses to other structures can provide insight into this data gap. Seabirds generally avoid collisions with ships, often sleeping on the wing or in rafts/flocks at sea. Dynamic soarers, like albatrosses, shearwaters, and petrels, fly toward ships and awaken before impact, while more maneuverable birds, like gulls, terns, and murrelets, can avoid vessels more easily. Data from Europe and the East Coast have limited relevance to the West Coast, as dynamic soarers are less common there. Besides collisions, structures may also pose a risk of secondary entanglement.

Offshore aquaculture data gaps

- Effect of chemicals from offshore aquaculture on birds
- Effect of disease transmission from offshore aquaculture on birds
- Effect of offshore aquaculture on the migration paths of birds
- Effect of offshore aquaculture on the behavior of birds
- Effect of offshore aquaculture on the roosting, nesting habitat, and foraging areas
- Effect of offshore aquaculture on the population and population dynamics of birds
- Potential for offshore aquaculture to cause entanglement
- Risk of displacement of birds from offshore aquaculture
- Effect of offshore aquaculture structure on birds
- Effect of human intervention on birds

Effect of chemicals from offshore aquaculture on birds. The effects depend on the specific chemical and can occur through direct toxicity or indirectly by affecting prey species. Birds are highly sensitive to environmental chemicals, which can accumulate in their tissues through the food chain. Bioaccumulation happens when seabirds ingest contaminated prey, leading to the buildup of chemicals in their tissues. Contaminants can persist in bird tissues throughout their lifespan, and if a bird experiences starvation and relies on fat reserves, it may be exposed to toxins accumulated in its tissues. Extensive research has focused on how chemicals and contaminants accumulate in seabirds and on biomagnification in the food web. A valuable study would be to investigate regional differences in fatty tissue accumulation.

The impact of chemicals also depends on the scale, farmed species, and location. Net pens in fjords and sounds are particularly problematic due to poor circulation, unlike those in open ocean environments. How seabirds feed also influences their exposure risk. While nearshore diving birds are less likely to encounter plastic pollution, pelagic birds feeding near the surface are more prone to ingesting plastic, which can also accumulate harmful chemicals.

In Europe, there is limited evidence of chemicals from offshore aquaculture posing a significant issue for birds. These fish pens, often fed with local water resources, are common across the region. In situations where bird interactions may be problematic, some farms use nets to prevent access. While fish oils can have environmental impacts similar to petroleum oils, operations producing significant quantities are unlikely to release them into the environment due to strict regulations. Fish oil is economically valuable and is typically sold rather than discarded. Additionally, birds like fulmars can produce oil slicks as a defense mechanism, expelling stomach oil to deter perceived threats from other birds.

There are other ways in which chemicals from offshore aquaculture activities can affect birds. However, even in areas with higher concentrations of fish or waste, these materials are expected to disperse and dilute into the open ocean. Additionally, though small releases pose minimal risk, breaches from boats servicing the facility could result in larger oil spills, which present a more significant risk. Increased debris is also a concern, although the extent of contamination remains uncertain.

Effect of disease transmission from offshore aquaculture on birds. While there is considerable knowledge about bird diseases, less is understood about transmission from fish to birds. However, most raised species are likely too large for birds to consume. Even if the operation involves a species that can be consumed by birds, a fish to bird transmission is unlikely. Generally, diseases are not transmittable between fish and birds, though consulting an expert in the field would provide more clarity. Although disease transmission between fish and birds is generally rare, birds consuming shellfish contaminated with domoic acid could face a potential risk. Additionally, there may be concerns with parasites, but parasites tend to be highly host-specific and instances of transmission from fish to birds are not well-documented.

If the facility is near a colony, the impact on disease transmission could be more pronounced. Offshore aquaculture could also alter the food web, potentially influencing the spread of diseases, parasites, and bacteria. Additionally, high concentrations of birds near aquaculture facilities could increase disease transmission within bird populations, though this may not differ significantly from natural colony conditions.

Effect of offshore aquaculture on the migration paths of birds. Migration patterns are shaped by food availability and habitat needs. Many species rely on multiple stopover sites to rest and replenish resources, seeking feeding grounds and habitats that offer protection from environmental conditions.

If a consistent food source, such as fishing barges, is available in a particular area, most bird species observed are typically residents. Offshore migratory birds usually do not frequent these areas enough to cause concern. For example, geese and ducks following migratory routes along the West Coast generally avoid fish pens. While coastal migrants may occasionally stop by, migration is an ingrained behavior, and a persistent food source would be needed to significantly alter routes. Significant migration issues or population-level impacts are not expected. An exception applies to gulls which breed inland and are known for learning new feeding areas. Hence, the potential impact of offshore activities depends on proximity to shore, but offshore aquaculture activities are unlikely to have a significant effect.

Studies are currently underway to assess whether offshore activities are displacing seabirds and the extent of this impact. Understanding how migration patterns are affected will require more time and data, including whether shifts are permanent or temporary. Additionally, interannual variability remains a challenge due to the lack of annual offshore surveys.

Effect of offshore aquaculture on the behavior of birds. Increased food availability or heightened chemical consumption could influence bird behavior. Direct impacts may occur if fish are fed bait fish that birds rely on for foraging. Birds may also prey on cultivated fish; however, fish farms typically use nets to prevent bird access, helping to mitigate potential negative effects. Offshore aquaculture could also attract fish or displace important prey, potentially altering bird foraging behaviors.

Changes in food availability can significantly affect migration. Birds rely on various stopover sites to replenish resources, seeking areas with abundant food and suitable habitats for protection from environmental conditions.

While large-scale offshore aquaculture may attract certain bird species, significant operations would be needed for it to substantially impact bird behavior.

Effect of offshore aquaculture on the roosting, nesting habitat, and forage areas of birds. There is limited information on this topic. Offshore aquaculture could potentially benefit bird populations, unless risks such as entanglement arise. The effect will vary by species, depending on factors such as foraging range, nesting, chick-rearing, and egg-laying periods. Some species-specific data on these behaviors is available.

Offshore aquaculture facilities typically involve minimal surface structure. Whether they provide roosting or nesting opportunities depends on the specific facility, but most do not. Additionally, birds are unlikely to nest unless suitable material is available, which is rare offshore. If nesting opportunities exist, they are unlikely to cause issues unless bird droppings concern fish farmers. Roosting behavior is also more common among nearshore species, while true seabirds typically come ashore only for breeding. However, if maintenance is necessary, it may involve activities that could disturb birds.

Offshore aquaculture could also artificially increase food sources or chemical consumption. The impact will vary by location. It's unclear how or to what extent hormones in fish may impact chicks or breeding, as there is limited research on this topic. In Mexico, aquaculture has been found to supplement food resources for some species.

Effect of offshore aquaculture on the population and population dynamics of birds. Factors such as site attraction, resource availability, and risks like disease or plastic transmission could influence bird population dynamics. An indirect effect might include increased predator density, such as gulls preying on other seabird species. The impact depends on the scale and location of offshore aquaculture and bird ranges, with closer proximity to shore likely leading to greater effects. Effluent discharge, particularly near net pens, is the primary concern, although significant impacts are unlikely unless operations are large-scale.

This data gap will be challenging to resolve, requiring informed speculation. Detecting measurable impacts will be difficult, and assessing any population-level effects seems improbable. While, for example, structures attracting mussels and fish may also draw gulls, quantifying population impacts remains uncertain. Researchers are using simulations to study habitat loss or shifts. However, these models involve many assumptions and uncertainties.

Potential for offshore aquaculture to cause entanglement. There is a divided perception regarding the risk of entanglement, with some viewing it as a high risk and others seeing it as a less probable "what if" scenario. Regardless, the risk of seabirds becoming entangled should be carefully considered.

The risk depends on the type of netting, including factors such as mesh size, visibility, material composition, net integrity, and tension. There are various factors that could result in entanglement. If there is a breach in the net or if the net is made of soft, foldable, or loose material (which is unlikely to be used for aquaculture), there is a risk of entanglement. Additionally, bycatch during harvest could be a concern related to the netting. However, if birds can detect the net and it remains intact without fraying or becoming detached, it is unlikely to pose a significant issue. For instance, gill nets are designed to be nearly invisible to fish, inadvertently posing a hazard to diving birds that cannot easily see them either. These nets catch large quantities of fish, which then attract birds.

Extensive work has been conducted in gillnet and, to a certain extent, trawl fisheries to develop net structures that reduce seabird bycatch. Lessons learned from these fisheries can be applied to aquaculture practices. Notably, unlike fisheries where the goal is to make nets invisible to fish, this aspect is less critical for offshore aquaculture operations. Additionally, nets can be placed over fish pens to deter birds like cormorants without causing entanglement issues.

Risk of displacement of birds from offshore aquaculture. There is concern that aquaculture operations could pose a risk of displacement, although the exact level of this risk remains unclear. Potential issues include the displacement of prey species or the occupation of key feeding areas by offshore aquaculture structures, which could affect bird populations that rely on them. For certain species, this displacement could lead to habitat loss. Additionally, while some species may benefit from increased feeding habitats, others, like bottom-feeding sea ducks (e.g., scoters), may not. However, the risk of displacement may be more relevant to areas like Puget Sound, while waters off the west coast are known for their productivity and ample habitat availability.

Effect of offshore aquaculture structure on birds. Structures could attract birds, particularly species like gulls and Pelecaniformes, which may roost on them. This roosting behavior on structures, such as buoys, is a long-standing phenomenon. Methods like using wires can help discourage roosting. Additionally, the presence of structures may attract fish, potentially affecting bird foraging behavior.

Effect of human intervention on birds. Active aquaculture operations involve interactions between birds and humans, with birds vulnerable to disturbance from boats and the risk of entanglement in structures. In areas with large-scale aquaculture, increased nutrients and phytoplankton may also attract birds, raising concerns about whether these birds need to be deterred or managed to avoid conflicts. In salmon aquaculture, the need to protect the fish has led to the killing of thousands of birds, underscoring the tension between bird conservation and aquaculture operations.

Resources

Table 10. Resources relevant to birds.

NAME	ACCESS	TYPE	DESCRIPTION
BOEM: Modeling At-Sea Density of Marine Birds to Support Renewable Energy Planning on the Pacific Outer Continental Shelf of the Contiguous United States (Aug. 2021)	https://espis.boem.gov/final%20reports/BOEM_2021-014.pdf	Report	Describes marine bird distributions in Pacific OCS waters and aims to estimate long-term average spatial distributions using transect survey data and various environmental predictor variables.
Framework for assessing and mitigating the impacts of offshore wind energy development on marine birds	https://www.sciencedirect.com/science/article/pii/S0006320722003482?via%3Dihub	Published article	Presents a framework to assess and mitigate offshore wind energy development and includes monitoring and modeling techniques like collision risk models and population viability analysis.

NAME	ACCESS	TYPE	DESCRIPTION
National Marine Sanctuaries capture enhanced abundance and diversity of the California Current Ecosystem avifauna (May 2023)	https://www.sciencedirect.com/science/article/pii/S0924796323000313?via%3Dihub	Published article	Using an extensive at-sea survey dataset (1980 to 2017), characterized spatial patterns of seabirds, and compared mean relative abundance, diversity, and community composition both within and outside the NMS.
Pacific Seabird Group	https://pacificseabirdgroup.org/	Website	The Pacific Seabird Group (PSG) is a society of professional seabird researchers and managers dedicated to the study and conservation of seabirds. The website contains information on news, meetings, jobs, grants, and conservation work, as well as publications.

Corals and Sponges

Key Data Gaps

General Data Gaps

- Abundance, distribution, health, and trend of corals and sponges
- Coordinated long-term monitoring of corals and sponges
- Biology of corals and sponges across all taxa
- Population connectivity
- Effect of corals and sponges on population productivity of other species (and vice versa)

Offshore Wind Data Gaps

- Effect of offshore wind structures on corals and sponges

Other Data Gaps

General Data Gaps

- Community data
- Sensitivity of and effect of shift in environmental parameters on corals and sponges
- Recovery of corals and sponges from fishing gear impacts

Offshore Wind Data Gaps

- Effect of electromagnetic fields from offshore wind on corals and sponges
- Effect of offshore wind on ocean transport of larval and juvenile stages of corals and sponges
- Effect of light from offshore wind on corals and sponges
- Effect of noise and vibrations from offshore wind on corals and sponges
- Effect of offshore wind on marine snow and the effect on corals and sponges

Offshore Aquaculture Data Gaps

- Effect of waste products, nutrients, and chemicals from offshore aquaculture on corals and sponges
- Effect of offshore aquaculture on early marine survival of corals and sponges
- Effect of offshore aquaculture on disease and the effect on corals and sponges
- Effect of offshore aquaculture on distribution of corals and sponges
- Effect of offshore aquaculture structure on corals and sponges

Background

The seafloor habitat includes biogenic structures like deep-sea corals, sponges, and anemones, attracting fish and invertebrates. Although the entire MSP Study Area hasn't been surveyed, biogenic habitats are prevalent and are highest in density in canyon areas like the Juan de Fuca Canyon region.

Changes in ocean temperature, acidification, hypoxia, and surface productivity due to climate change are expected to affect seafloor and deep-water habitats. Deep-sea corals in the MSP Study Area, which rely on aragonite for their skeletons, may face particular challenges from shifts in water temperature and acidification. Ocean temperature changes affect sea level through thermal expansion. The heat in ocean surface waters fuels storms, influences weather patterns, and impact ocean currents. These temperature shifts and altered circulation patterns can disrupt marine ecosystems, affecting species distribution, migration, breeding, coral health, and the occurrence and intensity of harmful algal blooms.

On acidification, when the ocean absorbs carbon dioxide (CO_2), its pH decreases, and the availability of carbonate ions (CO_3^{2-}) also diminishes. This reduction lowers the saturation state of calcium carbonate ($CaCO_3$), making it more challenging for shell-forming organisms—such as oysters, crabs, corals, pteropods, and phytoplankton—to build and maintain their shells, which are essential for their survival. In the northeast Pacific Ocean, aragonite-corrosive conditions are expanding much more rapidly than calcite-corrosive conditions. Scientific studies have found that heavily calcified organisms including calcified algae, corals, mollusks, and the larval stages of echinoderms are the most negatively impacted by ocean acidification.

Turbidity and sediment deposition on the seafloor can also impact corals and sponges. Dynamic offshore environments typically adapt to natural sedimentation. However, turbidity and sedimentation pose significant concerns for coral reef, hard-bottom habitats, and spawning areas. A decline in the quality or extent of deep-sea coral ecosystems would affect fish and invertebrates that use them for habitat. Species like bivalves, corals, sea urchins, and sea stars also make up significant proportions of some flatfish, rockfish, and sea otter diets.

Human activities can also affect corals and sponges. Bottom trawl gear used in groundfish fishing can directly damage seafloor habitats, particularly hard bottom habitats and biogenic environments like deep-sea coral reefs and sponges. These habitats are critical for marine life, but their slow growth means they may take decades to recover from damage. Although the full extent of biogenic and hard bottom habitats within the MSP Study Area is unknown, decades of bottom trawl fishing have likely caused some degradation.

Furthermore, marine organisms, including sponges, microalgae, coral, and bacteria from hydrothermal vents, are increasingly recognized for their potential in developing new products. The rate of discovering new natural products from these organisms is outpacing species discovery. High biodiversity habitats, such as coral reefs and hydrothermal vent environments, offer the greatest economic potential, with the marine biotechnology industry already a multibillion-dollar sector. While the potential for marine product extraction along Washington's Pacific coast is uncertain, its unique environments, such as hydrothermal vents and deep-sea corals, suggest potential. As technology advances and new species are discovered, novel chemicals and DNA sequences may emerge within the MSP Study Area.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to corals and sponges:

General data gaps

- Abundance, distribution, health, and trend of corals and sponges
- Coordinated long-term monitoring of corals and sponges
- Biology of corals and sponges across all taxa
- Population connectivity
- Effect of corals and sponges on population productivity of other species (and vice versa)

Abundance, distribution, health, and trend of corals and sponges.

Abundance and distribution: There is a decent snapshot of abundance and distribution, particularly along the Washington coast, though the quality of the available data varies. Most data come from remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) at select coastal sites, which leaves gaps in comprehensive coverage along the entire coast. More is known about areas believed to be prime habitats than about marginal ones. Exploration of deep-sea corals off Washington has primarily focused on the Olympic Coast National Marine Sanctuary (OCNMS), especially at Quinault and Quileute canyons, with cruises conducted in 2008, 2017, and 2020. Earlier data are available from Grays Canyon. Additional data sources include the 2017 Nautilus NA086 cruise, which concentrated on southern regions due to Bureau of Ocean Energy Management (BOEM) interest; significant geochemical work by the United States Geological Survey (USGS) and Pacific Marine Environmental Laboratory (PMEL) in the Cascadia margin area; and stony coral records from 2006. Funding from the deep-sea coral program has also supported ROV data analysis in the sanctuary. The deep-sea coral database contains visual surveys from ROVs and information from fisheries bycatch collected during trawl surveys. These surveys, designed in a patchy grid pattern, occur annually from Neah Bay to San Diego. Additionally, the bottom trawl survey provides informative records for corals and sponges; however, coverage is restricted to trawlable habitats.

Data collection is irregular and often driven by available funding, lacking a systematic approach. This creates spatial and temporal gaps that hinder predictions about habitat density, extent, and coverage, especially in nearshore environments. Available records may also be limited. Records of shallow hydrocorals (less than 110m) dating back more than a century lack the quality needed for trend analysis. Additionally, identification of species can be challenging and often requires genetic analysis. Ongoing research is uncovering newly discovered species and range extensions, including sea pens. Some species are grouped into categories for easier classification.

Health: Health assessments are needed. Although damage is noted during site visits, the long-term effects remain unknown due to infrequent revisits.

Trends: There are efforts to better understand trends through re-surveying areas.

For specific groups of corals and sponges:

Hard coral: Information is primarily known only about the orange cup coral, which exhibits a slower growth rate and smaller size compared to four decades ago. There are three other hard coral species that are poorly understood. Scleractinia was studied at the Strait of Juan de Fuca. This is a data gap because only 1 place has been studied.

Soft corals: There are 10 different species in this area which include the orange sea pen. The sea pen has more information than most of the others.

Sponges: Sponges are better understood in terms of their function rather than their general ecology. There are few studies that quantify their abundance or community composition. In particular, glass sponges receive more attention than other sponge species, and mapping efforts have identified the locations of reefs. Locally, with this group being highly abundant, there are likely 30 or more species. However, species other than glass sponges are less dominant and are often recorded incidentally during surveys focused on other marine elements.

Feedback on importance: To understand the impact of new infrastructures, it is crucial to evaluate them within the context of their interaction with the distribution, abundance, and quality of sponges and corals. Additionally, while trends may not be immediately discernible and could pose challenges for long-term measurement, addressing this data gap is paramount. Doing so will provide baseline data and offer insights that are informative for addressing other data gaps.

Coordinated long term monitoring of corals and sponges. There is currently no coordinated regional or national monitoring program, and data collection largely relies on independent efforts. Additionally, regular and frequent data collection is lacking. While a national database exists to record deep-sea corals, it is limited to presence-only data, indicating surveyed areas and locations where corals were found, but does not include absence records. Often, individual research groups retain absence data.

While there are efforts to coordinate monitoring of the intertidal zone from California to Alaska, there is a significant gap in such efforts for the subtidal zone in Washington and other states. This lack of consistent monitoring contributes to the absence of baseline data and impedes the ability to assess changes in abundance over time. Currently, no plan seems to be in place to address this gap. Research efforts have mainly focused on the OCNMS.

The first step toward improvement is coordination, but a comprehensive, long-term monitoring program also requires consistent data collection methodologies and an increased number of sampled sites. Enhanced monitoring in rocky areas, which have high density and diversity, is especially needed. Even basic knowledge of untrawlable areas would be valuable. Trawl surveys, which are not designed to collect corals, currently use a randomized grid design, with the same sites not being surveyed consistently. Identifying untrawlable habitats can help develop techniques to preserve coral populations without causing harm. Improved data handling and more effective sampling methods are crucial for better monitoring of corals.

Feedback on importance: Acquiring this information will not only help answer other questions regarding corals and sponges but is also critical to understand the relative cover, abundance, diversity, and distribution of sponges and corals.

Biology of corals and sponges across all taxa. Biological studies in this area are limited, with much of the existing knowledge inferred indirectly from research on passive transport systems. Coral biology, apart from *Lophelia*—a globally distributed species studied by numerous research teams—represents a significant data gap. Although isolated studies exist, there are no coordinated efforts to study corals across different taxa. Additionally, there is no established genetic framework to analyze the genetic makeup of coral and sponge populations. Available information is sporadic, patchy, and of varying quality across species, primarily due to limited access to data. Addressing this gap is crucial for improving the understanding of recovery processes.

Research on the life history of corals and sponges, particularly in terms of growth and reproductive patterns, is minimal. Early life history studies suggest that corals and sponges predominantly settle on hard bottom habitats, where they begin to form structures, although species like sea pens thrive on soft bottoms. Some information is available on colony lifespan, with certain coral and sponge species known to have exceptionally long lifespans. Dispersal patterns are partially understood, largely due to broad spawning behavior observed in these organisms. Most of the current knowledge on dispersal comes from oceanographic studies and passive dispersal modeling.

Feedback on importance: No specific feedback provided.

Population connectivity of corals and sponges. There is some information available about dispersal of corals and sponges due to their broad spawning behavior. Corals and sponges disperse widely, with individuals potentially traveling from Mendocino to Alaska, yet the understanding of movement of gametes and offspring in the water column remains limited. In their early life stages, corals and sponges typically settle on hard bottom habitats and begin forming structures, although exceptions exist for species like sea pens that thrive on soft bottoms. Current knowledge is largely derived from oceanographic studies and passive dispersal modeling which predicts the movement of propagules to areas with suitable hard habitat by currents (a method used to determine connectivity). Whether the population in Washington waters is entirely unique or connected to those in neighboring states is uncertain.

Feedback on importance: No specific feedback provided.

Effect of corals and sponges on population productivity of other species (and vice versa). There is interest in understanding the impact of corals and sponges on fish productivity and the productivity of other species. While the effect on fish productivity is often assumed to be significant, demonstrating a direct impact on their biology—rather than just their distribution—remains challenging. Additionally, community data typically focuses on species associated with corals and sponges. A data gap exists regarding the dependence of community species on corals and sponges, as well as the reciprocal dependence of corals and sponges on community species. While these associations are known, the nature of the interaction is still unclear.

Feedback on importance: No specific feedback provided.

Offshore wind data gaps

- Effect of offshore wind structures on corals and sponges

Effect of offshore wind structures on corals and sponges. While specific data on offshore wind structures is lacking, insights from offshore oil and gas operations can be drawn upon. Similar to oil platforms, these structures may serve as habitats for hard and soft corals. Many corals and sponges require hard substrate for attachment. The introduction of additional hard structure such as through anchor systems and cables is expected to yield a net positive benefit. Some growth, known as biofouling, could occur on cables depending on the amount of movement and anchors could become integral parts of subtidal communities. If there is excessive biofouling, cleaning may be necessary to prevent undue weight accumulation. Surface resistance to biofouling might inhibit growth, but this is more of a concern for companies than for benthic ecosystems.

Any potential positive effect of offshore wind developments may be offset by negative impacts, particularly concerning habitat destruction, which depends on location. There are also potential scouring issues and episodic concerns during the installation and construction phases of offshore wind projects. Episodic sediment plumes can result from activities such as anchor deployment. Certain species may exhibit better resilience to sedimentation as the response varies depending on taxa. Sponges, being filter feeders, have the capacity to purge some sediment, although their ability to do so varies among species. In situ observations often reveal instances where parts of sponges are choked by sediment, while other areas remain seemingly healthy.

The prospect of physical structures blocking light isn't a significant concern, given that deep-sea corals and sponges predominantly rely on suspension feeding and are often situated in complete darkness. However, there are mesophotic corals, which represent a blend of light-influenced and suspension-feeding taxa. The reduction of light might affect suspension feeders if it disrupts primary production, hindering their access to organic nutrients. Nonetheless, this would necessitate considerable shading. If shading is substantial enough, it could create a stressful environment impacting corals and sponges. There are no known relevant studies on the effects of shading.

There's apprehension regarding potential alterations in distribution patterns if these structures function like a fish aggregating device (FAD). Researchers are currently investigating the impact of physical structures on offshore circulation, particularly regarding phenomena like upwelling. Plans are underway to initiate monitoring efforts to address these data gaps. NOAA is collaborating with BOEM to study California and the Gulf of Maine.

Feedback on importance: It's essential to consider both the potential positive effects of creating settlement habitat and the negative impact of habitat damage during installation.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Community data
- Sensitivity of and effect of shift in environmental parameters on corals and sponges
- Recovery of corals and sponges from fishing gear impacts

Community data. Community data pertains to the species associated with corals and sponges. In specific areas, community data is documented fairly well. Fish communities in demersal areas and corals and sponges in hot spots are known. This information is available in marginal habitats as well due to the availability of various observation methods such as cameras and observer data.

This is a true data gap in terms of the invertebrate density these habitats can sustain. Ongoing efforts are aimed at gaining a better understanding of the nature of associations between various marine species with a focus on fish, corals, and sponges. Relevant data is being collected through trawl and ROV surveys, with the latter method focusing on identifying, measuring, and counting specimens over 10cm in size. Additionally, funding from the deep-sea program has directed attention towards invertebrates, commercially important fish, corals, and sponges. However, the data remains patchy due to the sporadic nature of submersible surveys. Comprehensive information on the entire benthic invertebrate community, including algae, is needed. Any community survey examining growth on rocks, for example, would contribute valuable insights. Initiatives are also underway to conduct eDNA analysis for corals and associated groundfish communities. In Washington and California, the functional relationship between corals and groundfish is nuanced and is a major research question.

Sensitivity of and effect of shift in environmental parameters on corals and sponges. This is a significant data gap. The extent of knowledge varies depending on the generality of the information. Key areas of concern include temperature, pH, and anything relating to the calcium carbonate mineralization process in corals. Although the sensitivity of corals to these factors is well-established through studies of their tropical relatives, the extent to which cold-water corals and sponges in this region are affected remains uncertain. Tropical corals are significantly different. Their responses may not directly apply to their cold-water counterparts. Beyond assessing the sensitivity of individual species, there is a need to study their interactions. This includes examining species that feed on corals and sponges, as well as those that corals and sponges rely on for food.

Changes in environmental parameters can have widespread effects on community interactions, including indirect impacts. Extensive modeling efforts, supported by data from autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs), and conductivity-temperature-depth (CTD) sensors, provide valuable insights on the environmental conditions. CTD data, along with oxygen data from sensors near the seabed, are routinely collected, and there is an increasing trend toward regular collection of oxygen concentration information. Additionally, routine cruises gather data on water column profiles, allowing the creation of time series to monitor changes over time. Larger regional models, such as those focusing on water depth and aragonite saturation, also offer valuable insights into coral health and can indicate when corals may cease exoskeleton production. Some laboratory studies have examined the aragonite saturation point for *Lophelia* species. One data collection area that remains limited is pH, which is crucial to understand coral and sponge health.

Temperature: There have been some studies on temperature. This parameter is better understood for tropical corals and sponges. In Washington, there has been a significant 1° C temperature increase over the past century, which poses considerable challenges for marine organisms adapted to colder northern climates. It remains unclear how species in temperate zones respond to such temperature shifts.

Ocean acidification: A research group has been dedicated to studying ocean acidification (OA) for the past decade, but unfortunately, there has been no specific focus on corals or sponges. There is a need for funding.

Upwelling: Upwelling brings water with low oxygen levels and increased acidity, amplifying the effects of OA, which are notably higher off the Washington coast than the global average. This is primarily attributed to the upwelling of coastal waters and the presence of deep fjord areas that experience heightened hypoxia and acidification. There is speculation that species in this region have adapted to these acidification conditions compared to other locations.

Sediment: The type and abundance of corals in a given area vary depending on the intensity of water flow. The majority of sponges and corals thrive on rocky substrates, meaning any shifts in sediment could render their habitats less suitable and potentially lead to clogging of their feeding apparatus. These organisms are most successful in areas subject to currents and on vertical surfaces, where sediment accumulation is minimal. While some sediment can be beneficial as it is organically rich and serves as a food source for certain species, excessive sedimentation can have detrimental effects.

Recovery of corals and sponges from fishing gear impacts. Sponges and corals are particularly vulnerable to damage in rocky bottom environments where dragging occurs, and recovery can extend over years to decades. Recovery rates depend on settlement and growth rates which are species-specific. Stony and traditional hard corals associated with rocky areas are often slow-growing, long-lived, and susceptible to gear damage. Soft bottom habitats, especially those hosting fleshier species like sea pens, tend to experience less significant impacts and heal more quickly. Glass sponges, being both long-lived and fragile, are the focus of conservation efforts due to their potential destruction by fishing gear. Considerable knowledge exists regarding the recovery process following physical disturbance from bottom-contact fishing gear. This type of gear is more commonly used in soft-bottom habitats, which minimizes direct impact on core coral and sponge habitats.

Surveys have been conducted in collaboration with the deep-sea coral program, focusing on areas near groundfish conservation zones established due to gear restrictions on the bottom trawling fishery. These surveys are vital for making before-and-after closure comparisons.

Currently, there is no specific focus on areas off the coast of Washington. Early analyses have also compared fishing activity between 1998 and 2000, following the implementation of certain regulations, which may offer valuable insights. Additionally, initial transboundary surveys and assessments have been conducted within and adjacent to the OCNMS, in partnership with treaty Tribes.

Offshore wind data gaps

- Effect of electromagnetic fields from offshore wind on corals and sponges
- Effect of offshore wind on ocean transport of larval and juvenile stages of corals and sponges
- Effect of light from offshore wind on corals and sponges
- Effect of noise and vibrations from offshore wind on corals and sponges
- Effect of offshore wind on marine snow and the effect on corals and sponges

Effect of electromagnetic fields from offshore wind on corals and sponges. The effect of electromagnetic fields (EMF) represents a significant data gap, with no known studies addressing it. However, a technique used in tropical coral reef restoration involves applying a low electrical current through a metallic structure to promote coral settlement. This method has shown promise at a local scale, with potential positive impacts anticipated. However, EMF is likely to have a more pronounced effect on fish and marine mammals, as studies have focused on its impact on sharks and rays. Physical structures are more likely to affect corals and sponges.

Effect of offshore wind on ocean transport of larval and juvenile stages of corals and sponges. Corals reproduce both asexually through budding and sexually via gamete dispersal. The expansion of new colonies depends on local currents and the availability of suitable substrate for larval settlement. However, there is a significant data gap regarding the transport of coral larvae, with little known about the specific layers of the water column they inhabit during transport.

Predicting significant impacts is challenging. For corals and sponges, offshore wind structures may merely serve as additional rocky substrates. However, the installation of offshore wind infrastructure could alter local currents, with primary effects likely resulting from these changes. Some propagules may be found closer to the surface, and the altered currents could affect the connectivity of corals and sponges. While the National Marine Fisheries Service (NMFS) is developing models to assess how offshore wind installations might influence regional currents and upwelling, there remains a lack of research on the potential impacts to biogeochemical cycling at the seafloor interface. Understanding how offshore wind developments affect physical oceanography is crucial to addressing this data gap.

Effect of light from offshore wind on corals and sponges. Species are likely to exhibit varied responses based on color, with this effect primarily affecting species that inhabit the top 100 feet of water. Corals and sponges, residing at greater depths, are unlikely to be significantly impacted by light. However, limited data on *Lophelia* suggests that their larvae may be influenced by light during settlement. These findings are preliminary, and few studies have been conducted on this topic.

Effect from noise and vibrations from offshore wind on corals and sponges. Although no significant effect is suspected, there is a lack of studies on this issue. The amount of noise generated by offshore wind is uncertain, but it is more likely to affect fish and marine mammals. While extreme vibrations could potentially have an impact, it seems unlikely, as corals and sponges are capable of withstanding earthquakes. The primary concern lies in the physical breakage of stony corals. Strong storms are a major driver of both coral reef formation and degradation.

Effect of offshore wind on marine snow and the effect on corals and sponges. The development of offshore wind infrastructure may influence marine snow, potentially affecting the feeding of corals and sponges. Offshore wind is also expected to alter currents, which could impact the distribution of substances within the water column. While these changes are likely to have some effect, it is challenging to determine whether the impact will be positive or negative. Marine snow is currently monitored by the USGS, which conducts studies on dissolved inorganic carbon off the west coast.

Offshore aquaculture data gaps

- Effect of waste products, nutrients, and chemicals from offshore aquaculture on corals and sponges
- Effect of offshore aquaculture on early marine survival of corals and sponges
- Effect of offshore aquaculture on disease and the effect on corals and sponges
- Effect of offshore aquaculture on distribution of corals and sponges
- Effect of offshore aquaculture structure on corals and sponges

Effect of waste products, nutrients, and chemicals from offshore aquaculture on corals and sponges. The potential effects of waste products, nutrients, and chemicals from offshore aquaculture depend on factors such as depth and enclosure. Generally, the effects of aquaculture are expected to be more pronounced nearshore compared to further offshore, due to influences like physical currents and local water retention. For example, in shallow areas with salmon pens, fecal buildup on the seabed can make the area uninhabitable for some species due to poor flushing. Enclosed embayments are particularly vulnerable to such issues. However, in offshore open ocean environments, dispersion is expected to be more effective, making waste accumulation unlikely. Therefore, assuming offshore aquaculture operates on a small scale, its effects are likely to be localized or diffused as waste becomes more broadly distributed. However, if aquaculture operations lead to higher rates of sedimentation, literature suggests this could negatively affect the survival of corals and sponges, depending on the extent and duration of the sediment buildup. In some cases, corals and sponges may mitigate these impacts through adaptive responses.

Offshore aquaculture is also expected to alter carbon flow around its facilities, but the specific impacts on sponges and corals are unclear. Some literature, particularly from regions like

Norway, and limited studies in the Gulf of Mexico, may provide insight into these effects. Nutrient profiling does not appear to be a decisive factor in coral distribution, but even in nutrient-rich waters off Washington, deep-sea nutrients are often scarce. The addition of nutrients could pose challenges if it leads to changes in oxygen levels or anoxic conditions.

In addition to waste and nutrient runoff, activities associated with offshore aquaculture, such as vessel operations, equipment leaks, maintenance, and accidental spills, can introduce chemicals and further stress marine ecosystems. Certain coral species are sensitive to hydrocarbons, while others are more tolerant. Many deep-sea species in Mexico show resilience to hydrocarbons but are highly susceptible to the chemicals used to disperse oil plumes.

Effect of offshore aquaculture on early marine survival of corals and sponges. This is a notable data gap, primarily due to the limited understanding of the larval stages of corals and sponges. There are significant concerns regarding the transmission of diseases and parasites from captive stocks to wild populations. Other than this concern, it's doubtful that offshore aquaculture would occur at a scale large enough to measurably affect population-level survival. The life history of corals and sponges is already adapted to cope with low early marine survival rates.

While the accumulation of fecal material in significant amounts could potentially have an impact, it's difficult to envision such buildup occurring in deep water in the open ocean environment. At most, it might contribute slightly increased nutrient levels to the ocean floor, but unless there's substantial accumulation, it is unlikely to significantly affect early life stages.

Sediment accumulation on rock surfaces can pose challenges for certain larvae in recognizing suitable habitats. Corals and sponges, being suspension feeders, depend on the dispersal of gametes and larvae as well as the availability of substrate for larval settlement to facilitate new colony growth. Any adverse effects on these factors, such as excessive sediment or nutrient levels, could impact coral and sponge growth, reproduction, and other vital processes. However, in this scenario, significant buildup isn't anticipated. Even if pens are placed over soft substrates, any sediment precipitation typically has a positive effect as it augments food availability for organisms inhabiting the area.

Lastly, on whether aquaculture species might consume the larvae or propagules, it's worth noting that there are already many organisms in the ocean that feed on them.

Effect of offshore aquaculture on disease and the effect on corals and sponges. While a problem for aquaculture operations in closed areas, as observed in the Canadian part of the Salish Sea, the transfer of disease to corals and sponges is unlikely. Corals and sponges have their own distinct diseases, which are unlikely to be transmitted from fish. Nevertheless, disease outbreaks have led to notable collapses in tropical coral colonies, with large-scale impacts observed, including those caused by bacterial pathogens. A greater effect is expected on the broader ecological community.

Effect of offshore aquaculture on distribution of corals and sponges. Minimal impact on the range or area occupied by corals and sponges is expected, though some minor effects may occur. For example, waste buildup could potentially affect distribution, but such occurrences are unlikely in the open ocean. Localized nutrient inputs from aquaculture may also influence colony size in specific areas. Additionally, there is concern that coral larvae could be smothered, hindering their settlement. Over time, prolonged negative impacts from aquaculture operations could affect the distribution of coral and sponge communities.

It is worth noting that the NMFS does not designate aquaculture opportunity areas near known coral and sponge habitats.

Effect of offshore aquaculture structure on corals and sponges. The impact of future offshore aquaculture developments remains uncertain. While current fish aquaculture generally involves minimal gear, limiting its potential impacts, this may change in the future.

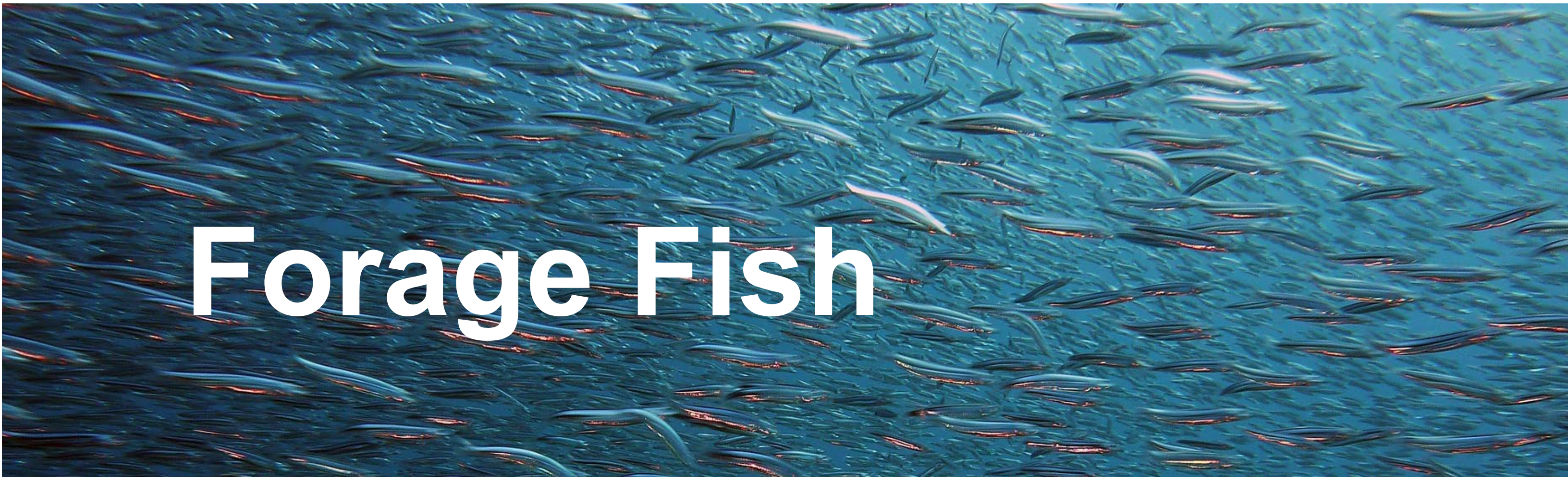
Both corals and sponges are fragile and highly susceptible to physical disturbances, easily damaged by mechanical forces. Offshore aquaculture is expected to cause small, localized effects similar to the impacts of general marine debris on seafloor habitats. However, for example, if a net pen aquaculture system were to collapse, it could cause significant damage, especially if tidal movements cause it to scrape along the seafloor. Once toppled, corals and sponges often perish due to difficulties in filtering sufficient nutrients.

Certain sponge species, such as *Farrea* spp. and *Heterochone calyx*, can form reefs or bioherms, with new sponges settling on the silica skeletons of older generations. Given that reef development takes thousands of years, any damage could have long-lasting, adverse impacts. Additionally, corals and sponges could be smothered by heavy sedimentation or subjected to anoxic events, further exacerbating the harm to these fragile ecosystems.

Resources

Table 11. Resources relevant to corals and sponges.

NAME	ACCESS	TYPE	DESCRIPTION
Effect of suspended sediments on the pumping rates of three species of glass sponge in situ	https://www.int-res.com/abstracts/meps/v615/p79-100/	Published article	Studies the response of 3 glass sponge species to changes in suspended sediment concentrations. A sediment transport model shows that sediment concentrations can remain high enough to affect sponge behavior as far as 2.39 km from the source of the plume.
NOAA: Deep-Sea Coral & Sponge Map Portal	https://www.ncei.noaa.gov/maps/deep-sea-corals/mapSites.htm	Data Portal	National database of known locations of deep-sea corals and sponges. Recorded demersal and benthic fish occurrences are also included.



Forage Fish

Key Data Gaps

General Data Gaps

- Abundance, distribution, health, and trend of forage fish
- Pathogen and virus susceptibility of forage fish

Offshore Wind Data Gaps

- Effect of offshore wind structures on forage fish

Offshore Aquaculture Data Gaps

- Effect of offshore aquaculture on forage fish competition, predation, and other interactions
- Effect of waste products and chemicals from offshore aquaculture on forage fish
- Effect of disease from offshore aquaculture on forage fish

Other Data Gaps

General Data Gaps

- Effect of the timing of forage fish lifecycle on other species
- Climate impacts on forage fish
- Stressor and biological threshholds of forage fish

Offshore Wind Data Gaps

- Effect of offshore wind on spawning and growth of forage fish
- Effect of noise and vibrations from offshore wind on forage fish
- Effect of electromagnetic fields from offshore wind on forage fish
- Effect of light from offshore wind on forage fish
- Effect of offshore wind on forage fish migration

Offshore Aquaculture Data Gaps

- Effect of offshore aquaculture on early marine survival of forage fish
- Effect of fish escapements from offshore aquaculture on forage fish
- Effect of offshore aquaculture on forage fish migration
- Effect of offshore aquaculture structure on forage fish
- Effect of offshore aquaculture on fishers' behavior and the subsequent effect on forage fish

Background

Multiple forage fish species inhabit the MSP Study Area, including surf smelt, night smelt, whitebait smelt, Pacific sand lance, Pacific herring, northern anchovy, and Pacific sardine. They primarily inhabit pelagic waters, with species like smelt and sand lance spawning on coastal intertidal sandy beaches and Pacific herring spawning on submerged aquatic vegetation.

Forage fish serve as crucial links in the ocean food web, bridging primary and secondary trophic levels to larger predatory fish, marine mammals, and seabirds. They feed on plankton during certain life stages, often forming dense schools, and serve as crucial prey for commercially valuable and legally protected species such as salmon, marine mammals, and birds.

Pelagic fish species face various pressures, including fishing, pollution, and climate variations. These variations encompass factors like upwelling, influences from source waters, and El Niño/La Niña events, including the effect of these events on prey availability and habitat. Forage fish beach and submerged vegetation spawning areas are also threatened by coastal development, overwater structures, increased nearshore boat traffic, and environmental pressures such as increasing erosion, storm intensity, and storm frequency.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to forage fish:

General data gaps

- Abundance, distribution, health, and trend of forage fish
- Pathogen and virus susceptibility of forage fish

Abundance, distribution, health, and trend of forage fish. The understanding of the abundance, distribution, health, and trends of forage fish is limited, particularly along the coast, creating a significant data gap. Greater insight exists within Puget Sound and the Strait compared to coastal areas. Addressing this challenge is complex due to the diverse habitats of forage fish, seasonal variations, and the difficulty and cost of monitoring. Additionally, populations exhibit wide variability and grouping them is challenging because of the species diversity involved.

Abundance and distribution: Data on the general presence and distribution of forage fish are available, though for some species and stocks, only rough estimates exist. A clear stock structure is lacking, primarily due to their movement patterns. For example, herring spawn in Puget Sound but migrate to the ocean during adulthood, with limited information on their subsequent whereabouts.

Forage fish studies are conducted in the high seas, outer coastal areas, and the Columbia River plume, with most research relying on surface trawl work. Midwater trawl surveys focus on habitat utilization, frequency of occurrence, and the availability of forage fish to predators such as birds, salmon, and marine mammals. A significant survey effort is also underway along the entire West Coast, from southern British Columbia to northern Mexico, targeting sardine, anchovy, jack mackerel, and Pacific mackerel. Acoustic trawling provides broad estimates on species occurrence, and the survey includes a database for egg occurrences, primarily for anchovy and sardine. The survey takes place annually from June through September, although timing can vary based on funding and other factors. Additional methods and resources, such as plankton imagers, in-water snorkel surveys, and insights from tribal communities, also contribute valuable information.

The reasons behind their movements—whether driven by habitat loss or climate change—remain unclear. Understanding the broad-scale habitat of forage fish species and potential shifts or losses in their habitat is crucial. While some fishery surveys provide relevant data, many are outdated. For instance, the last comprehensive survey on spawning habitat, particularly for beach-spawning species like smelt and sand lance, was conducted in 2013. There are ongoing efforts focusing on better understanding their specific spawning habitat needs.

Health: This is a data gap. This requires managing the evaluation of genetic stock structure under appropriate scales.

Trend: Monitoring trends is important, especially considering observed seasonal population shifts. Available data are primarily associated with spawning biomass and limited to a few year classes on spawning grounds. However, a significant portion of the life history remains unknown. Tracking adults is challenging, trophic dynamics vary among species, and trends have become unpredictable with climate change. The effects of climate change on the abundance and distribution between the coast and Washington have been observed, but not understood. For example, during the warm years, there was low coastal abundance but higher abundance in Puget Sound. The effect of changes in climate and temperature on species abundance, such as anchovy, is unknown. Understanding in one area (Puget Sound/Coast) doesn't reflect what happens in the other area.

Feedback on specific species:

Herring: More is understood about herring compared to other species. Distribution is well-known. Until 2009, abundance was monitored by both acoustic and vegetation rake surveys in spawning areas. Currently, rake surveys are used annually across all known nearshore spawning areas. There is about 40 years of data. However, due to shifting ecosystems, spatial and temporal variations occur yearly, emphasizing the need for ongoing monitoring. Information on spawning locations, fish numbers, and spawner age variation are also available. Periodic surveys in Willapa Bay and Grays Harbor depend on staff availability. These involve minor stocks with limited spawning areas. Genetically, herring are categorized into several groups based on spawn timing. There appears to be three or more lineages.

Surf smelt: Genetically, smelt appear to form a single, panmictic population. Abundance data is also lacking but estimates exist from recreational surf smelt catch and fish tickets from commercial harvest. Information is available regarding the timing and locations of surf smelt spawning. In the last few years, the WA Conservation Corps (WCC) obtained new documentation on beaches used by surf smelt. Between 2012 and 2014, intertidal forage fish spawning, including surf smelt and sand lance, was studied on the outer coast. Sediment sampling from coastal beaches yielded limited samples due to a paucity of sediment suitable for surf smelt spawning. Knowledge of surf smelt outside of beaches is scarce. There is little funding available for this effort.

Pacific sand lance: Pacific sand lance plays a crucial role in the diet of nesting birds, providing essential nourishment for clutches and chicks seasonally. Assessing their abundance is challenging due to their cryptic nature, small size, and difficulty monitoring. Sand lances are elusive and adept at burying themselves in sand to evade capture, rendering conventional sampling methods ineffective except for sediment grabs which provide limited coverage. Acoustic surveys are not viable due to their lack of a swim bladder. Data on the seasonal abundance of juveniles and first-year fish show a significant increase in spring and summer.

Feedback on importance: Understanding the abundance and health of forage fish is crucial. Baseline data are needed to assess whether the species are improving or declining. Currently, there is insufficient capacity to determine whether the effects are positive or negative.

> **WCMAC:** The abundance, distribution, health, and trends of forage fish represent a significant data gap, particularly in the Northwest compared to California, where stock assessments for sardines and anchovies are more comprehensive. Washington lacks the same level of data collection and assessment for forage fish.

Pathogen and virus susceptibility of forage fish. Diseases in forage fish, especially herring, are well studied by colleagues at United States Geological Survey (USGS). Significant information exists on diseases like *Ichthyophonus* and viral hemorrhagic septicemia (VHS).

Emerging diseases from other regions are also receiving attention. Forage fish imported as bait for aquaculture operations have been well-documented as vectors for pathogens, potentially causing significant mortality in native stocks. While there is a basic understanding of this issue, there is no comprehensive program in place to monitor pathogen levels or the importation of pathogens. A major concern is the presence of pathogens resistant to freezing, which can be reintroduced and impact local populations. Additionally, sediment beds may serve as a reservoir for these pathogens.

Feedback on importance: This data gap should include parasites.

> **WCMAC:** No specific feedback provided.

Offshore wind data gaps

- Effect of offshore wind structures on forage fish

Effect of offshore wind structures on forage fish. It is challenging to pinpoint the direct impacts of offshore wind structures, but their development could potentially affect forage fish. Some species are more coastal-focused, while others, such as anchovies and sardines, migrate farther offshore. Different species are likely to respond in varying ways. Nearshore species may experience minimal effects, while species like anchovies and mackerel could be more impacted, as offshore wind structures may alter their habitat and aggregate different fish species. NOAA's

Coastal Pelagic Survey (CPS) provides valuable insights into species distribution and habitat preferences.

The structures could act as "attractive nuisances," drawing fish in and increasing feeding activity. They may also serve as haul-out sites for birds, marine mammals, and predators of forage fish, potentially increasing predation on forage fish and disrupting resource availability for other species. However, some species may show no association with the structures. There has long been debate surrounding structures and fish aggregating devices (FADs). While FADs attract fish, their effects depend on their size and number. Since pelagic fish typically navigate open waters and migrate along the coast based on temperature and salinity, the impact of placing structures in their habitat remains uncertain. Some fish may explore the structure before resuming normal activities, while others may choose to stay, which could be disruptive. The threshold for when such disruptions occur is still unknown. Additionally, depending on their location relative to lateral thermal gradients, offshore wind structures could also impact spawning habitats.

If offshore wind structures do not cause major changes in currents, forage fish may not be significantly affected. However, the down-current effects of these structures remain unclear, and there may be no long-term studies specific to Washington waters. Insights from other regions, such as oil rigs off the coasts of California and Mexico, may provide useful context for understanding potential impacts.

Feedback on importance: There is a need to understand the downstream effect of these structures.

> **WCMAC:** Certain offshore wind structures will impact forage fish, but it remains unclear whether this effect will be positive or negative. It would be interesting to explore how species like squid might respond, as they are known to be attracted to light, which could influence their distribution around these structures. There may be adverse effects on truly pelagic species that exhibit site fidelity. Comparatively, oil rigs, which are located below Point Conception in Santa Barbara, differ significantly from offshore wind structures. The structural characteristics are dissimilar enough that insights gained from one may not apply to the other. For instance, oil rigs have legs that rest on the seabed, whereas wind platforms will feature anchor arrays and electrical transmission lines that carry high volumes of electricity.

Offshore aquaculture data gaps

- Effect of offshore aquaculture on forage fish competition, predation, and other interactions
- Effect of waste products and chemicals from offshore aquaculture on forage fish
- Effect of disease from offshore aquaculture on forage fish

Effect of offshore aquaculture on forage fish competition, predation, and other interactions. There is still much to be understood about the food web, particularly regarding the substitutability of forage fish. The impact would depend on the infrastructure and species being raised. For example, if offshore aquaculture provides a structure for marine mammal haul-outs or bird roosting, it could attract schools of forage fish, increasing predator interactions. If the structures function as a fish aggregating device (FAD), they may aggregate other species, with forage fish becoming bait for larger fish. Predators might linger around net pens, preying on wild forage fish passing by. The response of forage fish remains uncertain and would require understanding their migration corridors and predator-prey behavior.

If offshore aquaculture involves raising finfish such as rainbow trout or sablefish, concerns may arise, as these species are predators of forage fish. While local research on this topic may be limited, insights from net pen studies in regions like South America and Asia could offer valuable perspectives.

On the other hand, shellfish-based aquaculture may have less impact on forage fish. Since forage fish typically feed on zooplankton and phytoplankton, there is little concern about direct competition with shellfish aquaculture species. Additionally, shellfish farms could provide habitat, potentially benefiting the surrounding ecosystem.

Feedback on importance: No specific feedback provided.

> **WCMAC:** It is likely that offshore aquaculture will have minimal effects on forage fish, assuming that the aquaculture facilities maintain their integrity and do not frequently suffer damage. Under these conditions, a significant impact on forage fish from aquaculture is not anticipated.

Effect of waste products and chemicals from offshore aquaculture on forage fish. The influx of nutrients from offshore aquaculture operations poses a risk of triggering hypoxia events or Harmful Algal Blooms (HABs). Hypoxia is already a significant issue on the shelf, where it can be severe and prolonged. Offshore aquaculture could exacerbate these hypoxic episodes by introducing additional nutrients or waste products. This risk is present regardless of location, as hypoxia can occur in highly stratified water columns, particularly during certain times of the year. Natural phenomena like upwelling can help reverse these conditions, but their effectiveness may be limited by challenges such as stratification and trapped water columns, which have been observed along the coast.

The introduction of chemicals, such as antibiotics, further complicates the situation, although the specific impacts of these chemicals remain difficult to assess without more detailed information. However, contamination linked to aquaculture activities raises the risk of bioaccumulation, which could have broader ecological consequences. The extent of these effects depends on various factors, including the resources available, the species being cultivated, and the substances introduced into the water.

Excess nutrients could also lead to eutrophication, though this may be less of a concern in the open ocean. In localized areas, excess nutrients could cause plankton enrichment, potentially benefiting wild forage fish populations, or, conversely, it could contaminate local waters and increase the prevalence of disease.

Feedback on importance: No specific feedback provided.

WCMAC: Although unfamiliar with the potential effects of waste products and chemicals from offshore aquaculture on forage fish, it seems that assessing these impacts wouldn't be difficult.

Effect of disease from offshore aquaculture on forage fish. The potential for offshore aquaculture facilities to contribute to disease spread is uncertain. Tracking the origins of diseases, understanding how they spread, and determining whether they can cross species barriers or be transmitted by infected species is complex. Moreover, effectively controlling these diseases presents significant challenges.

Offshore aquaculture, particularly finfish aquaculture, raises significant concerns regarding disease transmission. The location of these facilities can affect other species through escapement or disease transmission. The high-density environment in aquaculture systems increases the risk of infection, as it only takes one infected animal to initiate an outbreak. Diseases tend to evolve rapidly within such populations, leading to the emergence of new variants. For example, escaped Atlantic salmon were reported to carry infections. These diseases can easily transfer between fish species. While there is concern about these variants escaping and affecting wild fish, documented cases remain relatively few. Additionally, importing feed can introduce new viruses to wild stocks or concentrate existing pathogens in areas that were previously unaffected.

Feedback on importance: No specific feedback provided.

WCMAC: Given the absence of offshore aquaculture for forage fish and no anticipated developments in the foreseeable future, there is no data gap that needs to be filled concerning the effect of disease related to offshore aquaculture operations on naturally occurring forage fish species.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Effect of the timing of forage fish lifecycle on other species
- Climate impacts on forage fish
- Stressor and biological thresholds of forage fish

Effect of the timing of forage fish lifecycle on other species. The presence of forage fish is of critical importance to many species. Hence, the timing of their lifecycle directly impacts others within the ecosystem. There is a need to better understand the effect of this timing on other species.

Climate impacts on forage fish. There is a data gap regarding the influence of climate on forage fish. Ocean acidification is one of the most certain yet least understood climate impacts on the ecosystem and its species. Early research suggests that the timing of exposure to suboptimal conditions during specific life stages can have significant consequences. For instance, sand lance exposure to ocean acidification during the initial stages of egg development appeared to have minimal impact, whereas exposure during later phases of development caused more pronounced effects.

Additionally, there are concerns tied to climate change as effects on the abundance and distribution of forage fish, particularly between coastal areas and Washington, have been observed. For example, during warm years around 2015, coastal areas experienced low abundance of anchovy, while Puget Sound saw higher abundance, highlighting the disparate effects across regions. It remains unclear how climate and temperature changes will influence this dynamic. This example also underscores that insights from one area, such as Puget Sound, may not necessarily apply to coastal regions. Seasonal population shifts have also become increasingly unpredictable with climate change, and different trophic dynamics are being observed. A better understanding is needed of this cause, whether due to climate change, habitat loss, or other factors.

While many forage fish species are identified as highly vulnerable to climate change, there is low confidence in understanding their sensitivity to climate impacts. Rather, there is higher confidence in their vulnerability to nearshore development and non-climate stressors. Gaining a better understanding of their resilience or vulnerability to future conditions will be crucial.

Stressor and biological thresholds of forage fish. There is information on the optimal range of temperature and dissolved oxygen for the development of forage fish. While some information exists, the full implications of suboptimal conditions on growth and development remain unclear.

Offshore wind data gaps

- Effect of offshore wind on spawning and growth of forage fish
- Effect of noise and vibrations from offshore wind on forage fish
- Effect of electromagnetic fields from offshore wind on forage fish
- Effect of light from offshore wind on forage fish
- Effect of offshore wind on forage fish migration

Effect of offshore wind on spawning and growth of forage fish. The Continuous Underway Fish Egg Sampler (CUFES) provides information on the distribution of eggs at large (away from shore), up and down the coast. It facilitates the identification of hotspots, making it easier to determine areas to avoid when siting offshore wind projects. The survey involves using a filtering device attached to a net, which selectively collects eggs for analysis.

Changes to the open ocean current, such as water flow and pattern in a geographic area or to the California Current Ecosystem, may have some influence but are unlikely to be meaningful as fish are adaptable to these changes. The greatest concerns would be with anchovy and sardine due to their pelagic spawning behavior. If offshore wind affects currents, this can change surface water temperature or cause turbidity which may affect spawning and growth. This effect would primarily affect species that spawn offshore like sardines. Their eggs are fertilized and hatched in the pelagic zone, with no connection to the nearshore or sediment beaches. Sardines are particularly sensitive to temperature changes and shifting currents could affect their occurrence, spawning locations, and larval survival. Offshore win projects may have a positive effect if it brings about an increase in prey resources. Forage fish rely heavily on zooplankton.

Species like surf smelt that rely on beaches may be less affected by changes to offshore currents. However, if changes in currents affect their migration or swimming patterns, it may affect their ability to reach spawning beaches. Offshore currents may also influence waves and nearshore drift which may significantly affect nearshore sediment transport and geomorphology. This may change the viability of beaches for successful spawning.

Offshore wind structures may also affect the spawning and growth of forage fish. Depending on whether they are buried or not, cables could serve as a spawning area.

Effect of noise and vibrations from offshore wind on forage fish. Effects are possible. Clupeid fishes, which include herring, are well known to be highly sensitive to sounds, especially high-frequency sounds. These sounds help them avoid echolocating marine mammals. As a result, they tend to avoid noisy areas. The addition of extra noise in areas critical for spawning, feeding, or other essential activities could have a significant effect. While there is limited understanding of how noise affects other local forage fish species, the burying behavior of sand lance suggests they may vacate areas with intense noise that affects the benthos. This may be caused by activities like pile driving, port operations, large ships, and possibly offshore wind moorings. The intensity and frequency of sound are likely crucial factors. It is uncertain whether there are specific studies evaluating these thresholds.

Forage fish are also sensitive to approaching predators. Noise may attract or deter predators. There is a data gap on how forage fish would respond. There is also evidence that some forage fish communicate by sound or producing gas. Chronic noise may mask communications between forage fish.

Effect of electromagnetic fields from offshore wind on forage fish. The effect of EMF on forage fish is an important data gap; however, concerns regarding the effect of benthic cables running to shore are low since most forage fish inhabit the midwater. Forage fish also typically lack strong EMF receptors, but there may not be a good understanding of their migratory patterns and how they migrate, particularly how they navigate back to spawning areas. Species like herring and eulachon, which move in and out of shore, rely on an olfactory or internal compass for navigation. EMF may influence their ability to migrate.

Effect of light from offshore wind on forage fish. Forage fish exhibit strong responses to light, potentially being attracted or repelled by it. Artificially lighted structures at night could attract them, as most forage fish are drawn to artificial lights during darkness. However, if light intensity is excessive, it may repel them from spawning areas. Recent studies showed that green light usage reduced eulachon bycatch in the shrimp fishery, suggesting color could be a factor. The extent of this influence is unclear since forage fish mainly respond to natural light cues from the moon and sun. If the lights on the structures do not interfere with the natural light availability, the lights may not have an effect. It is uncertain whether any studies quantified the effect of light on local forage fish species. Additionally, will the lights disorient other species? What animals will be responsive to these lights? NOAA's coastal pelagic survey (CPS) can offer insights into species distribution and the habitats and communities they inhabit.

Effect of offshore wind on forage fish migration. While the impact on migration may vary depending on the location of offshore wind installations, significant population-scale effects are not anticipated. What drives migration depends on the requirements of each forage fish species. Forage fish migration corridors usually relate to temperature, salinity, and other physiochemical clines in the pelagic environment. If the offshore wind platform location aligns with these areas, fish could choose to avoid, linger, or bypass the area in search of more suitable habitat. Overlaying known spawning areas from CUFES sampling with planned installations could help examine potential risk. NOAA's coastal pelagic survey (CPS) can also be used to understand species distribution and the habitats/communities these species are part of. However, there are gaps in data for certain species and life events, such as what triggers the herring spawning event.

There are concerns regarding offshore wind's potential effect on upwelling and subsequent productivity, which could affect forage fish populations and lead to cascading effects. There are significant data gaps regarding the implications of upwelling and productivity from OSW development. Ecological models could assist in better understanding some of the species-specific impacts. Additionally, there may be significant affects to migration if EMF disrupt the inner compass of marine species. However, it is challenging to envision offshore wind activities on a scale broad enough to substantially affect migration through EMF.

Offshore aquaculture data gaps

- Effect of offshore aquaculture on early marine survival of forage fish
- Effect of fish escapements from offshore aquaculture on forage fish
- Effect of offshore aquaculture on forage fish migration
- Effect of offshore aquaculture structure on forage fish
- Effect of offshore aquaculture on fishers' behavior and the subsequent effect on forage fish

Effect of offshore aquaculture on early marine survival of forage fish. The discharge from aquaculture pens could either enrich or contaminate the surrounding environment, depending on the substances released. Changes in nutrient levels and phytoplankton blooms could affect the entire food chain, particularly for forage fish species that largely feed on zooplankton. Localized nutrient enrichment may induce plankton blooms, influenced by what is released, how much is released, and how local currents affect dilution. Specific nearshore contaminants associated with vehicles and industry operations have been observed to have a sublethal risk on eggs and larvae. The effect would depend on the agent. For instance, eggs that are neutrally buoyant are particularly at a higher risk of exposure to hydrophobic chemicals than those that are deposited benthically. The effect will also depend on location and how the facilities are spaced out. Forage fish primarily inhabit nearshore areas. While an offshore facility may have fewer interactions with forage fish, if it's located on the shelf and lies within migration pathways, the impact could be more significant.

There are many forage fish that need specific range of temperature and salinity for eggs to develop to fry, grow and mature. Offshore aquaculture may alter these environmental conditions, particularly oxygen availability. Additionally, changes in phenology due to aquaculture activities could disrupt the timing of natural events, impacting forage fish and other species' life cycles. For example, if the timing of young salmon's arrival on the coast is disrupted, it could trigger cascading effects throughout the ecosystem. Aquaculture facilities might also influence currents, prey availability, and habitat structure. A current break could create lower velocity areas and forage fish may congregate. This disruption could also concentrate larvae and eggs, altering their distribution and early marine phase. If they are not in the right location with sufficient food, it could lead to their mortality.

Effect of fish escapements from offshore aquaculture on forage fish. The effect of escaped aquaculture species varies by species, with potential competition for food and habitat with native species. Escaped fish can also facilitate disease transmission as vectors. Predatory escapees, especially if they reproduce and proliferate, pose significant risks. Many aquaculture producers opt for docile, sterile species to mitigate this threat. While escaped fish may prey on forage fish, escapees would not be a good food resource for forage fish. Forage fish primarily feed on small larvae, including those of shellfish, depending on their life stage.

Effect of offshore aquaculture on forage fish migration. The placement of aquaculture facilities along migration pathways in coastal areas could disrupt forage fish behavior. Migrating fish may be deterred or attracted by the structures, potentially acting as FADs. It is hard to predict what will occur when they encounter something for the first time. The effect will also depend on the impact to currents. Low current zones might entice juveniles or adults to linger. Offshore aquaculture could also aggregate species. The level of influence on population dynamics will depend on the scale and number of structures.

Effect of offshore aquaculture structure on forage fish. There's concern about how physical structures may affect forage fish. Could they become entangled in nets and perish? Their encounter with new structures raises questions about potential hazards.

Effect offshore aquaculture on fishers' behavior and the subsequent effect on forage fish. If finfish aquaculture uses fishmeal made from forage fish, offshore aquaculture could result in a higher demand for forage fish harvest to sustain operations, intensifying existing pressure on these populations.

Resources

Table 12. Resources relevant to forage fish.

NAME	ACCESS	TYPE	DESCRIPTION
The Washington Department of Fish and Wildlife (WDFW): Forage Fish Spawning Map	https://wdfw.maps.arcgis.com/home/webmap/viewer.html?webmap=19b8f74e2d41470cbd80b1af8dedd6b3&extent=-126.1368,45.6684,-119.6494,49.0781	ArcGIS	Displays sand lance, smelt, herring spawning areas, herring pre-spawner holding areas, and the forage fish spawning survey beaches in WA.
WDFW: Summary of Coastal Intertidal Forage Fish Spawning Surveys: October 2012 – October 2014	https://wdfw.wa.gov/publications/01701	Report	WDFW, in collaboration with the Coastal Treaty Tribes, conducted a 24-month survey to document the presence of forage fish spawning eggs in the intertidal zone.

Groundfish

Key Data Gaps

General Data Gaps

- Abundance, distribution, health, and trend of groundfish
- Effect of environmental factors on the distribution and health of groundfish

Offshore Wind Data Gaps

- Effect of offshore wind structures on groundfish
- Effect of offshore wind on early marine survival of groundfish
- Effect of noise and vibrations from offshore wind on groundfish

Offshore Aquaculture Data Gaps

- Effect of waste products and chemicals from offshore aquaculture on groundfish

Other Data Gaps

General Data Gaps

- Basic biology of groundfish

Offshore Wind Data Gaps

- Effect of electromagnetic fields from offshore wind on groundfish
- Effect of light from offshore wind on groundfish
- Effect of offshore wind on groundfish migration
- Effect of offshore wind on human activities and the subsequent effect on groundfish

Offshore Aquaculture Data Gaps

- Efect of offshore aquaculture on groundfish competition, predation, and other interactions
- Effect of offshore aquaculture on early marine survival of groundfish
- Effect of disease from offshore aquaculture on groundfish
- Effect of fish escapements from offshore aquaculture on groundfish
- Effect of offshore aquaculture on groundfish migration
- Effect of offshore aquaculture on human activities and the subsequent effect on groundfish

Background

The groundfish assemblage comprises numerous species such as rockfish, lingcod, dogfish, halibut, whiting, flatfish, skates, and sablefish. The National Oceanic and Atmospheric Administration (NOAA) identified 30 rockfish species in the Study Area's waters and over 15 flatfish species in the OCNMS waters. Groundfish inhabit diverse habitats, including rocky bottoms, kelp forests, the seafloor, and pelagic zones. They feed on a variety of organisms including euphausiids, plankton, benthic invertebrates, forage fish, and other small groundfish.

Fishing has been a significant human pressure impacting groundfish. During the 1980s and 1990s, several species were overfished. Rockfish species, such as Yelloweye Rockfish, are particularly vulnerable to fishing pressures due to their long lifespan and low reproductive rates. Since 2000, a few rockfish stocks in the MSP Study Area waters have been declared overfished. However, recent fishery management efforts have been successful in rebuilding most groundfish stocks. The MSP identified that two stocks—yelloweye rockfish and Pacific Ocean perch—were classified as "overfished." However, according to the 2022 report "Status of the Pacific Coast Groundfish Fishery,"[23] there are no overfished West Coast groundfish stocks, and yelloweye rockfish is the only rebuilding rockfish stock on the West Coast.

In various areas of the Study Area, Essential Fish Habitat and Rockfish Conservation Area closures for groundfish bottom trawling were established. These measures aim to protect habitat and support stock recovery efforts. NOAA Fisheries, Tribes, and state fisheries management agencies monitor and assess groundfish populations. However, there are data gaps in monitoring rockfish populations due to the challenges and costs associated with conducting regular scientific surveys in rocky reef habitats. These habitats are inaccessible to bottom trawl gear used in stock assessments.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to groundfish:

General data gaps

- Abundance, distribution, health, and trend of groundfish
- Effect of environmental factors on the distribution and health of groundfish

Abundance, distribution, health, and trend of groundfish. Washington's groundfish population data is in good condition, with robust data on abundance, distribution, health, and trends. Groundfish are widely distributed, and their populations are assumed to be homogeneous. This means that if a species cannot be sampled in one area, it is expected to be found in similar conditions elsewhere. Annual monitoring through fishery-independent trawl surveys, acoustic

[23] https://www.pcouncil.org/documents/2022/09/status-of-the-pacific-coast-groundfish-fishery-stock-assessment-and-fishery-evaluation-july-2022.pdf/

surveys, and hook-and-line surveys provides comprehensive data on abundance, distribution, health, and trends of many groundfish species.

There is a solid understanding of major species targeted by commercial and recreational fisheries. Along the Washington coast, fisheries are co-managed by coastal Tribes and the federal government through the Pacific Fishery Management Council (PFMC), with the Washington Department of Fish and Wildlife (WDFW) collaborating closely with the council. Fisheries adhere to established data collection protocols for catch history, length, and age information. Comprehensive data are available for species such as black rockfish, lingcod, canary rockfish, petrale sole, rex sole, and yelloweye rockfish. Key data types include length information, catch composition, age distribution of populations, abundance indices, and amount of catch.

There are groundfish species that are not actively managed by the PFMC. The first category includes ecosystem component species, where the council believes fishing has minimal impact on their distribution and abundance. These species generally inhabit areas outside the primary fishing zones and are loosely monitored, focusing on detecting any fishing-related impacts. The second category consists of species found in shallow waters within 3 miles offshore, falling under state jurisdiction for management. For both categories, if significant fishing catch or data trends indicate a decline in an ecosystem component species, the PFMC may consider elevating its status to be actively managed. Due to the extensive number of species covered by fisheries management plans, there is a need to prioritize resources and research efforts. Priority is often given to commercially valuable species in these allocations.

Northwest Fisheries Science Center's (NWFSC) United States (US) West Coast Groundfish Bottom Trawl Survey, which spans the entire coast, represents the most reliable source of spatial information regarding abundance, health, distribution, and trends. Ongoing since 2003, over the past 20 years, the survey has been conducting systematic data collection of seafloor information. The survey employs four chartered commercial fishing boats annually that operate from Canada to Mexico. Using a bottom trawl net, each tow lasts 15 minutes. The survey covers trawlable habitats ranging from depths of 55m to 1,280m, ensuring coverage wherever feasible. Approximately 600 species, including about 200 fish and various invertebrates, are captured annually, identified, counted, and weighed. Many of the 80 species covered by the Pacific Coast Groundfish Fishery Management Plan are comprehensively surveyed. Common commercial species include flatfish, shortspine and longspine thornyheads, and Dover sole. There is also sufficient knowledge on rare and significant species such as cowcod, skates, dogfish, and rays. This information is stored in the database and is readily available. It can be used to create a time series on abundance and distribution and understand how new ocean uses and climate change may impact these trends. Publications for various species and annual assessment reports are also publicly accessible. All stock assessments conducted for groundfish are accessible in the PFMC archive[24].

[24] https://www.pcouncil.org/stock-assessments-star-reports-stat-reports-rebuilding-analyses-terms-of-reference/

However, there are limitations to the US West Coast Groundfish Bottom Trawl Survey. First, sampling is sparse. Out of 13,000 stations, only 752 are selected for sampling every year. While this ratio of 752 out of 13,000 sites per year is statistically acceptable when considering the entire coast, in Washington state waters, there are typically no more than 7 stations sampled. Increasing the number of sampled sites, particularly in untrawlable areas, would provide valuable insights.

Second, because the survey focuses on areas accessible to bottom trawling, data collection efforts are limited for species that do not inhabit trawlable habitats such as rocky areas. Bottom trawls are limited to flat, muddy/sandy bottoms. Consequently, nearshore areas and specific habitats that are challenging to sample are neglected. For instance, rockfish predominantly inhabit rocky areas rather than sandy bottoms, where the risk of damaging coral and other organisms from survey methods is also high. Trawl nets can snag on rocks, leading to ineffective fish sampling and potential equipment damage. With only one backup net available, replacing damaged gear is also time-consuming and costly. Consequently, areas with complex structures require alternative methods such as hook-and-line surveys and ROV (Remotely Operated Vehicle) surveys.

Over the years, there has been extensive discussion on how to sample untrawlable habitats. Washington, Oregon, and California have developed separate sampling approaches. Oregon has invested significantly in this effort. It uses drop cameras, which are deployed to the seafloor to gather information on fish within their view. Remotely Operated Vehicles (ROVs) have also been employed to capture video footage of fish around the vehicle, identifying species, quantities, and lengths. Oregon Department of Fish and Wildlife's inshore rockfish surveys are currently restricted to depths greater than 50 meters. Each method has its limitations. Because many species appear similar, species differentiation is challenging. Visual surveys alone are insufficient. There is a need to develop effective methods for obtaining clear photographs or videos and automating species identification. Additional information can only be obtained from specimens caught in trawl surveys and information such as age and health require sending samples. Efforts from past surveys should also be tracked and improved upon.

Due to this survey limitation, many approximations have been necessary. There is a critical need to establish a scientifically designed nearshore survey. After identifying non-trawlable habitats, there will be a need to develop a technique that will allow a survey of those habitats without disrupting populations or causing harm. Washington is actively working to address this data gap by developing a nearshore survey.

Additional sources of data include the Hake Acoustic Survey conducted by NOAA and the California Current Integrated Ecosystem Assessment's (CCIEA) Ecosystem Status Report. The latter source provides information on the abundance of juvenile sablefish, Dover sole, shortspine thornyhead, and longspine thornyhead. There are also ongoing efforts to study connectivity between Oregon and Washington, but more research in this area is needed.

There is also an international groundfish assessment. Assessors from both Canada and Washington collaborate to ensure consistency. However, data are not combined. International data integration has not been attempted, resulting in limited information on the connectivity between groundfish populations in Washington and Canada. Cross-collaboration is limited due to differing survey methods and the absence of cross-border surveys. Understanding how each country manages different species and assesses stock levels is crucial. Although the National Marine Fisheries Service (NMFS) has conducted coordinated pelagic studies with Canada and Mexico, political and diplomatic challenges may hinder multinational research surveys.

Significant work remains to be done for many groundfish species. There is an ongoing need for more comprehensive data across various species and factors. While some species have been studied regarding their movement and genetic connectivity, much more research is needed in these areas. PFMC's research priorities database[25] identifies priorities for research and data needs, such as sampling age data, investigating the relationship between length and age across spatial changes, and studying movement patterns and genetic relationships.

Improved data collection efforts and data on abundance, health, and status trends are also needed for stocks included in rebuilding plans and those in the lower precautionary zone. Efforts are underway to assess health and status as frequently as possible. With rebuilding stocks, limited fishery-dependent data are collected due to stringent catch limits. When restrictions and limits are stringent, data collection is typically reduced. Many of these stocks are also harvested well below their annual catch limits. As a result, these species often receive minimal assessment, typically only meeting the minimum requirement of every 10 years. However, if a stock becomes a constraint for the fishery, even with low attainment of the annual catch limits, there may be interest in more frequent assessments than the 10-year interval.

There is also insufficient genetic research to identify subpopulations and populations along the entire West Coast. Increasingly of interest to the PFMC, they are currently assessing potential genetic boundaries. Another significant data gap is understanding the distribution across all life stages of groundfish. While there is a good grasp of adults and recruitment into the fishery, there is less information available on larval distribution and pre-recruits.

Additionally, understanding the effect of other offshore uses and in different regions may require surveying different species and collecting different data. Currently, data are gathered by grouping species based on similar life histories and traits. The assumptions used to group species that face the most intense fishing pressure may not hold true for other offshore uses. There is a lack of data collection efforts for fish or species that are not consistently tracked or targeted by fisheries.

Given that current survey efforts already cover the entire coast, collecting additional data would require a different sampling approach. This would depend on finding new methods for data collection. For instance, to acquire biological data, tools within the Autonomous Underwater Vehicle (AUV) program at Hecate Bank show promise, including eDNA analysis and AI-based fish identification from photographs.

Health and trend: PFMC conducts stock assessments for selected species every two years to monitor health and trends. Information on these species can be found on the PFMC's website. Many of the stocks show a similar pattern: population declines in the 1980s and 1990s,

[25] https://www.pcouncil.org/resources-archives/research-and-data-needs/

followed by increases in the early 2000s, and stabilization over the past decade or so. Most groundfish species are currently not overfished and are near, at, or above target levels. Generally, they appear to be doing well. However, while populations appear healthy, there are indications of potential concerns. Some areas, like southern California, have specific species of concern.

There is a notable absence of an index of abundance to track population trends. Efforts to collect indicators for nearshore groundfish have been underway over the past three years due to limited data in this area.

Abundance and distribution: Distribution data are available from each of the states (WA, OR, and CA). The majority of data comes from trawl surveys, which are constrained by their depth limitations. If the survey does not extend as far offshore as a species inhabits, it does not capture the full scope of abundance and distribution. Ongoing research aims to refine and improve understanding of fish distribution in untrawlable areas.

The availability of abundance data varies depending on the type of information being sought. There are two primary categories of abundance data: 1) absolute abundance estimates, which quantify the total number of fish in a specific area, and 2) indices of abundance, such as Catch per Unit of Effort (CPUE), where effort is typically measured by fishing hours or the number of fish caught per rod per hour. It's important to note that some indices of abundance cannot be converted into absolute abundance.

Bottom trawl surveys, which measure fish density per square meter or kilometer, can be used to estimate absolute abundance by extrapolating the density over a larger area. These surveys also help identify species and provide insights into their general distribution. To further enhance understanding, spatial modeling can be employed for mapping, although maps may not be available for all species. NOAA's Essential Fish Habitat (EFH) documents include some of these generated maps.

Within state waters and certain depths, state surveys can provide indices and trends in abundance, indicating whether populations are increasing or decreasing over time. However, they do not provide absolute abundance numbers. State surveys are conducted in spring and fall, each targeting different groups of fish. Because some fish reside in the water column while others hug the bottom, different gear and techniques are required for effective surveying. The available data predominantly covers shallow waters, focusing on areas popular for angler fishing.

Information on the distribution, abundance, health, and trends is not uniformly available across all groundfish species. For example, data on less common rockfish species is limited. Although data on Canary Rockfish from bottom trawl surveys exist, they are often less reliable due to the small number of tows that sample these species. As a result, there is a greater reliance on data from commercial and recreational fisheries.

Feedback on importance: Information on abundance, distribution, health, and trend are essential for future assessments of impacts. Compared to the diversity of species present, there is still limited knowledge about groundfish. While substantial long-term data exists for certain species, information is lacking for others, especially those residing in untrawlable habitats.

WCMAC: Approximately 25% of fish stocks undergo formal assessments that provide information on their distribution, health, and trends. These stocks are required to be reassessed every five years, with about one or two new species assessed each year. A stock assessment prioritization process uses a model that considers factors such as the reliance of fisheries and communities on each stock, its economic significance, and its ecological role. Several dozen factors are incorporated into the model and weighted accordingly, allowing species to be scored. Those species with the highest scores are prioritized for assessment.

While there is substantial information on stocks that are important to fisheries and fishing communities, there are hundreds of other fish species for which data is lacking. For instance, the primary data source is an offshore trawl survey, leading to data gaps for species not captured in this survey. Some species, such as yelloweye rockfish, inhabit high rocky reef habitats that are inaccessible to trawl surveys. Additionally, other stocks reside exclusively in nearshore areas and are not captured by the survey. While Washington conducts nearshore surveys for rockfish, many other groundfish species, such as flatfish, are not included in any survey. There are notable spatial and habitat-related data gaps for these species as well.

Effect of environmental factors on the distribution and health of groundfish. With exception to a few species, the relationship between the environment and species is not well understood. The Integrated Ecosystem Assessment (IEA) report focuses on this link. There are significant correlations between benthic habitat, seawater properties, and the distribution, abundance, and condition of groundfish. Understanding the effects of climate on marine ecosystems is a complex area. The Pacific Fishery Management Council (PFMC) is currently investigating these dynamics, actively seeking to integrate ecosystem management into its framework. They publish an annual ecosystem report based on survey findings. For each species group covered in the Fishery Management Plan (FMP), the PFMC assesses factors influencing distribution using a traffic light system (green, yellow, and red) to indicate levels of concern. PFMC also uses an ecosystem model called Atlantis, which allows exploration of ecological hypotheses, simulation of climate scenarios, and evaluation of human impacts on the environment, including fisheries and effects of infrastructure like wind and wave farms. The frequency of updates to the Atlantis model is uncertain.

For most species, identifying which variables to incorporate into assessments remains a significant challenge. Among West Coast groundfish species, Pacific Whiting has been the subject of the most studies regarding the relationship between climate variables and distribution. The Alaska Fisheries Science Center possesses extensive data and statistical tools, which other centers are working to emulate.

More information is needed on habitat and environmental factors and their impacts on groundfish. Comprehensive monitoring is essential to address the fundamental gaps in the understanding of certain stocks. Many studies focus on biological factors in controlled lab settings. Unlike controlled lab conditions, the ocean environment is complex and doesn't allow for isolating and manipulating individual variables. For instance, elevated temperatures in the ocean can coincide with low dissolved oxygen levels.

Understanding the dynamics of time and space is also crucial. When overlaying variations in time and space on biological studies, there is inevitably a data gap. Populations do not have static biology; they evolve and adapt over time. It is essential to track biological relationships and observe how they evolve across different time frames and geographical areas.

Additionally, the factors controlling recruitment remain unclear. There is a significant need for data to predict which conditions will foster optimal recruitment and to understand the environmental indicators thereof. There are questions regarding whether increased prey availability or specific environmental windows enhance recruitment. For instance, the survival of groundfish offspring hinges on the environment they inherit. Limited information exists on the critical conditions for species like sablefish and petrale sole. Additionally, the impacts of coastal phenomena such as the "warm blob" on populations and recruitment patterns are not well understood. Species like rockfish, which have long lifespans, rely on periodic large recruitment events that occur every 5-10 years. Failure to experience these events can endanger populations. Given the dynamic nature of these systems, continual efforts are necessary to improve predictive models and projections.

Changes in food sources can also significantly affect growth outcomes. Observable fluctuations occur during El Niño and La Niña years, often resulting in large influx of specific species that serve as food for fish. Questions remain about how species' ranges shift with warming temperatures, the frequency of warm water events, and their overall impacts on groundfish populations. Some groundfish species forego reproduction in higher temperatures, reabsorbing their eggs to conserve energy (skip spawning). Current research is investigating how these dynamics evolve over time.

Long-term monitoring is essential to understand how environmental factors affect populations. The strength of the relationship between environmental factors and species dynamics is important to assess. While one variable cannot reflect environmental conditions, for instance, there is an understanding that depth influences sablefish recruitment, temperature serves as a proxy for environmental conditions affecting sardines, and El Niño and La Niña conditions influence year classes of certain groundfish species. The Pacific Decadal Oscillation (PDO) is integrated into the California Current Ecosystem (CCE) report to gauge current environmental conditions along the West Coast.

Human-induced changes, such as ocean acidification (OA) and hypoxia, can also affect species distribution. The full impact of climate change remains uncertain, with some species undergoing genetic migration. High year classes and increased juvenile populations can create the illusion of distribution shifts, including movement from north to south and between inshore and offshore habitats. To assess the effects of climate change, it is essential to collect data on fish distribution. While climate models can be combined with species distribution data, accurately capturing the variability influencing these models remains a challenge.

Feedback on importance: There is considerable interest in understanding the overall impacts of climate change on groundfish. Climate change is expected to have various effects, such as altering temperatures that can influence coastal currents. This temperature shift may disrupt coastal upwelling, bring about nutrient-deficient surface waters, and affect various ecological processes.

WCMAC: Environmental indicators recognized as effective for assessing groundfish stocks are incorporated into the groundfish stock assessment. There are approximately 150 potential indicators; however, the specific effects of each indicator on individual stocks remain unclear. Targeted studies are necessary for each stock.

For each stock with an assessment or study conducted, the tolerance range for relevant environmental variables is documented in the Ecosystem Report. These tolerance ranges help define the conditions under which the species can thrive. For example, if ocean temperatures exceed the established range, it can result in increased mortality or shifts in distribution patterns. Such changes are confirmed through trawl surveys.

Offshore wind data gaps

- Effect of offshore wind structures on groundfish
- Effect of offshore wind on early marine survival of groundfish
- Effect of noise and vibrations from offshore wind on groundfish

Effect of offshore wind structures on groundfish. The effect of offshore wind structures on groundfish may depend on their life stage. At the larvae phase, many groundfish larvae are pelagic. Hence, floating structures above the seafloor may affect larvae. For most adult groundfish, offshore wind structures may not have a direct impact. However, the introduction of structures may alter existing habitats and affect species already present.

When physical structures are introduced into the water, they are likely to either attract, repel, or have a neutral effect on species. Groundfish typically aggregate around physical structures like rocks and oil rigs; for instance, rockfish that previously relied on rocks for habitat now use oil rigs. Similar to oil rigs, offshore wind structures are expected to serve as artificial habitats and fish aggregating devices (FADs). If these structures attract species, it is uncertain whether this new habitat will be suitable. Not every structure is suitable for every species in the ocean. There are numerous artificial reefs in Puget Sound, yet not all of them attract fish. Fish aggregation depends on factors such as temperature, salinity, food availability, and whether fish find the structure appealing. The structure may also act as an ecological trap if the shift away from their current habitats proves detrimental. Attraction to a structure could lead to reduced growth. This is a knowledge gap that will require substantial funding and large-scale experiments. In contrast, certain fish species actively seek shelter and may use the floating platform for refuge, particularly if seagrass becomes ensnared in the structure. This feature could prove especially attractive to smaller fish in need of shelter. Research on the effects of such structures in West Coast waters has not yet been conducted but has been proposed. Additionally, it is unclear whether offshore wind structures would create movement barriers. However, cables, may act as barriers if densely laid. There is a substantial knowledge gap in this area.

Offshore wind structures may also affect primary production to some extent via shading, depending on its magnitude. Phytoplankton serves as food for zooplankton, which in turn supports small fish, ultimately contributing to the food chain for larger fish. However, man-made structures are unlikely to be made at a scale large enough to induce this effect. The structures could also alter local currents and influence turbulence, thereby impacting distribution patterns. While these effects may not be significant on a large scale, smaller organisms could be affected, potentially leading to a bottom-up ecological influence. The potential alteration of wind patterns and disruption of upwelling by offshore wind installations remain significant uncertainties.

Related to offshore wind structures, construction is expected to cause disruptions and negative impacts. For example, the installation of underwater cables can damage habitats. The ability of habitats to recover depends on their location; sandy bottoms tend to recover more easily, while the removal of rocky reefs presents greater challenges. While many groundfish do not inhabit sandy environments, particularly those targeted by fisheries, the installation could disrupt sub-sediment species that serve as food sources for groundfish. The impacts could be both positive and negative, though in the long term, benefits are more likely than harms. Anchoring would likely cause minimal disruption. However, construction effects may be potentially outweighed by the impact of restricting fishing activities. It remains unclear if areas where cables are buried will be designated as off-limits to fishery operations. Separately, distinguishing between the impacts of offshore wind structures and the potential habitat damage they may cause will be challenging. The installation of these structures could disturb habitats, destroying the original habitat, altering fish distribution, and bring about shifts in species interactions. The effects of offshore wind construction on fish distribution and species interactions remain uncertain.

Another indirect effect, groundfish surveys may undergo significant changes with the installation of offshore wind structures. Surveys employ consistent techniques and protocols year after year. Gathering data on relative abundance to facilitate year-to-year comparisons necessitate strict adherence to standardized methods. If data collection becomes unfeasible at a specific site, all associated monitoring data from that site must be excluded. Losing important survey sites hinders the ability to compare current data with historical records. Thus far, outside of Washington, Bureau of Ocean Energy Management (BOEM) has leased areas for offshore wind development where groundfish surveys occur. Maintaining access to these areas is imperative to assess impacts.

Research is currently underway to investigate the potential effects of offshore wind installations on groundfish. The technology in question is still in developmental stages and its feasibility remains uncertain. While two decades of research have been dedicated to evaluating the viability of offshore wind, limited information exists regarding its potential effects on fish populations. Although studies from the east coast may provide some information, they may not be directly applicable, as the west coast focuses on floating turbines, unlike the fixed turbines used on the east coast. Reports from the BOEM may provide valuable insights into this area of study.

Feedback on importance: Understanding this data gap is important because the effect of physical structures may influence currents and thereby affect the distribution of both groundfish larvae and adults.

> **WCMAC:** Numerous studies have been conducted on offshore oil and gas platforms. These platforms are derelict but continue to exist and function as artificial reefs. These structures tend to aggregate groundfish and rockfish, creating localized effects in their

vicinity. Similarly, in areas with muddy and sandy bottoms, the addition of offshore wind structures could attract fish from other regions where natural habitats are lacking. Placing a platform in areas with abundant natural rocky reef habitats may have a limited impact, as fish are already drawn to those natural structures. Additionally, while the effect of offshore wind cables are unclear, numerous cables are already present in the marine environment. If the cables are buried, their effect will likely be temporary.

The potential effect of offshore wind structures extends to indirect consequences, such as how wind turbines may alter ocean processes like upwelling, which could, in turn, affect the life stages of groundfish by influencing spawning and larval drift.

Effect of offshore wind on early marine survival of groundfish. The effect of offshore wind will vary with the life stage of groundfish. While it is not expected to affect spawning, it may influence larval survival and recruitment. Larval life histories differ significantly among species, especially concerning the water column depth they use. However, many groundfish larvae are pelagic. While NOAA conducts annual juvenile surveys that identify species and document larvae distribution and location, there is a significant data gap regarding larval behaviors for each species. As a proxy, a generalized behavior is applied to all. Without knowledge of larval locations or their developmental history, the effect of geographical and oceanographic parameters cannot be properly evaluated.

Larvae and juveniles may be influenced by floating offshore wind structures. The initial installation will be disruptive. However, depending on their design, offshore wind structures may function as a locus for habitat building. Other man-made structures have created habitat. Previous studies on the effects of other offshore installations, such as oil rigs, on fish populations could provide valuable insights. The primary benefit may lie in providing shelter from predators. While offshore wind may also draw predators, this is not perceived to be a significant risk. Introducing a hard substrate on the seafloor may also benefit species that prefer such environments over those favoring soft substrates.

There is also concern around the effect of offshore wind on larval drift. Offshore wind may influence local currents which could affect population connectivity. Larvae and pelagic juvenile groundfish are predominantly found near the water surface, making them susceptible to current alterations. They often inhabit drifting algae mats, crucial for shelter and larval dispersion. Larvae not sheltered in algae are subject to currents due to their limited swimming ability. There is currently insufficient direct evidence from oceanic studies to conclusively state that currents affect larvae distribution, but there is a strong belief that this is a potential outcome. However, a substantial number of offshore wind structures would be required to significantly affect water circulation that could affect larvae. Similarly, if offshore wind impacts plankton distribution, this shift could influence the growth of planktivorous species. Additionally, an indirect effect, if offshore wind structures altered the distribution of drifting algae, such as by entanglement, species distribution would also be affected.

It will also be essential to study fishing behavior in relation to the presence of offshore wind structures. Positive effects may arise if fishing activities are restricted in these areas. However, if fishing is permitted, fish could aggregate around the structures, and increased fishing pressure may have negative impacts. Additionally, fishing might become concentrated in nearby areas, potentially leading to localized depletion, particularly for non-migratory species.

Feedback on importance: Addressing this data gap is important because stock assessments require an understanding of recruitment events and the factors influencing spawning and larval distribution.

> **WCMAC:** The effects of wind turbines on ocean processes such as upwelling, which brings nutrients from deeper waters to the surface and supports marine life, remain unknown. Additionally, the influence of wind turbines on the life stages of groundfish, particularly regarding spawning and larval drift, is uncertain. This uncertainty is compounded by the lack of knowledge about the locations of different groundfish life stages. Some species migrate offshore to spawn and their larvae drift with ocean currents. For these species, the impact of offshore wind on their early marine phase will depend largely on how it affects ocean processes. Larval drift is influenced by currents, while nutrients from upwelling, including plankton and phytoplankton, provide essential food sources for larvae and juvenile fish.

Effect of noise and vibrations from offshore wind on groundfish. Research on fish communication has revealed that fish engage in more communication than previously thought and that rely on these interactions. This is especially evident in habitats like rocky reefs, which are complex, communal ecosystems with a wide range of sounds across different frequencies. The potential effects of sound and vibrations from offshore wind on groundfish remain poorly understood, highlighting a significant data gap. However, it is known that groundfish are sensitive to underwater noise.

The potential effect of sound on different species can be inferred. Existing literature provides substantial information on the impacts of low-frequency sound on marine life. Video studies have demonstrated fish reacting to vibrations, possibly visual cues, generated by bottom trawl survey nets. Observations revealed that the fish responded by moving ahead of the net. The distance at which vibrations affect fish behavior is uncertain, and any harm observed is primarily behavioral rather than physical.

For groundfish, there is a substantial body of knowledge derived from submersible studies on their response to sound. Responses to noise can vary; at times, fish are affected, while at other times, they do not react significantly. In one study, researchers compared fish vocalizations before, during, and after ferries passed overhead, a distinct human-generated noise source. They assessed how this noise affected fish behavior and vocalizations. Significant behavioral changes were observed in response to high noise levels. Fish compensated by vocalizing more loudly and showed reduced activity. After the ferry passed, fish became quieter. The study highlighted the nuanced effects of noise.

The type of noise may also have an effect. Heavy equipment operating at great depths and seismic exploration can potentially impact marine environments. Low-frequency sound waves generated by these activities can travel significant distances. Notably, floating offshore wind structures, unlike their fixed counterparts, may not encounter sound issues related to pile driving. Additionally, the effect of constant noise on groundfish is uncertain.

Rockfish, a long-lived species, often inhabits specific areas for years. The effects of noise could extend beyond simple avoidance behavior to potentially influencing their long-term residence and behavior. There is an interest in minimizing disruptions that could cause fish to leave their preferred habitats due to noise.

Feedback on importance: Considering the research examining the impact of ferries on fish vocalizations, there is interest in better understanding the effects of noise and vibrations on groundfish.

> **WCMAC:** There are studies on the effects of noise on fish and invertebrates, including some specific to groundfish. For instance, refer to "The Impact of Ocean Noise Pollution on Fish and Invertebrates."[26] Additionally, as far as these effects are understood, NOAA has provided comments to BOEM regarding the potential impacts of offshore wind on ocean resources, including fish, habitat, and protected species.

Offshore aquaculture data gaps

- Effect of waste products and chemicals from offshore aquaculture on groundfish

Effect of waste products and chemicals from offshore aquaculture on groundfish. Chemicals that may be introduced through offshore aquaculture operations include antifoulants, antibiotics, parasite treatments, nutrient additives, disinfectants, pharmaceuticals, and pesticides. These chemicals can impact the health of fish, raising concerns about the extent of bioaccumulation, particularly in commercially valuable species. The use of antibiotics in aquaculture may also present concerns. There is limited information regarding potential shifts in fish behavior due to chemical exposure.

The introduction of chemicals or waste into the environment could also potentially alter water temperature, salinity, or light penetration, affecting species sensitive to these changes. Temperature changes are likely to be localized, whereas salinity and chemicals may disperse more broadly into the ocean. Shifts in environmental factors may influence species distribution patterns. If offshore aquaculture is located at a shallow enough depth, waste can contribute organic content and potentially attract new invertebrates, grazers, and filter feeders, thereby altering the local community.

Notably, in addition to wastes and chemicals, offshore aquaculture will also introduce nutrients. While this may enhance local productivity if groundfish can consume the nutrients, it could also lead to blooms and, in severe cases, hypoxia—conditions to which groundfish have shown sensitivity. This concern is likely more significant for relatively sedentary groundfish species.

The potential concerns on the effect of added wastes and chemicals depends on the scale and volume of aquaculture operations. Even small pens can modify the substrate and in turn, affect the condition, abundance, distribution, and survival of marine organisms. However, unlike

[26] https://www.oceancare.org/wp-content/uploads/2022/05/Underwater-Noise-Pollution_Impact-on-fish-and-invertebrates_Report_OceanCare_EN_36p_2018.pdf

nearshore farms (e.g., salmon pens in Puget Sound), offshore aquaculture operates at depths where waste products and chemicals are less likely to pose environmental concerns. The increased flushing and water movement in deep water environments are expected to mitigate these issues compared to nearshore farms, but further studies are warranted.

Feedback on importance: For aquaculture operations, waste products and chemicals are likely to have the greatest impact on groundfish, potentially affecting them at all life stages.

> **WCMAC:** The effect of waste products and chemicals from offshore aquaculture varies depending on whether finfish or shellfish are being cultivated, as well as the type and scale of the facility. The effects are expected to be site-specific. Generally, issues related to waste and disease arise in crowded conditions; these problems can be mitigated by reducing fish density.
>
> This data gap may be a lower priority because, while offshore mariculture of kelp may be possible, offshore finfish aquaculture is not expected to be feasible. While aquaculture operations could occur in the nearshore area; it would involve stringent monitoring.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Basic biology of groundfish

Basic biology of groundfish. The biology of most managed species is well understood. The PFMC has comprehensive data on key fish species important to both commercial and recreational fisheries, including information on lifespan, growth rates, maturity, fecundity, relative distribution, and habitat associations. However, there are still gaps in knowledge. Further research is needed to better understand sources of mortality, growth patterns, reproductive behavior (including communication like grunting), and mate selection. Significant data gaps also remain in understanding predator-prey ecosystem dynamics. In particular, it is important to understand how diets change over time and with climate change. Unfortunately, analyzing the contents of fish stomachs, which are collected and preserved during bottom trawl surveys, is a labor-intensive process. There is also growing interest in how climate change influences maturity and fecundity patterns in marine species.

The biology of groundfish is less understood for unmanaged species such as those that are integral ecosystem components within PFMC Fishery Management Plans (FMPs). These are fish species essential to the ecosystem as prey or predators that are not targeted or caught by fisheries.

Though not directly linked to groundfish biology, changes in zooplankton composition and abundance have been observed to affect fish growth and mortality rates. Zooplankton that are richer in oil and fat can enhance fish growth and survival, while nutrient-poor zooplankton may lead to stunted growth and lower survival rates.

Offshore wind data gaps

- Effect of electromagnetic fields from offshore wind on groundfish
- Effect of light from offshore wind on groundfish
- Effect of offshore wind on groundfish migration
- Effect of offshore wind on human activities and the subsequent effect on groundfish

Effect of electromagnetic fields from offshore wind on groundfish. The effect of electromagnetic fields (EMF) on marine life is not well understood. Significant effects are unlikely but remain an important consideration. EMF may disrupt a groundfish species' sense of direction and affect their ability to navigate and orient themselves geographically. More information is known on this effect for salmon than groundfish.

Research from Europe is beginning to shed light on EMF impacts, but differences are expected on the West Coast where cables may be suspended in the water column rather than buried underground due to the focus on floating offshore wind technology.

Effect of light from offshore wind on groundfish. The effect of artificial light installed on offshore wind structures will depend on the intensity of light, its penetration through water, the depth offshore wind facilities will be installed, and species' response to light. The potential effect of light on groundfish species is uncertain, particularly at the depths under consideration for offshore wind.

Artificial lighting on infrastructure can alter the local vertical distribution of fish, potentially causing confusion by mimicking daylight conditions if too bright. Some fish, plankton, and squids exhibit diel or diurnal migrations, remaining below the photic zone during the day, ascending towards the surface after dusk, and returning to deeper waters before dawn to feed and avoid predators. Light may pose more significant concerns for squid and coastal pelagic species than groundfish.

Exposure to light is likely to also affect an organism's visual acuity. Fish exposed to light may experience temporary vision impairment, making them more vulnerable to predation. Light may also lead to behavioral changes, causing groundfish to avoid well-lit areas to minimize predation risk. Surface light may attract juvenile fish, potentially influencing the behavior and movement of larvae and young groundfish.

Some studies have explored the interaction between fishing practices that use light and the behavior of fish brought to the surface and released. Research in Newport, Oregon, is investigating the use of lights on fishing nets to reduce bycatch. This research examines how light can be used to attract or repel specific species, though it is still in its early stages. For groundfish species specifically, the application of light to target or avoid them remains poorly understood.

Effect of offshore wind on groundfish migration. Migration primarily applies to adult fish. While there could potentially be effects on migration due to various factors, the specifics remain largely unknown.

Groundfish exhibit varying degrees of movement. Species like hake, sablefish, and halibut can cover significant distances, while rockfish and other bottom-dwelling species tend to be more sedentary. Most demersal species, once mature, generally remain where they are. Offshore wind activities may affect nearshore and offshore migratory patterns rather than latitudinal movements. Some species utilize nearshore areas as nursery grounds before transitioning to offshore environments as adults. Life histories often involve depth-dependent shifts, and the development of offshore wind infrastructure could potentially disrupt these migratory pathways. The potential effects on groundfish species outside of currently fished areas remain unclear.

Additionally, while migratory groundfish typically inhabit areas near the seafloor, no studies currently suggest that offshore wind cables would impact their migration patterns.

The primary impact of offshore wind may be on the distribution of larvae and juveniles, rather than adult migration. During the larval phase, these organisms are carried by ocean currents.

Effect of offshore wind on human activities and the subsequent effect on groundfish. Offshore wind may affect other existing uses and activities of the ocean which may subsequently affect groundfish populations. Examples include pollution resulting from construction and operational processes, alterations in groundfish distribution that could affect commercial and recreational fishing, and potential closures of key survey areas. In particular, closures of survey areas may limit the ability to effectively monitor and manage groundfish populations, ultimately influencing conservation and management strategies The effects of offshore wind on other human activities and the potential repercussions for groundfish are not yet fully understood.

Offshore aquaculture data gaps

- Effect of offshore aquaculture on groundfish competition, predation, and other interactions
- Effect of offshore aquaculture on early marine survival of groundfish
- Effect of disease from offshore aquaculture on groundfish
- Effect of fish escapements from offshore aquaculture on groundfish
- Effect of offshore aquaculture on groundfish migration
- Effect of offshore aquaculture on human activities and the subsequent effect on groundfish

Effect of offshore aquaculture on groundfish competition, predation, and other interactions. The potential effect of offshore aquaculture on groundfish competition, predation, and other interactions is not currently a top priority, but it remains a concern. Significant effects would likely require the operation of a very large aquaculture facility. Absent substantial alterations to the ecosystem—such as the escape of highly predatory fish or significant escapement—impacts on groundfish are expected to be minimal.

Pelagic aquaculture species, which do not typically prey on groundfish, are unlikely to cause significant impacts. Predators of groundfish vary by life stage. As larvae, groundfish are vulnerable to a wide range of predators. As they grow, predators must also be larger, sometimes involving cannibalism within the same species, particularly when populations are abundant. Most groundfish are opportunistic feeders, consuming prey items that fit into their mouths and prioritizing feeding. Identifying specific predators is challenging, but species like lingcod and halibut are known predators. In the water column, tuna fish are also significant predators. The Northwest Fisheries Science Center (NWFSC) conducts diet studies by examining stomach contents.

Offshore aquaculture can also affect groundfish by potentially affecting their habitat. For instance, the potential impacts of offshore aquaculture on estuaries and groundfish behavior within these habitats are not fully understood. Estuaries also serve as crucial nursery grounds where many species mature and spawn. They are essential for nurturing and providing initial habitat before juveniles move to their permanent locations. For example, male Lingcod exhibit guarding behavior over their nests for 8-10 weeks until the eggs hatch. Certain fish species also display specific mating behaviors within estuarine environments.

Depending on aquaculture practices, there may also be increased nutrient loading, potentially altering benthic habitat, and affecting its ability to provide shelter and food. Any alteration to the base of the food web theoretically affects all species. The Atlantis Ecosystem Model can provide some insights into these potential impacts.

Lastly, inshore aquaculture is often linked to elevated levels of disease and parasitism, along with associated costs due to competition. It appears probable that similar challenges would arise in offshore aquaculture operations.

Effect of offshore aquaculture on early marine survival of groundfish. There are several potential direct effects. The impact on early marine survival depends on the scale of factors such as nutrient loads, disease, and chemical inputs. Any alterations in the water column can affect the survival, growth rate, and maturation of larvae. However, unless aquaculture significantly alters the local ecosystem, impacts on larvae are not expected to be substantial.

Directly, changes in temperature and salinity can affect larval growth rates, potentially extending the period during which they remain vulnerable or smaller. This could impact their maturity and reproductive capabilities. Offshore aquaculture operations may also increase local productivity, providing additional feeding opportunities for groundfish through supplemental feed. However, the overall impact—whether positive or negative—remains uncertain. Additionally, offshore aquaculture could attract predators and increase the risk of disease.

Indirectly, offshore aquaculture facilities may act as a buffer against fishing pressures. Whether this localized reduction benefits the early stages of groundfish is uncertain.

Effect of disease from offshore aquaculture on groundfish. The potential concern regarding the risk of disease from offshore aquaculture operations depends on scale, with demersal species likely to be more affected than pelagic species. There is currently a lack of research on disease specifically regarding groundfish. However, the risk of disease transmission from cultured to wild fish is generally similar to that of any other species.

Effect of fish escapements from offshore aquaculture on groundfish. The effect of fish escapement is primarily a concern for offshore finfish aquaculture. In Puget Sound, escapement of Atlantic salmon from hatcheries raised significant concerns, including issues related to predation and disease transmission. The effect of hatchery fish escapement depends largely on the risk of invasive species causing ecological disruptions. Concern is typically higher for non-native species. Hence, the impact of escapement depends on the species involved. Sablefish, for instance, could potentially exhibit similar predatory behaviors as hatchery salmon compared to native species. If hatchery fish were sterilized, it would likely reduce their ecological impact.

In offshore environments, the ecosystem is expansive enough that groundfish are not confined to a single area. Hence, the effect of fish escapement is likely minimal unless the escapement involves a substantial number of fish (e.g., the escape of 100 fish would have negligible effects), and if there is concurrent disease or parasite transmission, risking introduction of diseases to natural populations.

The genetic origin of the escaped fish will also influence the effect of escapement. Wild fish and those best suited for aquaculture often have different genetic characteristics. There are concerns about genetic impacts if the escaped fish are genetically modified, originate from a different part of the coast, or have genetic traits distinct from the native population. Interbreeding between escaped and wild fish could lead to negative effects, potentially introducing domestication traits into wild populations if escapees successfully reproduce in the wild.

Effect of offshore aquaculture on groundfish migration. Offshore aquaculture is unlikely to significantly affect migration patterns. Structural elements may create navigation challenges for fish, potentially affecting their ability to swim effectively. If operations are located high in the water column, this effect will be minimal for groundfish that inhabit the seafloor.

The presence of fish in a location is not solely determined by physical habitat; factors like salinity play crucial roles. Fish also tend to adjust their behavior based on oxygen levels; they may stay at the bottom or move to areas with better oxygenation. Instances of fish mortality due to low dissolved oxygen (DO) are documented, particularly when fish cannot relocate to oxygen-rich zones.

Unlike oxygen, which is essential for survival, groundfish are less likely to avoid areas where chemicals from offshore aquaculture operations are present. Chemicals that may be introduced through offshore aquaculture operations include antifoulants, antibiotics, parasite treatments, nutrient additives, disinfectants, pharmaceuticals, and pesticides. Unfamiliarity with these chemicals may not prompt fish to avoid them. The effect will vary depending on the specific chemicals involved and the scale of aquaculture operations. One significant data gap is unmapped bathymetry. It is unknown whether the topography of the seabed, such as corridors and features, influence groundfish migration patterns.

In contrast, kelp aquaculture has the potential to provide shelter for small fish or young-of-the-year individuals. Similarly, shellfish aquaculture can offer structured habitats through the use of shells.

Effect of offshore aquaculture on human activities and the subsequent effect on groundfish. If offshore aquaculture leads to the closure of fishing and survey areas, there would be significant implications for species management. The closure of fishing areas raises questions about how it would affect fishing distribution and effort. Changes in the distribution of fishing activities will influence fish distribution. Vessels typically target areas with high fish density. Closing these areas could benefit overall fish populations and lead to a spillover effect into adjacent regions. The extent of this spillover effect will vary by species. Understanding and accounting for density differences between closed and open areas require comprehensive data. The collection of this data may be feasible through the use of technologies such as ROVs and cameras deployed from smaller boats. Additionally, offshore aquaculture may affect groundfish species by habitat destruction and pollution.

Resources

Table 13. Resources relevant to groundfish.

NAME	ACCESS	TYPE	DESCRIPTION
Pacific Fishery Management Council: Groundfish stock assessment and fishery evaluation documents	https://www.pcouncil.org/stock-assessments-star-reports-stat-reports-rebuilding-analyses-terms-of-reference/	Website	Provides access to stock assessment documents and stock assessment/ fishery evaluation documents.
Pacific Fishery Management Council: Research and data needs	https://www.pcouncil.org/resources-archives/research-and-data-needs/	Website	Shares a database on research priorities and data needs.
The Impact of Ocean Noise Pollution on Fish and Invertebrates	https://www.oceancare.org/wp-content/uploads/2022/05/Underwater-Noise-Pollution_Impact-on-fish-and-invertebrates_Report_OceanCare_EN_36p_2018.pdf	Report	Reviews 115 studies that examined the effect of human-produced underwater noise on various fish and invertebrate species.

Invasive Species and Pests

Animals

Key Data Gaps

General Data Gaps

- Management of invasive species and pests
- Effect of environmental paramters on invasive species and pests
- Identification of invasive species and pests

Offshore Wind Data Gaps

- Pathways and points of introduction of invasive species and pests through offshore wind activities
- Monitoring and mitigation of invasive species and pests with offshore wind activities
- Effect of offshore wind on distribution and abundance of invasive species and pests

Other Data Gaps

General Data Gaps

- Natural dispersal method, pathways, and points of introduction of invasive species and pests
- Spatial distribution of invasive species and pests
- Biology of invasive species and pests
- Abundance and trend of invasive species and pests
- Communication of aquatic invasive species

Offshore Wind Data Gaps

- Effect of electromagnetic fields on invasive species and pests from offshore wind infrastructure
- Effect of disturbance from offshore wind on invasive species and pests
- Effect of offshore wind structure on invasive species and pests
- Effect of shift in water circulation from offshore wind on invasive species and pests
- Effect of port enhancement on invasive species and pests

Offshore Aquaculture Data Gaps

- Effect of added nutrients, wastes, and chemicals from offshore aquaculture on invasive species and pests
- Effect of offshore aquaculture structure on invasive species and pests
- Effect of parasites from offshore aquaculture on invasive species and pests
- Effect of escapement on invasive species and pests

Plants

Key Data Gaps

General Data Gaps

- Spatial distribution of invasive species and pests
- Identification of invasive species and pests
- Abundance and trend of invasive species and pests
- Effect on invasive species and pests on businesses
- Effect of invasive species and pests on ocean acidification

Offshore Wind Data Gaps

- Effect of shift in water circulation due to offshore wind on invasive species and pests

Offshore Aquaculture Data Gaps

- Effect of added nutrients, waste, and chemicals from offshore aquaculture on invasive species and pests

Other Data Gaps

General Data Gaps

- Management of invasive species and pests
- Natural dispersal method of invasive species and pests
- Effect of environmental parameters on invasive species and pests
- Biology of invasive species and pests
- Species that consume invasive species and pests
- Role of invasive species and pests in the trophic food web and its interaction with other species
- Effect of invasive species and pests on ecology
- Cost of management of invasive species and pests

Offshore Wind Data Gaps

- Effect of electromagnetic fields from offshore wind infrastructure on invasive species and pests
- Effect of disturbance from offshore wind on invasive species and pests
- Transportation of reproductive material of invasive species and pests by offshore wind
- Effect of offshore wind structure on invasive species and pests
- Effect of port enhancement on invasive species and pests
- Monitoring and mitigation of the effect of offshore wind on invasive species and pests
- Effect of offshore wind on distribution and abundance of invasive species and pests

Offshore Aquaculture Data Gaps

- Effect of offshore aquaculture structure on invasive species and pests
- Effect of parasites from offshore aquaculture on invasive species and pests

Background

The MSP Study Area is affected by invasive species, notably in coastal estuaries. Examples include Atlantic cordgrass (*Spartina alterniflora* and *S. densiflora*), Japanese eelgrass (*Zostera japonica*), and European Green Crab (*Carcinus maenus*).

RCW 77.135.010 provides the following definitions:

> "Invasive species" means "nonnative species of the animal kingdom that are not naturally occurring in Washington for purposes of breeding, resting, or foraging, and that pose an invasive risk of harming or threatening the state's environmental, economic, or human resources. Invasive species include all stages of species development and body parts. They also include genetically modified or cryptogenic species. RCW 77.135.010(13)
>
> "Aquatic invasive species" means an invasive species of the animal kingdom with a life cycle that is at least partly dependent upon fresh, brackish, or marine waters. Examples include nutria, waterfowl, amphibians, fish, and shellfish. RCW 77.135.010(2)
>
> "Noxious weed" means a plant that when established is highly destructive, competitive, or difficult to control by cultural or chemical practices. RCW 17.10.010(8)
>
> "Aquatic noxious weed" means an aquatic plant species that is listed on the state weed list under RCW 17.10.080. RCW 17.10.010(3)

Invasive species include diseases, parasites, plants, invertebrates, and vertebrates that occur along the Washington coast in various habitats. They enter through various vectors, including but not limited to, ballast water discharge, shipping, aquaculture fouling, and the aquarium trade. These species disrupt habitats, food webs, and ecology, and impose significant economic and social costs, especially on fisheries and salmon recovery efforts. New uses such as marine renewable energy or offshore aquaculture may potentially introduce additional species.

Washington's Pacific coast hosts 59 of the state's 94 marine invasive species. It is important to distinguish that not all non-native species are invasive. Some introduced species, such as Pacific oysters and Manila clams, have become vital to commercial and recreational harvests in the MSP Study Area. Pacific oysters, introduced from Japan since 1928, now support economically significant aquaculture operations benefiting the coastal and statewide economy.

Preventing and controlling invasive species in Washington depends on how a species is introduced or spread, as well as the effective treatments available for that species. There are multiple prevention strategies such as recreational vessel cleaning, ballast water management, vessel inspections, biofouling management, and prohibitions of the release of non-native species. When invasive species become established, management varies based on factors such as species, distribution, degree of possible containment, and urgency of the threat to the state's environmental, economic, or human resources. Methods range from physical removal to chemical and biological controls.

Multiple agencies are involved with decisions related to invasive species control. State agencies collaborate through the Washington Invasive Species Council to support a comprehensive strategy to protect the state against invasive species. There are also programs like the Washington State Aquatic Invasive Species Prevention and Enforcement Program co-administered by Washington Department of Fish and Wildlife (WDFW), Washington State Patrol, the Washington State Noxious Weed Control Board that advises the Washington State Department of Agriculture (WSDA) on invasive species control, and the Washington State Department of Ecology's Aquatic Weeds Program. These programs play a crucial role in outreach, education, reporting, prevention, enforcement, and control efforts concerning invasive species.

Unlike invasive species, which are non-native organisms that cause ecological or economic harm, pests are typically native species that become problematic. For example, burrowing shrimp (*Neotrypaea californiensis* and *Upogebia pugettensis*) have become a significant nuisance in the aquaculture industry of Willapa Bay and Grays Harbor. Although they are native to Washington, their populations have surged dramatically since the 1940s and 1950s. Burrowing shrimp destabilize sediment, making it too soft to support oysters and aquaculture equipment, thereby impacting the industry's economic viability. The pesticide carbaryl was used to control burrowing shrimp starting in the 1960s, but it was phased out due to environmental concerns. In response, an integrated pest management plan was implemented, focusing on developing cost-effective and environmentally friendly methods to manage them. Some growers are exploring alternative pesticides to address the expanding populations of burrowing shrimp.

Data Gaps for Animals

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to animal invasive species and pests:

General data gaps

- Management of invasive species and pests
- Effect of environmental parameters on invasive species and pests
- Identification of invasive species and pests

Management of invasive species and pests. Management of invasive species and pests focuses on limiting expansion rather than complete eradication. Per RCW 77.135.020, the Washington Department of Fish and Wildlife is the lead agency for managing invasive species in the animal kingdom.

Managing invasive and pest species requires understanding what species are present, their priority, and the specific threats that need to be prevented. The effectiveness of management efforts varies depending on the species. Some species are managed well due to the availability of necessary resources and funding. Two well-known invasive species are the zebra and quagga mussels. They are amongst those with the highest Aquatic Invasive Species (AIS) risk in

Washington State. Significant investments have been made in resources and funding for mussel management, including rapid response plans, state management strategies, and regional coordination.

There are data gaps regarding species and their vectors. AIS do not adhere to state boundaries. For instance, the risk of European Green Crabs (EGC) dispersal via watercraft transportation is a known low risk that is well-documented. Thousands of watercrafts have been inspected and EGC have not been detected. However, there are less understood vectors. Ecology is assessing a project to ascertain the presence of EGC in dredged material. If EGC are in the disposal material, their survival and life stage are unknown. It is unclear whether detections would require halting dredging operations due to disposal concerns.

Table 14. Table of known invasive species and feedback on their management.

SPECIES	FEEDBACK
Horn snails	This is not a significant management concern. Native crabs affect horn snail survival.
Ascidians	Not very much of a management concern. Among bryozoans, sponges, and ascidians, ascidians are of highest concern due to their rapid growth and potential to smother young oysters and seagrass, leading to significant mortality.
Sponges	This is not a significant management concern.
Orange bryozoan	This is not a significant management concern.
Slipper shells	This is not a significant management concern in the coastal estuaries. They are more abundant in Puget Sound.
European Green Crab	In March 2024, a paper was submitted to the Aquaculture Research journal on the effects on commercial clams in coastal estuaries ("Recruitment and losses through the life cycle of two intertidal clam species in Willapa Bay, Washington"[27]). The impact and management of EGC are currently actively being explored. There are several recent publications.
Eastern mud snail	Widespread. This is not a known predator, but the feeding habitats of newly hatched snails are not documented. There is a need for further work given that they are widespread and overlap with clam farming.

27 https://onlinelibrary.wiley.com/doi/10.1155/2024/7411697?af=R&msockid=3b9e835e1c476be318f596171dfd6af0

SPECIES	FEEDBACK
Burrowing shrimp	There is collaborative work with industry and agencies on large scale experiments for mechanical control. A manuscript that should be ready in 2024 will discuss the various ways to mechanically control burrowing shrimp. Very few have been successful. This represents a critical data gap, particularly due to its substantial implications for aquaculture interests and its significant economic impact. Willapa-Grays Harbor Estuary Collaborative[28] provides information[29] on burrowing shrimp control, including chemical control strategies.

Feedback on importance: The harmful nature of invasive and pest species is well-established, necessitating effective management strategies. Existing approaches to managing established populations are typically well-documented from experiences in other regions. However, there is a critical gap in impact studies that are necessary to inform resource allocation and the development of targeted management objectives.

Effect of environmental parameters on invasive species and pests. The impact of environmental parameters, aside from pest species, remains poorly understood. However, there is some knowledge about how invasive species respond within their distribution. For example, research has focused on how certain species, like oyster drills, respond to specific stressors, such as changes in salinity.

The impact of climate change on invasive aquatic species (AIS) is also uncertain, but generally, warming waters and other factors that reduce the reproductive capabilities of native species may create opportunities for invasives to thrive. Studies have shown that the distribution of EGC, for instance, has expanded with rising temperatures. While extreme water temperatures can make species vulnerable, particularly at the high end, such extremes are unlikely in Washington. Similarly, temperatures cold enough to significantly impact native species are improbable, as their tolerance ranges are quite broad.

Understanding the environmental thresholds and tolerance levels of species depends largely on the funding allocated to research and management efforts, which is often unevenly distributed. Currently, significant attention is given to species like EGC, zebra mussels, and northern pike, but not all thresholds are fully understood. For instance, more research is needed on the larval stage of EGC along the coast because larvae are particularly vulnerable to predation and extreme conditions during their free-floating phase. Further modeling is also essential to better understand their dispersal patterns from California. While some species have well-documented thresholds and management strategies, others, such as ascidians, have received little attention and research. Tunicates in Washington represent a key area for further research. There is currently no dedicated funding for invasive tunicate management.

Feedback on importance: Understanding how environmental variations affect species abundance is crucial. As this will be species dependent, species identification is the first step.

[28] https://wghec.org/resources-and-publications/
[29] https://wghec.org/wp-content/uploads/2024/01/WGHEC.BSM_.pdf

However, from a regulatory and management perspective, this information is not as important as others. Anything that moves can transport invasive species and introduced species are inherently adaptable, capable of colonizing both heavily and lightly impacted environments. Economic and environmental impact studies for existing invasive and pest species are more pertinent than understanding their environmental preferences.

Identification of invasive species and pests. Aquatic invasive species fall under either prohibited or regulated categories, with three tiers: Prohibited levels I, II, and III, and Regulated types A, B, and C. The most severe category, prohibited level I, includes zebra mussels. These species are a high invasive risk and are a priority for prevention and expedited rapid response management actions. For regulatory information, please refer to Chapter 77.135 RCW[30] and Chapter 220-640 WAC[31].

The WA Invasive Species Council published a document[32] listing 50 priority invasive species, both aquatic and terrestrial, that pose the greatest threat to Washington's environment, economy, and human health. Not all are currently present in Washington. Other resources are also available. The study "Trends in marine biological invasions at local and regional scales: The Northeast Pacific Ocean as a model system"[33] documented 43 non-native species (both plants and animals) in coastal estuaries.

Identification method: Depending on the species, identification methods vary from visual identification to DNA analysis. Misidentifying species has led to significant issues, such as mistaking high-risk Aquatic Invasive Species (AIS) for native species and vice versa. Current protocol mandates confirmation of identity by two experts: one from WDFW and another from an independent lab. However, finding experts proficient in species identification, especially cryptic ones that closely resemble native species, can be challenging. Despite these challenges, the protocol has generally proven successful.

Identification efforts: A few publications from the early 1990s, including the Puget Sound expedition in 1998, discussed rapid assessments of nonindigenous species in Washington. Some of this data contributed to the study "Trends in marine biological invasions at local and regional scales: The Northeast Pacific Ocean as a model system."[34] There has been no strategic sampling approach since then.

While there are no current regular monitoring efforts to identify new species, there are identification efforts. The first is the Early Detection Monitoring program, which is often dictated by specific AIS funding. Priority species include zebra mussels, quagga mussels, and

[30] https://app.leg.wa.gov/RCW/default.aspx?cite=77.135
[31] https://apps.leg.wa.gov/WAC/default.aspx?cite=220-640
[32] https://invasivespecies.wa.gov/invasive-species/our-priorities/
[33] https://www.researchgate.net/publication/226212871_Trends_in_marine_biological_invasions_at_local_and_regional_scales_The_Northeast_Pacific_Ocean_as_a_model_system
[34] https://www.researchgate.net/publication/226212871_Trends_in_marine_biological_invasions_at_local_and_regional_scales_The_Northeast_Pacific_Ocean_as_a_model_system

EGC. The second is the reporting of non-native species by the public to the WA Invasive Species Council. A significant data gap exists in predicting which AIS poses a threat to Washington. Modeling potential new invasions is challenging and often uncertain. Helpful tools such as horizon scanning are available. Horizon scanning is an evidence-based process that combines risk screening and consensus building to identify threats.[35] It is a valuable tool to prioritize invasive species management and prevention. *Id*.

Feedback on importance: Addressing data gaps related to invasive species begins with accurate species identification. With the use of tools like horizon scanning, species identification is generally achievable and well-understood. However, taxonomic and genetic laboratories often face funding limitations that hinder effective identification.

Offshore wind data gaps

- Pathways and points of introduction of invasive species and pests through offshore wind activities
- Monitoring and mitigation of invasive species and pests with offshore wind activities
- Effect of offshore wind on distribution and abundance of invasive species and pests

Pathway and points of introduction of invasive and pest species through offshore wind activities. In particular, offshore wind development may introduce invasive and pest species through two pathways: watercrafts and marinas. First, managing offshore wind systems will involve vessels from various locations, making it challenging to ensure these structures remain free of aquatic invasive species (AIS). Second, AIS can spread through marinas; for instance, a tunicate present in one marina may attach to a boat and subsequently be transported to another marina. However, many of these species are already widely distributed. Non-native species are commonly transported by existing water and vessel traffic. Further movement through offshore wind activities is unlikely to significantly alter their distribution. Moreover, the survival of these species will depend on specific environmental conditions being favorable for their establishment.

Feedback on importance: To manage invasive species, understanding the pathway and points of introduction of invasive and pest species through offshore wind activities is a priority.

Monitoring and mitigation of invasive species and pests through offshore wind activities. The monitoring and mitigation requirements for offshore wind projects is unknown. Plans for long-term monitoring and mitigation of AIS will need to be developed and adequate funding will be necessary to explore effective mitigation strategies. Experts anticipate that each entity involved in offshore wind projects will be expected to have a monitoring and mitigation plan, an AIS rapid response plan, and a state management plan in place.

[35] https://www.usgs.gov/publications/identifying-invasive-species-threats-pathways-and-impacts-improve-biosecurity

Feedback on importance: No specific feedback provided.

Effect of offshore wind on the distribution and abundance of invasive species and pests. The effect of offshore wind on species distribution and abundance will vary by species. The potential influence of offshore wind structures on AIS depends on their function as fish aggregating devices (FADs) for both AIS and native species, the specific fish species present and their dietary habits, and the interactions between native species and AIS. These dynamics could result in both positive and negative outcomes for AIS.

Feedback on importance: No specific feedback provided.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Natural dispersal method, pathways, and points of introduction of invasive species and pests
- Spatial distribution of invasive species and pests
- Biology of invasive species and pests
- Abundance and trend of invasive species and pests
- Communication of aquatic invasive species

Natural dispersal method, pathways, and points of introduction of invasive species and pests. The natural dispersal methods of invasive and pest species are well-documented in numerous publications. For example, some of these species possess planktonic larvae, while others do not. Among those with planktonic larvae, some remain in the water for less than three days, while others can stay for up to three months, significantly influencing their dispersal potential. The basic life cycles of these non-native and pest species are well understood.

Human activities have been known to disperse species like European green crabs, zebra mussels, and quagga mussels beyond their natural dispersal range. Any object or activity that comes into contact with water can serve as a potential pathway or vector for species introduction. Various potential vectors exist, including, but not limited to, seaplanes, schools, aquariums, live seafood pet trade, hydro facilities, dam operations and maintenance, and barges. Historically, pet trade was primarily associated with items sold; however, invasive and pest species have been found to hitchhike. For example, zebra mussels were discovered on an aquarium plant in a pet store. Additionally, humans serve as vectors for species introduction. Individuals conducting surveys in water bodies often wear waders and boots. These items represent high-risk vectors for spreading invasive species and require decontamination before entering another body of water.

Boats brought to Washington can also introduce new species, and inspections have recorded the invasive species found on watercraft. Private and smaller vessels generally pose a lower risk. In particular, ballast water and trailer watercraft are the most prevalent vectors. Substantial funding is dedicated to studying these pathways. Since 2011, there has been a strong understanding of ballast water's role in spreading invasive species, with data on the volume of ballast water discharged, emerging trends, and management methods, as well as their efficacy. Although quantifying the effectiveness of these strategies is challenging, a wealth of information is available. Risk is assessed qualitatively, with higher volumes of ballast water, larger wetted surface areas, and longer exposure increasing the risk. Vessel voyage profiles and operations are also considered, with inspectors using risk matrices for evaluation.

Compared to ballast water, there is less understanding of biofouling. There are no estimates regarding species movement due to insufficient data from industry participants. Efforts are underway to identify marine service providers to improve data collection in this area. However, it is recognized that the risk of introducing invasive species is influenced by seasonal variations. For example, there is decreased tanker traffic during inclement weather. Summer, on the other hand, marks the cruise ship season, characterized by fast-moving vessels with extensive wetted surfaces. While these ships are generally well-maintained, they are allowed to clean their hulls in Washington, which could make them significant vectors for invasive species. Additionally, summer sees increased activity from super yachts, some of which arrive unexpectedly, complicating regulatory and management efforts, especially concerning ballast water. Similarly, reefers—large fishing vessels equipped with flow-through systems for live fish—occasionally anchor in the Strait of Juan de Fuca during the summer.

Beyond seasonal factors, vessel traffic patterns are also influenced by economic conditions such as labor strikes, longshore labor issues, and embargoes, which can alter the origins of vessels and shift risks associated with the introduction or spread of invasive species. Technological advancements, such as the implementation of ballast water treatment systems in 2017, can further affect these risks.

Spatial distribution of invasive species and pests. The availability of data on spatial distribution varies by species and is influenced by funding, which affects the depth and continuity of monitoring efforts. For example, coastal monitoring has primarily focused on European green crabs (EGC), with data collected since the late 1990s, along with some limited public reports. In contrast, there is no spatial data for hornsnails, which have expanded their distribution since their introduction in 2004 and are now found throughout coastal estuaries. Expanding monitoring to include prohibited and regulated species could be beneficial.

There is also an interest for a comprehensive map of all AIS. The United States Geological Survey (USGS) maintains the Nonindigenous Aquatic Species Database, a research-based national database for AIS. WDFW is interested in supporting this database by providing all confirmed detections of AIS to USGS. While detections are shared typically on an annual basis, there is a lag of about a year and a half. There are plans to expedite this effort.

Despite the interest in spatial data, there is ongoing debate about making spatial data on AIS available. If AIS is detected in a specific area such as a private lake, there are typically no issues with making that information public. However, the situation becomes more complex with species that may be at private beaches and effectively managed by growers. Sharing precise coordinates raises privacy concerns. There are also concerns about the potential misuse of information, especially if regulations for their control are lacking. For instance, placing signage at lakes to indicate the presence of northern pike might encourage anglers to catch and kill them, reframing northern pike as a fishery rather than an invasive species. Anglers may also be motivated to catch them and transfer them to another lake, potentially spreading them beyond their current boundaries. Similarly for the coast, in the absence of regulations prohibiting the transportation of invasive species, people could inadvertently facilitate the spread of invasive species.

Biology of invasive and pest species. Understanding the biology of invasive and pest species varies significantly. Research efforts are heavily dependent on funding and available resources. Some species, like the Chinese mitten crab, are well-studied due to their high impact in areas such as California. EGCs also have well-documented seasonal and reproductive patterns, with ongoing research at the University of Washington focusing on larval dispersal and the genetic origins of populations. In contrast, comprehensive studies on species like tunicates and sponges often begin only after they become problematic and funding is allocated. This challenge is compounded by the sheer number of species; any non-native species that establishes and reproduces in a new environment can potentially become invasive.

Abundance and trend of invasive and pest species. The availability of data on the abundance and trend of invasive and pest species depends on the species. Monitoring along the coast is primarily focused on EGCs. Data on EGC has been collected since the late 1990s.Since 2018, EGC abundance has significantly increased, likely due to the establishment of a self-reproducing population. There is robust data on the situation. Another species with available data is burrowing shrimp. Sea Grant compiled local knowledge, revealing their widespread expansion as well as their disappearance from certain areas. However, the reason for this shift remains unclear and currently a topic of research. In contrast, there are significantly less data for species such as tunicates. Although valuable information was collected during previous infestations of invasive tunicates, that funding is no longer in place, and there is currently no active research or management efforts focused on them. To fill this gap, prohibited and regulated species could be reviewed to identify those that should be included in monitoring efforts.

Trend data can be queried, with the availability of records depending on the species. Monitoring began in the early 1990s, but data gaps are likely present.

Communication of aquatic invasive species. There is a disproportionate focus on information collection rather than dissemination. It is essential to raise awareness about AIS among both professionals and the public. Within departments, staff should be educated on decontamination protocols and the risks of species release. The public also plays a crucial role and must be informed about these protocols and risks. Social media, which was instrumental in Idaho's campaign to control AIS and enable rapid responses, could be an effective tool for raising awareness.

Offshore wind data gaps

- Effect of electromagnetic fields on invasive species and pests from offshore wind infrastructure
- Effect of disturbance from offshore wind on invasive species and pests
- Effect of offshore wind structure on invasive species and pests
- Effect of shift in water circulation from offshore wind on invasive species and pests
- Effect of port enhancement on invasive species and pests

Effect of electromagnetic fields on invasive species and pests from offshore wind infrastructure. The effect of electromagnetic fields (EMF) on invasive and pest species is a data gap. There is no known research on this matter. It is conceivable that EMF could have effects.

Effect of disturbance from offshore wind on invasive species and pests. This is a data gap. “Disturbance” is a complex ecological term. Terrestrially, any disruption can lead to intended or unintended consequences for nearby plants and animals, potentially serving as a pathway. Similarly, offshore wind activities may create pathways or affect existing marine populations through disturbance. Generally, any fluctuations in oxygen or sunlight levels generally affect both native and invasive species. Effects will depend on the species, the location of offshore wind facilities, and whether the species are in the intertidal or the pelagic zone. Influence on estuarine species is unlikely.

Effect of offshore wind structure on invasive species and pests. The effect of offshore wind structures will vary by species. Thorough decontamination will be essential before deploying any structures. Introducing new installations could also create suitable habitats for AIS that were previously absent. Many AIS are found in marinas due to the presence of artificial structures, and offshore wind installations may similarly serve as artificial habitats. These structures will feature additional wetted surfaces, whether they are spar-buoys, tension legs, or barge-mounted platforms, which could become prime habitats for invasive species.

Ensuring these structures remain free of AIS poses a significant challenge. Species that attach to structures may proliferate, especially in niche areas like chains and chain lockers, necessitating targeted management strategies to prevent invasive species from attaching to structures and breaking off to float freely. Considerations include implementing internal seawater systems with marine growth prevention technologies, using sacrificial anodes to deter corrosion and biofouling, and employing ballast water treatment methods. Cleaning barges can also present challenges due to sedimentation. Additionally, the type of surface treatment, including paint, will be critical. Structures may also inadvertently create catchment areas for marine debris, allowing potential species to raft on these debris.

Additionally, offshore wind activities may also attract AIS through human activities like watercraft operations which may originate from various locations. AIS have historically spread via marinas. A tunicate may attach to a boat at one marina and be transported to another. In this way, invasive species confined to one area could potentially spread outside, especially ascidians, bryozoans, and sponges.

Effect of shift in water circulation from offshore wind on invasive species and pests. There have been studies that examined how different currents affect both native and invasive species, but significant data gaps remain. The effect on AIS will largely depend on the species involved and the location of offshore wind structures. For example, EGCs behave differently inland compared to the coast. Inland, human interactions may have greater influence on dispersal patterns. Along the coast, there is a natural dispersal from the south. Any changes to currents—such as circulation and upwelling—can have either positive or negative effects on dispersal, even if these changes are localized and temporary.

Additionally, water flow around structures can create favorable conditions for capturing larvae and aiding their settlement through eddy formation. However, strong currents can dislodge organisms and carry them downstream. Understanding the local flow dynamics and boundary layer effects around these structures, as well as the downstream consequences, is essential. It is important to determine the expected flow patterns, identify areas where organisms are likely to break off and accumulate, and assess the effects on the shoreward side. Existing modeling studies may provide valuable insights into accumulation patterns and help direct future research efforts.

Lastly, if offshore wind affects water circulation and upwelling, it may influence the food supply available to invasive and pest species.

Effect of port enhancement on invasive species and pests. Offshore wind projects may require the enhancement of existing ports. The extensive dredging and construction that may be involved can disturb habitats and facilitate the introduction of invasive species. Additionally, this work will involve large vessels which pose their owns risk for introducing invasive and pest species. Enhancements may also include the construction of additional docks, creating more structures vulnerable to fouling organisms. The origin and transportation of equipment will be crucial. For instance, a major barge rental company in Seattle poses a significant risk for AIS introduction due to its extensive operations. Utilizing such equipment for port enhancements could potentially introduce or spread AIS to both nearby and distant locations. Robust prevention protocols and heightened awareness are essential, as even wading boots can act as vectors for AIS.

Offshore aquaculture data gaps

- Effect of added nutrients, wastes, and chemicals from offshore aquaculture on invasive species and pests
- Effect of offshore aquaculture structure on invasive species and pests
- Effect of parasites from offshore aquaculture on invasive species and pests
- Effect of escapement on invasive species and pests

Effect of added nutrients, wastes, and chemicals from offshore aquaculture on invasive species and pests. Invasive species often thrive in conditions that native species cannot tolerate, especially in disturbed or stressed habitats. Offshore aquaculture can significantly alter environments by introducing nutrients, wastes, and chemicals, creating favorable conditions for invasives. This can enable invasive species to outcompete native species and perform better in this altered ecosystem.

Effect of offshore aquaculture structure on invasive species and pests. The presence of artificial structures provides species with new habitats, enhancing their establishment and spread. Offshore net pens, support vessels, and other structures can become fouled and harbor invasive species.

Decontamination of equipment is essential for all ocean uses. Understanding the effect of offshore aquaculture structures on invasive and pest species requires detailed information on factors such as location, structure type, vessel traffic, cleaning protocols, and the species to be cultivated. Key considerations include whether the proposed structures will be a net pen or fully submerged, their depth, and the frequency with which they are cleaned by divers. Additionally, capturing effluents from cleaning and responding to breakages are crucial considerations. The type of anchoring structures used, and their maintenance or replacement schedule also play a role. Furthermore, evaluating how the added structures will alter water flow is essential for assessing their ecological impact. Changes in flow caused by stationary structures may either promote or deter marine growth.

Effect of parasites from offshore aquaculture on invasive species and pests. Disease and parasites pose major risks, particularly in open systems where containment is lacking. High concentrations of any single species can lead to increased parasite loads, including non-native parasites. Washington has invasive shellfish diseases, and resources like the RCO's "Safeguard Our Shellfish" page[36] provide valuable information on this issue. It is crucial to identify which marine parasites are present in Washington that are not native to the region, as well as whether the cultivated species are part of their life cycles. However, the effects of parasites from aquaculture fish on native species remains unsettled, highlighting the need for further research in this area.

Effect of escapement on invasive species and pests. Concerns about escapement primarily focus on the impact of non-native organisms, especially due to genetic or species differences. Understanding the effects of cultivated species is crucial, as raising any species carries risks, particularly during outbreaks. For example, escaped Atlantic salmon can transmit diseases to Pacific salmon and compete for resources. Escaped farmed species may also introduce new diseases and parasites, though evidence for aquatic species remains limited. Additionally, farmed species can facilitate the spread of invasive species. The New Zealand mud snail, for instance, thrives in high salinity and may survive ingestion by fish. To mitigate these risks, effective measures must be implemented to prevent escapement and ensure that any escaped organisms cannot reproduce.

[36] https://invasivespecies.wa.gov/campaigns/safeguard-our-shellfish/

Resources

Table 15. Resources relevant to animal invasive species and pests.

NAME	ACCESS	TYPE	DESCRIPTION
Bang for buck: cost-effective control of invasive species with different life histories	https://depts.washington.edu/jlrlab/PDF/2005_EcoEcon.pdf	Published article	Combines biological population data with economic costs to find the least costly strategy to prevent the further growth of an established invader.
Comparing residence time and natural enemies between low- and high-density invasions	https://link.springer.com/article/10.1007/s10530-018-1776-2	Published article	Investigates how residence time and natural enemies differ between two introduced populations of the intertidal snail, *Batillaria attramentaria*.
Impacts of invasive oyster drills on Olympia Oyster (*Ostrea lurida* Carpenter 1864) recovery in Willapa Bay, Washington, United States	https://shellfish.memberclicks.net/assets/docs/buhle%20%20ruesink%202009.pdf	Published article	Investigates the potential role of two introduced predatory gastropods in limiting Olympia oyster recovery.
Marine Clams	https://invasivespecies.wa.gov/priorityspecies/marine-clams/	Website page	Provides information on marine clams, including their characteristics, photographs, how to stop their spread.
Nonindigenous Aquatic Species Database	https://nas.er.usgs.gov/	Database	A centralized repository for spatially referenced biogeographic records of introduced aquatic species. The program offers scientific reports, real-time online queries, spatial datasets, distribution maps, and general information.

NAME	ACCESS	TYPE	DESCRIPTION
Positive effects of a dominant invader on introduced and native mudflat species	https://www.int-res.com/articles/meps2005/289/m289p109.pdf	Published article	Explores how horn snails support hermit crabs by providing shells and promoting *Zostera japonica* growth.
Reconstructing the range expansion and subsequent invasion of introduced European green crab along the west coast of the United States	https://www.researchgate.net/publication/227051756_Reconstructing_the_range_expansion_and_subsequent_invasion_of_introduced_European_green_crab_along_the_west_coast_of_the_United_States	Published article	Uses oceanographic data to model larval transport along the West Coast. Timing of release and seasonal currents affected distances traveled.
Recruitment and Losses through the Life Cycle for Intertidal Clams in Willapa Bay, Washington	https://onlinelibrary.wiley.com/doi/10.1155/2024/7411697?af=R&msockid=3b9e835e1c476be318f596171dfd6af0	Published article	Evaluates the potential limiting factors that affect the life stages of Manila clams and softshell clams in Willapa Bay, WA.
Status of the European Green Crab, Carinus maenas, (aka 5-spine crab) in Oregon Estuaries.	https://ir.library.oregonstate.edu/concern/technical_reports/73666d40c	Technical report	Compilation of trapping data for the European Green Crab from various sources and estuaries.
Trends in marine biological invasions at local and regional scales: The Northeast Pacific Ocean as a model system	https://www.researchgate.net/publication/226212871_Trends_in_marine_biological_invasions_at_local_and_regional_scales_The_Northeast_Pacific_Ocean_as_a_model_system	Published article	Analyzes patterns of marine invasion success in the cool temperate waters of the Northeast Pacific Ocean.
Washington Invasive Species Council	https://invasivespecies.wa.gov/invasive-species/our-priorities/	Webpage	Information on invasive species management priorities.

NAME	ACCESS	TYPE	DESCRIPTION
Willapa-Grays Harbor Estuary Collaborative	https://wghec.org/	Website	Provides information on the Collaborative's work to increase the resilience of communities and ecosystems in Washington's southwest coastal estuaries.
Willapa-Grays Harbor Estuary Collaborative: Burrowing Shrimp Management in Willapa Bay and Grays Harbor	https://wghec.org/wp-content/uploads/2024/01/WGHEC.BSM_.pdf	Report	Reviews the history and strategies informing burrowing shrimp management.

Data Gaps for Plants

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to plant invasive and pest species:

General data gaps

- Spatial distribution of invasive species and pests
- Identification of invasive species and pests
- Abundance and trend of invasive species and pests
- Effect of invasive species and pests on businesses
- Effect of invasive species and pests on ocean acidification

Due to a tie between multiple data gaps, there are seven key data gaps identified for this topic.

Spatial distribution of invasive species and pests. At the state level, there may be a lack of comprehensive spatial distribution of invasive species and pests. Current survey efforts are insufficient to determine the distribution and density of these species across various areas. While the state has the capacity to monitor invasive species, multiple agencies conduct their own surveys, making it challenging to compile a complete dataset that accurately reflects their presence throughout the region. For instance, the Department of Natural Resources (DNR) has access to certain spatial data and employs remote sensing to track aquatic vegetation. Despite this current limitation, collaboration with partners is improving year by year and various tools are being used such as ArcGIS. DNR is working with the Department of Agriculture, which possesses extensive invasive species data, to create a standardized approach for county coordinators, Tribes, and other entities to collect and share data effectively.

Counties may possess some information regarding their portion of the coastline, including basic maps that indicate the presence of certain species. There is potential to collaborate and develop a comprehensive master map. However, they often lack specific data points that detail the locations of infestations. Funding and resources are limited for counties, which impacts their capacity to collect data and share resources effectively.

Understanding what invasive species and pests are present is a significant data gap. Currently, there is a higher priority for tracking species that are uncommon but pose greater threats. There is a need to identify what flora and fauna are present—both native and non-native—and what that landscape looks like. For instance, annual species may only be visible for certain months before disappearing. This information is crucial for developing spatial data. Additionally, for more widespread species like Scotch broom, the sheer volume makes data collection challenging, leaving significant gaps in information.

Feedback on three particular species is provided below:

***Zostera japonica* (*Z. japonica*):** *Z. japonica* typically thrives in shallow waters, around 0 meters (mean lower low water, MLLW) or shallower, with some observations as deep as -1 foot. Its only occurrences along the coast are in Willapa Bay and Grays Harbor. The Department of

Natural Resources (DNR) has compiled reports on *Z. japonica*, though these do not encompass all estuaries. While there is a general understanding of *Z. japonica* in these areas, additional data may be available such as this mapping effort: [Change in productivity associated with four introduced species: ecosystem transformation of a "pristine" estuary][37]. Some of the work differentiates between *Zostera japonica* and *Zostera marina*, based on tidal elevation, specifically whether the plants are found above or below 2 feet.

Spartina: There are 201 mapped sites, with data current through 2018. The distribution was carefully documented during its increase phase, and there is information on section, range, and township. More comprehensive surveys are planned. However, there are concerns that making accurate spatial data publicly accessible could potentially result in its unintentional spread. Detailed data could be made available through a FOIA request.

Knotweed: The data on knotweed is outdated, dating back before 2018. Plans are in place for more thorough surveys to update this information.

Feedback on importance: Currently, there is a lack of comprehensive spatial data, leaving the extent of infestation largely unknown. Unfortunately, this critical information often becomes available only after it's too late to take action. Conducting surveys is essential to accurately determine the locations of infestations and validate reported sightings.

Identification of invasive species and pests.

Data on identified invasive species: It's unclear what data individuals possess, making it difficult to determine which species information is available. Many departments conduct surveys and species counts to address this gap. For example, the Early Detection and Distribution Mapping System[38] (EDDMapS) is an early detection reporting app that collects data from the public, which is then verified by a dedicated team. This data is publicly accessible for viewing. Additionally, sources such as "Trends in marine biological invasions at local and regional scales: The Northeast Pacific Ocean as a model system"[39] document 43 non-native species—both plants and animals—in Willapa Bay. Since then, an additional four animal taxa have been identified and reported as non-native species through the DFW's reporting link for record-keeping purposes.

Species identification method: The identification of invasive species and pests is generally effective. When an unfamiliar specimen is observed, samples can be collected and identified with the assistance of experts. If necessary, these samples may also be forwarded to a laboratory for further analysis. Established processes for genotyping and species identification are in place. However, some cryptic species are challenging to distinguish from their native counterparts, and only a few individuals possess the expertise to identify them accurately.

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37 https://www.researchgate.net/publication/236027531_Change_in_productivity_associated_with_four_introduced_species_ecosystem_transformation_of_a_pristine_estuary

38 https://www.eddmaps.org/

39 https://www.researchgate.net/publication/226212871_Trends_in_marine_biological_invasions_at_local_and_regional_scales_The_Northeast_Pacific_Ocean_as_a_model_system

Furthermore, there are limitations in recognizing species that may have recently undergone mutations.

Species identification efforts: There were a couple of publications from the early 1990s (Puget Sound expedition 1998) that conducted a rapid assessment of nonindigenous species in Washington. Some of this information was included in the publication "[Trends in marine biological invasions at local and regional scales: The Northeast Pacific Ocean as a model system](https://www.researchgate.net/publication/226212871_Trends_in_marine_biological_invasions_at_local_and_regional_scales_The_Northeast_Pacific_Ocean_as_a_model_system)."[40] However, there hasn't been a strategic sampling approach implemented since then.

There is currently no regular effort to monitor for new species. Furthermore, it remains unclear how frequently samples are collected from marine plants compared to those that wash ashore or are observed along the shoreline. There appears to be a lack of dedicated focus on marine plants, and it is uncertain whether personnel would venture into the water to assess invasive species and pests in aquatic environments. Nonetheless, a monitored species list is maintained. When agencies or the Noxious Weed Board observe plants in unexpected locations, they initiate monitoring of those species. Each year, these plants are evaluated and assigned a rating. There are individuals specifically trained to identify out-of-place species and to classify them accurately. Surveys are typically conducted in areas of concern based on the proximity of known invasive sites. For example, when reviewing a 1,000-acre area on a map, attention is directed toward confirmed locations of invasive species, which often reveals suspicious gaps that require further investigation.

Feedback on importance: This data gap is important to address as species are often not identified until it is too late.

Abundance and trend of invasive plant species. Emerging technologies, such as drone imaging, provide innovative monitoring options that could transform the practices used to assess the abundance and trends of invasive plant species.

Spartina: The current abundance of spartina is low, and trends have been thoroughly documented since the 1980s.

Z. japonica: The Department of Natural Resources (DNR) published findings in 2010 in a report titled "[Distribution and potential effects of a non-native seagrass in Washington State](https://www.dnr.wa.gov/publications/aqr_zostera_study.pdf)"[41]. This report indicated high abundance and stability of *Z. japonica*, estimated to cover approximately 10% of Willapa Bay.

Feedback on importance: Data gaps exist regarding the abundance and trends of invasive species and pests. There is uncertainty about their current locations and the directions in which they are moving. Additionally, it remains unclear whether their populations have stabilized or continue to increase.

[40] https://www.researchgate.net/publication/226212871_Trends_in_marine_biological_invasions_at_local_and_regional_scales_The_Northeast_Pacific_Ocean_as_a_model_system

[41] https://www.dnr.wa.gov/publications/aqr_zostera_study.pdf

Effect on invasive species and pests on businesses. Key inquiries for managing invasive species and pests include their economic impact on the community, whether the species meets the true definition of an invasive species, and the naturalization threshold.

Coastal communities face various challenges due to invasive species and pests. Spartina poses a significant threat to shellfish growers and the industry, prompting substantial eradication efforts. Additionally, cranberry growers contend with scotch broom encroaching on valuable land. The tourism industry and state parks also grapple with scotch broom and gorse, which obstruct access to trails and beaches, complicating navigation and limiting recreational activities.

Additionally, in Willapa Bay, *Zostera japonica* (*Z. japonica*) is expanding into sandy tide flats and bay sands, transforming the landscape into a vegetated environment. It is crucial to explore the implications of this change, weighing potential benefits against drawbacks. Questions arise about whether *Z. japonica*'s growth is economically detrimental or if it restricts access to species vital for harvesting. Furthermore, its role in providing habitat for crucial species like salmonids and forage fish, mitigating ocean acidification, and enhancing carbon storage and sequestration must be considered. These benefits should be considered in the context of the transformation of sandy tide flats into vegetative meadows. Limited funding constrains research on *Z. japonica*.

It remains unclear whether specific studies have examined the effects of invasive plant species on coastal economies. The economic impacts of most invasive species can often be inferred by examining experiences from other environments. Typically, once an invasive species becomes established, its effects on businesses and industries can be severe and long-lasting, necessitating stringent long-term control measures. Without effective management, invasive species can dominate ecosystems and create monocultures.

Feedback on importance: No specific feedback provided.

Effects of invasive species and pests on ocean acidification. There is a lack of data on the mitigation of ocean acidification by aquatic invasive plant species. Existing studies on eelgrass indicate minimal and localized effects, typically within meters rather than kilometers surrounding eelgrass beds.

Feedback on importance: Information on the effects of invasive species on ocean acidification is unavailable. Additionally, insufficient data exists regarding whether environmental changes such as ocean acidification will facilitate the establishment of invasive species.

Offshore wind data gaps

- Effect of shift in water circulation due to offshore wind on invasive species and pests

Effect of shift in water circulation due to offshore wind on invasive species and pests. If offshore wind alters water circulation or upwelling, it is unlikely to directly affect invasive species or pests, as they do not rely on water circulation for growth. Offshore wind may also increase wave energy, but this is unlikely to be a strong enough stressor to directly affect invasive species and pests. However, secondary effects downstream may arise from changes in nutrient distribution or the creation of new habitats. Additionally, vessel activities associated with offshore wind development may also have an effect. Studies have examined how ships and currents influence both native and invasive species.

In nearshore environments, estuaries are sensitive to shifts in upwelling. The effect on invasive species and pests within estuaries will depend on whether these shifts in water circulation will significantly affect primary producers, such as macrophytes.

Feedback on importance: No specific feedback provided.

Offshore aquaculture data gaps

- Effect of added nutrients, waste, and chemicals from offshore aquaculture on invasive species and pests

Effect of added nutrients, waste, and chemicals from offshore aquaculture on invasive species and pests. Plants are sensitive to nutrient availability and competition from phytoplankton blooms. Although invasive species can tolerate conditions that native species cannot or may outperform them, they may not immediately adapt to the environment associated with offshore aquaculture. Their normalization will depend on whether nutrient additions from aquaculture operations occur regularly or as one-time events. In some cases, there may be no discernible effect at all. In the dynamic ocean environment where offshore aquaculture may be located, added substances may disperse.

Nearshore, tides can transport nutrients, waste, and chemicals into the estuary, but the volume is likely to be relatively small compared to natural nutrient dynamics.

Feedback on importance: No specific feedback provided.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Management of invasive species and pests
- Natural dispersal method of invasive species and pests
- Effect of environmental parameters on invasive species and pests
- Biology of invasive species and pests
- Species that consume invasive species and pests
- Role of invasive species and pests in the trophic food web and its interaction with other species
- Effect of invasive species and pests on ecology
- Cost of management of invasive species and pests

Management of invasive species and pests. Managing invasive species involves maintaining populations at levels lower than they would reach without intervention. Instead of aiming for complete eradication, the focus is on reducing population density and distribution. It is crucial to understand the current species composition to determine management priorities and identify what is being prevented. This presents a challenging data gap. To begin with, there are two definitions of "invasive species." First, the term can refer to a species that aggressively outcompetes and colonizes an area where native species reside, displacing them, altering the ecosystem, and creating new dynamics within the food web. Another perspective considers whether the species impacts economic activities. This is why *Zostera japonica* (*Z. japonica*) is considered invasive, although there is insufficient data to definitively support this classification and there is disagreement on this classification. The Department of Natural Resources (DNR) does not have dedicated efforts to remove *Z. japonica* from State Owned Aquatic Lands, even within its Invasive Species Program. Moreover, the limited control methods available for *Z. japonica* are not effective.

It is imperative to thoroughly understand all aspects of the species before devising a management plan and assessing its controllability. Addressing this data gap requires:

> **Identifying the source of recruitment:** Understanding where the species is recruiting from enables managers to focus their efforts on those areas and investigate the means of introduction. If human activities facilitate recruitment, there may be opportunities for implementing control measures. Conversely, for example, if birds are the primary facilitators of recruitment, the challenge shifts to developing effective management strategies for this vector.
>
> **Understanding the reproduction and dispersal method:** There is a need to consider if a species dispersal is, for example, aggressive or prolific and if the spread can be controlled.
>
> **Identifying the control agent:** Many invasive species studies involve introducing a competitor or natural control agent from its native habitat. There are inherent risks in identifying and deploying natural control agents. For example, introducing a snail to control a plant may result with the snail itself becoming invasive and displacing native snails. There are similar numerous cautionary examples.

Overall, there is a fairly good understanding of how to manage invasive species. The state has been actively addressing invasive species for over 50 years, guided by a state code focused on noxious weed control. The WA State Noxious Weed Control Board oversees this effort, targeting nonnative plants that are invasive or economically dangerous, whether aquatic or terrestrial. Species like spartina, knotweed, and Japanese eelgrass are among those prioritized. The Board updates the state weed list annually and supports county boards in on-the-ground control efforts. Collaborations with other agencies facilitate coordinated projects, and there are education and outreach efforts which include distributing informational materials. Additionally, the Environmental Protection Agency (EPA) authorized Ecology to issue permits for treating these species in or near water. Ecology likely has detailed information on the species present, their locations, and the efforts to address them. While this data will not include tribal or federal efforts, it should cover about 90% of the activities in the state.

Established management systems and control procedures are in place statewide, with ongoing monitoring post-treatment to ensure eradication success. The approach varies depending on the species involved. When an infestation occurs, county authorities are engaged to identify the appropriate entity for control. There are integrated weed management plans to assess all aspects, including herbicides, biological agents, and manual control, to determine the most effective management methods. Effective strategies can differ based on factors such as the species' characteristics, available funding, whether the infestation is on private land, and responsibility for the affected area. Securing adequate funding remains a separate challenge.

There is an established methodology for managing shoreline habitat species; however, effective management of some species requires substantial funding and a dedicated workforce. While the management techniques are known, the challenge often lies in securing the necessary resources, funding, and staff for comprehensive invasive species control. For example, efforts to manage spartina have led to a significant reduction in plant numbers, particularly along coastal areas, with systematic management approaches in place. In some regions, eradication of the species is nearly complete.

Feedback on the management of three species was shared:

Spartina alterniflora: There is concern that spartina could lead to the formation of a monoculture, displacing native salt marsh plants and native spartina populations and reducing avian diversity. In Willapa Bay, long-term control efforts have relied on herbicide as an effective method to eliminate and prevent the return of spartina. This chemical control has been fairly effective for at least two decades. Spartina went from expanding at 20% per year in 2004 to only a few scattered plants remaining after 2007. It required a million-dollar investment annually to remove the last remnants of spartina, making it a costly effort. However, there are still gaps. Regular inspections are necessary because blooms occasionally occur in unexpected areas.

Sargassum muticum: Brown seaweed is known to compete with native seaweeds. It was documented in publications from the 1950s when it first entered Willapa Bay, raising concerns about its impact on oyster culture. While it is not common and observed rarely, it is recognized as an invasive species in the area.

Z. japonica: There is a good understanding of its introduction, spread, and effective management strategies. This species presents greater challenges for management than spartina. Currently, the Imazamox herbicide is approved for its removal. Some clam growers also employ mechanical control methods, like boat-towed fins or tractor-towed tillers. However, the shoots of this species are challenging to fully eradicate, as they can easily recolonize via branching and seeding.

Natural dispersal method of invasive species and pests. Understanding the natural dispersal methods of species is crucial, and these methods vary significantly between species. Most environmental factors that disperse invasive species and pests, such as wind, currents, and migratory birds, are well documented, with few data gaps. Additionally, for managed species, their dispersal methods, whether via seeds or rhizomes, are generally understood, with water often acting as the primary vector. Events that fragment these species can also facilitate their spread. However, the introduction pathways for all species are not fully understood, with more information available for terrestrial species than for submerged ones.

The primary pathway for introducing species into the state is through human transportation. Established roads, ports, and transportation systems facilitate the movement of invasive species more effectively than any other vector. Proposed activities must ensure they do not inadvertently act as pathways for invasive species. For instance, if activities involve ballast water or biofouling, it is essential to implement effective prevention methods.

One approach to addressing data gaps on the dispersal of invasive species and pests is to maintain ongoing monitoring of ornamental plants and aquatic foreign species. However, it is worth noting that many of these species cannot survive the cold winters of the Northwest. While they may persist for a period, subsequent seasons typically limit their populations. Consequently, while numerous species are introduced into the state, many are not invasive and do not cause significant harm. Additionally, many non-native species are successfully coexisting in balance with native species.

Feedback on the dispersal of three species were shared:

Z. japonica and *Spartina*: Both species disperse through seeds and rhizomes. Their biology is well-documented, with seeds identified as the primary mechanism for long-distance transport, typically considered to be distances of at least 10 kilometers. Seeds can be dispersed by animals, but water transport is likely the most common method. If seeds are located at the end of a stalk, the stalk can break off and facilitate seed dispersal. The seed lifespan for *Z. japonica* is approximately one year, while for spartina, this characteristic is less clear. Germination typically occurs in May each year, with seeds shedding from plants in August and September.

Additionally, *Z. japonica* can potentially adhere to parts of vessels and anchors and their fragments can also be dislodged by wave action. Birds foraging in nearshore areas can also uproot plant fragments, which may drift to suitable locations and establish new populations. It is uncertain whether birds consume *Z. japonica* seeds and transport them through migratory routes.

Knotweed: This species originally thrived in Asian tropical climates and adapted as it spread to Northern Europe and North America. It evolved from Japanese knotweed to a new species known as bohemian knotweed. While Japanese knotweed initially did not proliferate through seeds, bohemian knotweed can propagate through both seeds and fragmentation.

Effect of environmental parameters on invasive species and pests. The effects of environmental parameters on invasive species and pests can vary significantly depending on the specific species involved. Invasive species go through multiple life cycle stages, each with unique sensitivities to environmental conditions. Overall, the environmental conditions along the Washington coast are suitable for these species. However, the impact of environmental parameters on new invasions remains uncertain and is under constant monitoring.

Two ways to examine species relationships to environmental parameters are:

> **Ecological niche modeling:** This method uses existing distribution data to identify suitable environmental conditions. There is a good understanding of the ranges for both

native and non-native species, as well as the corresponding suitable environmental conditions.

Quantification of performance curves: The second approach involves quantifying performance curves, which measure how quickly a species grows or reproduces under different conditions. For example, a species might grow better at 16°C compared to 25°C, even though it can survive in both temperatures. From a management perspective, understanding these differences in vital rates is crucial for controlling a species. Key factors such as temperature, salinity, exposure to air, pH, and oxygen concentration would each require a performance curve. These curves may vary depending on the interaction with other variables. However, performance curves may not exist for all species; they are typically generated for commercially important species or major pests.

One environmental parameter that is not well understood is nutrient accumulation in watersheds and its impact on the success of invasive plants in that altered environment. Human activities introduce nutrient-rich materials into water systems, resulting in conditions where typically benign species such as algae, can become harmful. Another parameter that needs to be better understood is climate change. Climate change promotes the growth of specific species. Ongoing research is currently investigating the relationship between climate change and invasive species. While the results are not yet available, studies in this area are actively underway.

Below, the relationship of *Zostera japonica* (*Z. japonica*) with certain environmental parameters are provided. *Z. japonica* are native to the coast of Asia, where conditions can be highly saline and hot. Published manuscripts from regions such as Japan, Korea, and Southeast Asia provide valuable insights.

Habitat: *Z. japonica* thrives in sandy mud to sandy sediment environments. They do not survive in rocky areas. They cannot withstand prolonged exposure and thus, requires submersion, although not continuously throughout the day.

Salinity: *Z. japonica* can tolerate a broad range of salinity levels and exhibit similar or even wider tolerance than *Zostera marina* (*Z. marina*). Salinity tolerance ranges from 0 parts per thousand (ppt) (for short periods) to 36-40 ppt.

Temperature: *Z. japonica* can endure temperatures from freezing up to 40°C. It can survive freezing conditions as long as its rhizomes remain intact which are typically sheltered below the sediment surface.

pH: Their specific pH requirements are not well-documented, but it is likely that studies have been conducted on this aspect. *Z. japonica* can regulate the pH of its surrounding environment through photosynthesis, helping to mitigate ocean acidification effects and create a more suitable habitat for seagrass. pH levels for *Z. japonica* are expected to align closely with oceanic pH levels and may fluctuate diurnally due to photosynthesis activities. Information on pH preferences for *Z. japonica* may draw upon applied research conducted on eelgrass in its native range.

Biology of invasive species and pests. The biology of invasive plant species is well understood, typically down to the genetic level. For instance, the biology of *Z. japonica* and spartina are well understood. Their lifecycles, seasonality, and contribution of seeds to population dynamics are thoroughly documented.

Once a species is identified, information on its biology can be readily obtained. Knowing whether a species is perennial, annual, or biennial is crucial for determining effective control methods, and this classification is generally well-documented. While some research has been conducted in Washington, most of the biological insights are derived from peer-reviewed publications originating in its native range.

Species that consume invasive species and pests. One of the significant factors contributing to the impact of invasive species is often the absence of natural predators. Without dedicated studies on species that consume invasive plants, it's challenging to provide a definitive answer. For species like eelgrass, the focus is more on its role as habitat rather than its consumption. However, there is some published data available. For instance, ducks and geese have been observed to eat Z*. japonica*. European green crabs (EGC) are also known to have a detrimental impact on eelgrass, which in turn affects other native species that rely on eelgrass for habitat, such as salmonids and Dungeness crabs. It is plausible that humans can also consume the rhizomes and seeds of *Z. japonica*. Historically, there is evidence that Indigenous Tribes used *Zostera marina* (*Z. marina*) for consumption. They consumed the rhizomes of *Z. marina*, rich in starch and sugars, and used the seeds to make flour.

Spartina can be grazed, but its suitability for grazing varies by location and is generally not a significant occurrence. Some studies have investigated the use of nonnative leafhoppers for biological control; however, these efforts did not achieve sufficient control to be practical for effective management.

Role of invasive species and pests in the trophic food web and its interaction with other species. Research on the role of invasive plant species in trophic food webs and their interactions with other species requires further exploration. Invasive plants are believed to have negative impacts, as they often lack natural predators or environmental controls, allowing them to displace native ecosystems and species. One approach to studying this involves comparing two systems—one with *Z. japonica* and one without—to highlight differences in nutrient dynamics and assess the ecological impacts associated with the presence of this plant.

Effect of invasive species and pests on ecology. Significant data gaps exist regarding the impact of invasive species on ecosystems and their ecological dynamics. Available data is limited, and the specific effects can vary widely by ecosystem. Invasive species often degrade or even destroy original ecosystems, leading to ecological degradation and the formation of monocultures. Initial assessments may underestimate the severity of the problem, revealing broader infestations and more severe degradation upon closer examination—an issue frequently encountered in ecological studies. Research will need to be conducted to understand the extent of this degradation.

Cost of management of invasive species and pests. If the cost of management is $1 today, it may increase to $10 next week and rise to $100 in a month. If additional research or data were available to project future costs associated with managing an invasive species, this would enable a comparative analysis between current management expenses and anticipated future expenditures. This analysis could help interested or affected parties make informed decisions about resource allocation and strategic planning.

Offshore wind data gaps

- Effect of electromagnetic fields from offshore wind infrastructure on invasive species and pests
- Effect of disturbance from offshore wind on invasive species and pests
- Transportation of reproductive material of invasive species and pests by offshore wind
- Effect of offshore wind structure on invasive species and pests
- Effect of port enhancement on invasive species and pests
- Monitoring and mitigation of the effect of offshore wind on invasive species and pests
- Effect of offshore wind on distribution and abundance of invasive species and pests

Effect of electromagnetic fields from offshore wind infrastructure on invasive species and pests. This is a data gap. There is currently a lack of research on the ecological effects of electromagnetic fields (EMF). It remains uncertain whether EMF has any effect on invasive plant species and pests and the nature of those potential effects is also unclear. EMF may influence plant development, and it may create conditions more conducive to the survival of invasive species. Specific species like *Z. japonica* are expected to be unaffected.

Effect of disturbance from offshore wind on invasive species and pests. Understanding the effects of these disturbances is crucial, as they can influence the survival of nearby plants and animals and act as conduits for invasive species. For example, through disturbance, offshore wind activity can create pathways for invasive species and pests or affect existing populations. Disturbances often mobilize seeds and plant fragments, promoting the proliferation of existing vegetation. Disturbances via fluctuations in oxygen and sunlight levels can also affect both native and invasive species. Invasive species generally thrive in disturbed and open habitats.

The impact of a disturbance largely depends on its distance from shore. Disturbances occurring farther offshore are less likely to establish new populations and typically do not significantly affect estuarine environments. Additionally, the potential influence varies based on structural design, particularly whether surfaces are conducive to plant attachment (e.g., wood versus metal).

For nearshore disturbances offshore wind may cause, existing activities that cause disruption can offer valuable insights. Terrestrial disturbances have frequently resulted in the displacement of native flora, facilitating the establishment of invasive species. Similar to the spread of scotch broom in construction zones and other disturbed areas, major construction projects can disrupt the seabed and potentially promote the spread of invasive species.

Transportation of reproductive material of invasive species and pests by offshore wind. The effect of offshore wind on the transportation of reproductive material of invasive species and pests is a significant data gap. There is a potential for these operations to inadvertently transport reproductive material, which could pose ecological challenges. For example, servicing operations could facilitate the movement of invasive species to new locations. Unlike invertebrates, which may have planktonic larvae and therefore a higher risk of transport, rooted plants present a different level of concern. While it is unlikely that species from the shore would survive if transported offshore, the likelihood of survival depends on various factors, including whether the species can float, propagate at the water's surface, or attach to structures rather than the ocean floor. Assessing the potential for survival requires expertise tailored to each organism, as environmental conditions must be favorable for their persistence. Dredging activities can also transport species. Newly created islands often become dominated by invasive species such as phragmites. Addressing this data gap necessitates increased education and awareness among interested or affected parties.

Effect of offshore wind structure on invasive species and pests. The effect of offshore wind structures on invasive species and pests remains uncertain. Some invasive species may exploit these structures; for instance, English ivy secretes an adhesive substance that enables it to attach and potentially damage surfaces. The design of the structure will be a significant factor for this effect. However, the likelihood of establishment is expected to decrease with distance from shore, and if nutrient levels are insufficient, the structure may not facilitate successful establishment.

Additionally, if cables are installed from the beach to an offshore wind station or terminal, they are unlikely to affect invasive species or pests. Specifically, for *Z. japonica*, there are no known occurrences on the outer coast of Washington state. *Z. japonica* also requires sandy sediment for growth, and cables would not provide suitable substrate. If installed within estuaries, the cables will likely be positioned too deep to influence macrophytes, which typically occur in intertidal zones.

Effect of port enhancement on invasive species and pests. Port enhancement will certainly affect invasive plant species and alter local vegetation. The specific nature of this effect—whether positive or negative—is unclear.

Disturbances typically increase the presence of invasive species by mobilizing seeds and plant fragments. The impact of port enhancements on invasive species is expected to be similar to that of other construction projects. In terrestrial environments, native plants are often displaced by invasives after disturbances. The extent of the disturbance also affects the likelihood of invasive species establishment, with offshore areas being less prone to invasion. Additionally, if port enhancements involve sediment removal from tide flats, the effects on invasive species will depend on where the sediment is relocated and whether seeds are transported with it.

The potential for establishment may also vary depending on the structure. For instance, structures that provide suitable habitats for plant growth or use materials conducive to settlement (e.g., wood versus metal) could affect the likelihood of species establishment. The structure may also affect parameters like light availability. Typically, macrophytes do not thrive in shaded areas under docks.

The effect of boating activities related to port enhancement on invasive species and pests will depend on the species. Vessel activities are unlikely to affect Zostera japonica (*Z. japonica*), as this species typically thrives further inland and in shallower waters. Moreover, coastal areas such as Grays Harbor already experience significant shipping traffic.

Monitoring and mitigation of offshore wind effects on invasive species and pests. There is uncertainty regarding the monitoring and mitigation of offshore wind farms' effects on invasive species and pests. However, for non-native estuarine plant species, as long as offshore wind development takes place outside estuaries, offshore wind is expected to have minimal effects.

Effect of offshore wind on distribution and abundance of invasive species and pests. Offshore wind structures are unlikely to serve as habitat for macrophytes.

Offshore aquaculture data gaps

- Effect of offshore aquaculture structure on invasive species and pests
- Effect of parasites from offshore aquaculture on invasive species and pests

Effect of offshore aquaculture structure on invasive species and pests. There is insufficient data regarding the effect of offshore aquaculture structures on invasive species and pests; however, these structures are unlikely to have a significant effect. The design of the structures, particularly the availability of suitable areas for plant colonization, may influence the presence of invasive species. However, structures located farther from shore are generally less conducive to their establishment.

Effect of parasites from offshore aquaculture on invasive species and pests. There is lack of data on the effect of parasites on invasive plant species; however, it is unlikely parasites will have a significant effect. Generally, fish parasites do not influence plants and most parasites are species-specific. This specificity mirrors terrestrial parasites, which target specific plant species without affecting others in their vicinity.

Resources

Table 16. Resources relevant to invasive and pest plant species.

NAME	ACCESS	TYPE	DESCRIPTION
Changes in productivity associated with four introduced species: ecosystem transformation of a 'pristine' estuary	https://www.researchgate.net/publication/236027531_Change_in_productivity_associated_with_four_introduced_species_ecosystem_transformation_of_a_pristine_estuary	Published article	Examined changes in ecosystem function associated with introductions of non-native species into Willapa Bay.
Comparison of photosynthetic characteristics of the seagrass congeners *Zostera marina* L. and *Zostera japonica* Ascher. & Graeb.	https://www.sciencedirect.com/science/article/abs/pii/S0304377013001307?via%3Dihub	Published article	Compared the photosynthetic characteristics of *Z. japonica* and *Z. marina* after exposure to high and low light.
Competition and coexistence in a rare Northeastern Pacific multispecies eelgrass bed	https://www.researchgate.net/publication/354505019_Competition_and_coexistence_in_a_rare_Northeastern_Pacific_multispecies_seagrass_bed	Published article	Surveyed and manipulated a multispecies seagrass meadow in Willapa Bay.
Congener comparison of native (*Zostera marina*) and introduced (*Z. japonica*) eelgrass at multiple scales within a Pacific Northwest estuary	https://www.researchgate.net/publication/45500577_Congener_comparison_of_native_Zostera_marina_and_introduced_Z_japonica_eelgrass_at_multiple_scales_within_a_Pacific_Northwest_estuary	Published article	The congeners of *Z. marina* and *Z. japonica* were compared.

NAME	ACCESS	TYPE	DESCRIPTION
Development and validation of a habitat suitability model for the non-indigenous seagrass *Zostera japonica* in North America	https://www.reabic.net/journals/mbi/2016/2/MBI_2016_Shafer_etal.pdf	Published article	Developed a habitat suitability model to identify and predict areas at high risk for *Zostera japonica* invasion.
Distribution and potential effects of a non-native seagrass in Washington State *Zostera japonica* Workshop	https://www.dnr.wa.gov/publications/aqr_zostera_study.pdf	Report	Documentation of the discussions during a workshop on *Zostera japonica* on its distribution and species interaction.
Duration of temperature exposure controls growth of *Zostera japonica*: Implications for zonation and colonization	https://www.sciencedirect.com/science/article/abs/pii/S0022098114003372?via%3Dihub	Published article	Considered the influence of temperature on *Z. japonica* growth as a driver of vertical zonation.
Early Detection and Distribution Mapping System (EDDMapS)	https://www.eddmaps.org/	Website	A mapping system that documents invasive species and pest distribution.
Effects of salinity on photosynthesis and respiration of the seagrass *Zostera japonica*: A comparison of two established populations in North America	https://www.sciencedirect.com/science/article/abs/pii/S0304377011001033?via%3Dihub	Published article	Observed the photosynthetic and respiratory response of *Z. japonica* to a range of salinities.

NAME	ACCESS	TYPE	DESCRIPTION
Effects of salinity on survival of the exotic seagrass *Zostera japonica* subjected to extreme high temperature stress	https://www.degruyter.com/document/doi/10.1515/bot-2012-0144/html	Published article	To develop models that predict potential *Z. japonica* colonization, studied the response of *Z. japonica* to chronic, extreme temperature and salinity stress.
Effects of temperature, salinity, and seed age on induction of *Zostera japonica* germination in North America, USA	https://www.sciencedirect.com/science/article/abs/pii/S0304377015300024?via%3Dihub	Published article	Examined the effects of storage, induction temperature, salinity, and storage period on germination of *Z. japonica* seeds.
Population dynamics and control of invasive Spartina alterniflora: Inference and forecasting under uncertainty	https://www.researchgate.net/publication/225077947_Population_dynamics_and_control_of_invasive_Spartina_alterniflora_Inference_and_forecasting_under_uncertainty	Published article	Illustrated the use of statistical tools for invasive species management by doing a case study of smooth cordgrass invading Willapa Bay.
Trends in marine biological invasions at local and regional scales: The Northeast Pacific Ocean as a model system	https://www.researchgate.net/publication/226212871_Trends_in_marine_biological_invasions_at_local_and_regional_scales_The_Northeast_Pacific_Ocean_as_a_model_system	Published article	Using the Northeast Pacific Ocean as a model system, analyzed patterns of marine invasion success in cool temperate waters.

Marine Mammals

Key Data Gaps

General Data Gaps

- Abundance, distribution, health, and trend of marine mammals
- Sensitivity of marine mammals to habitat changes
- Effect of biotoxins and other naturally occurring threats on marine mammals

Offshore Wind Data Gaps

- Effect of offshore wind on marine mammal migration and distribution
- Risk of entanglement or collision with offshore wind

Offshore Aquaculture Data Gaps

- Effect of escapees from offshore aquaculture on marine mammals

Other Data Gaps

General Data Gaps

- Information from foreign countries on the effects of human activities on marine mammals

Offshore Wind Data Gaps

- Effect of offshore wind on marine mammal breeding and reproduction
- Effect of power transmission cables and electromagnetic fields of offshore wind on marine mammals
- Effect of offshore wind structures on marine mammals
- Effect of vibrations and noise from offshore wind on marine mammals
- Effect of surveying technology and methodology for offshore wind on marine mammals
- Effect of light from offshore wind on marine mammals

Offshore Aquaculture Data Gaps

- Effect of nutrients, waste, and chemicals from offshore aquaculture on marine mammals
- Risk of disease transmission from offshore aquaculture to marine mammals
- Effect of offshore aquaculture on marine mammal migration patterns and distribution
- Risk of entanglement with offshore aquaculture

Background

The Marine Spatial Planning (MSP) Study Area hosts at least 29 species of marine mammals. These include baleen and toothed whales, seals, sea lions, and sea otters. Many species play crucial roles as top predators, while large baleen whales like humpback and gray whales are primarily filter or bottom feeders. Particularly in southern Washington waters, harbor porpoises dominate nearshore sightings, while Dall's porpoises are common offshore. Humpback whales were frequently observed in the Olympic Coast National Marine Sanctuary during a survey in June 2008.

Ten marine mammal species listed under federal Endangered Species Act (ESA) or Washington's Species of Concern inhabit the MSP Study Area. Stressors include boat collisions, noise, entanglement in fishing gear and debris, contaminants, oil spills, habitat and prey changes, harmful algal blooms (HABs), and oceanographic conditions. The Marine Mammal Protection Act protects all marine mammals, whether ESA-listed or designated as Species of Concern.

Table 17. Marine mammals within the MSP Study Area on the federal or state Species of Concern lists (MSP Table 2.1-4).

COMMON NAME	SCIENTIFIC NAME	FEDERAL STATUS	STATE STATUS
Blue whale	*Balaenoptera musculus*	Endangered	State Endangered
Fin whale	*Balaenoptera physalus*	Endangered	State Endangered
Gray whale	*Eschrichtius robustus*	None	State Sensitive
Harbor porpoise	*Phocoena*	None	State Candidate
Humpback whale	*Megaptera novaeangliae*	Endangered	Endangered
Killer whale	*Orcinus orca*	Endangered[42]	Endangered[43]
North Pacific right whale	*Eubalaena japonica*	Endangered	Endangered
Sea otter	*Enhydra lutris*	Species of Concern	Endangered
Sei whale	*Balaenoptera borealis*	Endangered	Endangered

[42] This listing is for the Southern Resident Orca population, the other three populations (northern, offshore, and transient) are not listed under the ESA.
[43] The State of Washington lists all Killer Whales in the state as Endangered.

COMMON NAME	SCIENTIFIC NAME	FEDERAL STATUS	STATE STATUS
Sperm whale	*Physeter macrocephalus*	Endangered	Endangered
Steller sea lion	*Eumetopias jubatus*	Species of Concern	None

To inform the development of the MSP, the National Centers for Coastal Ocean Science (NCCOS) developed ecological models of predicted marine mammal distributions within the Study Area for four species of cetaceans and two species of pinnipeds. Data collected between 2000 and 2013 within or just beyond the Study Area were used for this effort. Species were chosen based on management concerns or ecological roles. Ecological models and maps were created for Steller sea lion (*Eumetopias jubatus*), harbor seal (*Phoca vitulina*), humpback whale (*Megaptera novaeangliae*), gray whale (*Eschrichtius robustus*), harbor porpoise (*Phocoena phocoena*), and Dall's porpoise (*Phocoenoides dalli*). Although species like gray whales and harbor porpoises are known to use the estuaries, the maps did not include cetacean use of the estuaries due to a lack of comparable spatial data.

Ecologically Important Areas (EIAs) were also identified by a state interagency team, focusing on areas most used by marine mammals. Relevant to marine mammals, WDFW produced EIA hotspot maps for: seal and sea lion haul-outs (harbor seal, California sea lion, Steller sea lion, and Northern elephant seal); nearshore seabirds and marine mammals (harbor seal and harbor porpoise); sea otter; and marine mammal abundance (Steller sea lion, harbor seal, humpback whale, gray whale, harbor porpoise and Dall's porpoise). While some individual EIA maps cover features inside the estuaries (e.g. marine mammal haul-outs), there was not enough data for the estuaries to perform the same EIA overlay method that was used in the open ocean regions of the Study Area.

The MSP provides in-depth information for a few groups of marine mammal species which are summarized below:

Orcas: Also known as killer whales, orcas inhabit the MSP Study Area and are divided into four distinct populations based on ecological, genetic, dietary, behavioral, and social characteristics. Three populations are classified as "resident" orcas: northern, southern, and offshore. Resident orcas primarily feed on fish, with the northern and southern populations consuming salmonids and occasionally bottomfish. In contrast, transient orcas in Washington waters are mammal-eating, primarily targeting harbor seals.

All four orca populations are present within the MSP Study Area, although their distribution, abundance, and seasonal use vary. The distribution of the populations is best known for the summer. During summer, the northern resident orcas are concentrated in inshore British Columbia, while the southern residents frequent inshore waters near the Washington-British Columbia border. The offshore population ranges across the continental shelf from southern California to the Aleutian Islands. Satellite tags and passive acoustic recorders have provided insights into the winter migrations of southern resident killer whales and the extent of their range. Satellite tagging data from 2015 showed resident orcas had foraging areas outside estuaries like Willapa Bay and Grays Harbor, and at the Columbia River mouth.

Population sizes are well-documented for northern and southern resident orcas, but less precise estimates exist for offshore residents and transient orcas. Southern resident orcas are listed as endangered under the ESA, reflecting their vulnerable status, and all killer whales are protected as endangered species in Washington State.

Seals and sea lions: Harbor seals, elephant seals, California sea lions, and Steller sea lions gather on rocky islands, coastal areas, and estuaries within the MSP Study Area. Harbor seals and California sea lions are frequent visitors to coastal estuaries. Northern fur seals transit through and forage within the MSP Study Area. NCCOS developed relative density models to predict the distributions of these animals across the MSP Study Area, excluding their presence in estuaries.

Sea otters: Sea otters typically inhabit rocky habitats and kelp forests in the Study Area, with lower densities in soft-sediment areas along the Olympic Peninsula coast. Once extirpated by fur trade hunters, they were reintroduced to the outer coast in 1969 and 1970, with their population growing steadily at a rate of 7.6% annually from 1991 to 2012. By 2015, approximately 1,394 sea otters inhabited the area. Listed as endangered in Washington State, sea otters are keystone species vital for maintaining kelp forest habitats by controlling sea urchin populations and consuming a variety of prey including abalone, mussels, crabs, snails, and chitons.

Marine mammals within the MSP Study Area faces numerous stressors resulting from human activities. The MSP discusses the major stressors that Washington's ocean faces. The stressors are summarized below:

Marine debris: Marine debris poses significant threats to wildlife through entanglement, ingestion, and associated impacts. Entanglement in debris can cause injuries, illnesses, and fatalities. Ingestion of marine debris, often mistaken for food, harms species like sea turtles, marine mammals, and seabirds. Marine debris can also introduce non-native species, exacerbating ecological and economic challenges in affected areas.

Ocean noise: Marine mammals heavily rely on sound for communication, navigation, and food detection. Ocean noise, whether natural (from animals, waves, and wind) or anthropogenic (from shipping and drilling), impacts the MSP Study Area. This area faces both chronic and acute anthropogenic noise sources. However, noise pollution in pelagic habitats is not well characterized or evaluated for its potential impact on wildlife. Assessing the noise impacts on Washington's marine ecosystem and the potential effects of new activities requires further study.

Vessel strikes: Collisions between vessels and marine mammals, particularly large whales, are a global concern where high ship traffic intersects with whale populations. Whales are vulnerable to strikes from all vessel types. Such strikes can injure or kill whales and may be unnoticed by vessel crews. If injured, their carcasses may not wash ashore. As a result, the number of strikes may be greater than the number documented. In Washington, blue whales, fin whales, and gray whales have been fatally struck by ships, highlighting the ongoing threat posed by vessel traffic to these species.

The West Coast Marine Mammal Stranding Network monitors stranded marine mammals across Washington, Oregon, and California. Authorized by NOAA, network participants respond to and examine dead marine mammals, collecting data vital for research, public education, and compliance with NOAA Fisheries mandates under the Marine Mammal Protection Act and ESA.

Aquaculture: There are minimal documented cases of marine mammals being injured or entangled in aquaculture gear. However, other potential impacts such as habitat exclusion, marine debris, underwater noise disturbance, and behavioral changes have been identified. Marine mammals that can echolocate are believed to detect and avoid offshore aquaculture structures. In contrast, baleen whales, lacking echolocation, may be at higher risk of entanglement due to their reliance on visual and auditory cues. Management strategies to mitigate impacts include siting aquaculture facilities away from migration routes and critical habitats.

Negative interactions between pinnipeds and finfish farms have been reported, leading to financial losses through predation or stress to fish. Farm management practices to reduce pinniped interactions include net tensioning, using false bottoms to prevent predation, removing dead fish, and employing antipredator nets. Pinnipeds do not feed on shellfish so direct predation effects are not an issue.

The MSP also discussed the potential effects of several new activities, some of which are briefly provided below:

Dredged material disposal: There is limited understanding or prediction of potential impacts on marine mammals from dredged material disposal. The Regional Sediment Management Plan (RSMP) expects minimal impact on marine mammals from dredged material disposal at Mouth of the Columbia River locations and recommends timing disposal activities to avoid Gray Whale migrations.

Sand and gravel mining operations: Sand and gravel mining (dredging) operations may impact marine mammals through vessel interactions, noise, and changes in water quality. While vessel strikes pose a risk, dredge vessels are typically slow-moving and there are mitigation measures available. There are no reports of marine mammal strikes from dredging or support vessels. Noise from dredging and vessel operations can alter marine mammal behavior, with effects depending on noise levels and species. Few studies document marine mammal reactions to dredging noise. Direct injury from sound associated with offshore dredging is unlikely based on NOAA noise criteria; however, disturbance and harassment are possible. The impacts of disturbance on bottom habitats, turbidity, and sediment deposition are uncertain.

Offshore oil and gas activities: The potential effects on marine mammals depend on species and activity levels. The 2012-2017 Programmatic Environmental Impact Statement listed general potential effects, including collisions with support vessels; disruption from seismic exploration; behavior disturbance from construction, operation, and support vessels; physical disturbance or reduced habitat quality from construction; toxicity from drilling fluids; ingestion or entanglement with solid wastes and debris; and spill-related toxicity. Predicted impacts in

Gulf of Mexico and Alaska lease blocks range from negligible to moderate. Specific impacts on Washington coast marine mammals from offshore drilling will be assessed in an environmental impact statement during the permitting process.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to marine mammals:

General data gaps

- Abundance, distribution, health, and trend of marine mammals
- Sensitivity of marine mammals to habitat changes
- Effect of biotoxins and other naturally occurring threats on marine mammals

Abundance, distribution, health, and trend of marine mammals. Data availability varies by species. There is a better understanding for species in inland waters. Distribution data are generally limited, with significant gaps in abundance estimates and a pressing need for more comprehensive multi-seasonal data. Climate change is expected to alter and continue altering the distribution of marine mammals.

There has been a significant amount of work on marine mammals. "Vulnerability Index to Scale Effects of Offshore Renewable Energy on Marine Mammals and Sea Turtles Off the US West Coast (VIMMS)"[44] examines each species, detailing their distribution, potential threats, and impacts. Additionally, NOAA provides resources and conducts research efforts, such as its Marine Mammal Stock Assessment Reports[45] and the Southwest Fisheries Science Center's (SWFSC) California Current Marine Mammal Assessment Program[46]. This program conducts cruises off the West Coast and models cetacean densities across both space and time. NOAA's Science Centers have conducted surveys since 1991, providing valuable data to assess trends over time. However, available data is not comprehensive. Updated abundance estimates for specific species like humpback whales are lacking. The Marine Mammal and Turtle Division (MMTD) also does extensive ship surveys, primarily from July to early December, when weather conditions are more favorable. Researchers use this data to model the winter distribution of marine mammals and turtles and incorporate oceanographic variables. An important dataset is the National Marine Fisheries Service's (NMFS) Oregon, California, and Washington Line-transect Expedition (ORCAWALE) program. This program surveyed the West Coast between 1996 to 2008, out to a distance of approximately 300 miles offshore, to estimate the abundance and distribution of cetaceans. NOAA also published distribution maps in 2016: Predictive mapping of seabirds, pinnipeds and cetaceans off the Pacific Coast of Washington[47].

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[44] https://tethys.pnnl.gov/sites/default/files/publications/BOEM_2023-057.pdf
[45] https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-stock-assessment-reports-species-stock
[46] https://www.fisheries.noaa.gov/west-coast/science-data/california-current-marine-mammal-assessment-program
[47] https://repository.library.noaa.gov/view/noaa/9329

The Washington Department of Fish and Wildlife (WDFW) also operates surveys through its Science Division, specifically the marine bird and mammal observation team. These pelagic surveys extend across the entire coast beyond the continental shelf, utilizing six transects covering the entire Washington coast. Currently, the University of Washington (UW) uses the data from these surveys to create maps identifying hot spots and cold spots. UW collaborates with both WDFW and Cascadia Research Collective for data integration. Some species have sufficient data available for modeling purposes. Others are not encountered frequently enough.

Data on interactions with fixed gear fisheries, such as Dungeness crab gear, are also being used to develop species distribution models.

a. Cetaceans

Overall, the understanding of cetacean distributions is generally more advanced compared to that of pinnipeds. Recent years have seen increased data collection using drones, which capture information on various species such as blue whales, minkes, and transient whales. Large whale surveys occur infrequently, and smaller cetaceans are documented during NOAA cruises. NOAA conducts temporally distinct surveys during breeding seasons (early June to late September annually) from northern California to the tip of Vancouver Island, BC. They typically extend beyond the continental shelf. There are robust habitat models and distribution surfaces available for most species during the summer-fall period. However, there is a notable data gap in understanding their distribution during the winter-spring months. These surveys are not year-round due to weather constraints and resource limitations. Funding availability can also be intermittent. Securing more reliable funding would be beneficial. WDFW also conducts research on whales.

Adding to this challenge, some species are rare, limiting comprehensive understanding. For species like Southern Resident Killer Whales, more data is available from Puget Sound than offshore areas. There are also significant data gaps for North Pacific Right Whales, with only an estimated 20 individuals remaining in the population. These whales are elusive and rarely observed, making them challenging to study. Acoustic methods are often employed to locate them. Industrial marine activities may impact their habitat, further complicating conservation efforts.

Data availability is also affected by a species' status under the ESA. Data for listed species are typically refreshed every one to two years and detailed in stock assessment reports. Species like coastal harbor porpoises are not listed and therefore, lack consistently updated data. There is currently a particular focus on monitoring harbor porpoises, with ongoing efforts to enhance genetic data collection.

Gaps also exist for abundance data. The Pacific coast feeding group of gray whales is one species for which data is available. This group, behaviorally distinct but not classified as its own stock, resides off the Northwest coast year-round as part of the eastern North Pacific population. Monitoring efforts for this group have been ongoing since at least 1995, providing valuable abundance data through photo identification and mark-recapture studies.

Performing trend analyses is limited to certain species as well because historical data is not available for all. Some species, such as humpback whales, exhibit positive population trends, with numbers increasing over time. However, more data is needed on multiple stocks or distinct population segments (DPS) to better understand the abundance and distribution of each breeding population of humpback whales along the West Coast.

b. Pinnipeds

Pinniped data is more comprehensively understood at the state level. Information is available for all pinniped species except the Guadalupe fur seals; however, collaborative efforts with Mexican colleagues have greatly improved knowledge of this species. California sea lions, northern fur seals, and Steller sea lions breed during the summer months. During winter, California sea lions migrate northward, a pattern confirmed through data from marked animals and satellite telemetry. Aerial surveys using fixed-wing aircraft provide comprehensive images for enumerating various species. Drones, although limited in spatial coverage, focus on specific species of interest. Robust design studies are not currently used to examine other species. While some winter data exists, it is regionally specific. In Washington, collecting winter data is challenging due to harsh weather conditions, and attempts are often hindered by rough weather during this season.

The Oregon Department of Fish and Wildlife (ODFW) and Washington Department of Fish and Wildlife (WDFW) have primarily taken over harbor seal research. Harbor seals are particularly vulnerable to habitat loss and declines in prey availability. They do not typically travel far to locate food. Infrastructure and development projects at estuaries and ports where seals congregate pose significant threats. Other species, such as Northern elephant seals and Guadalupe fur seals, exhibit greater flexibility in foraging behaviors.

Figure 8. Close up of a harbor seal

Similar to cetaceans, data availability partially depends on the protection status of the species. For example, seal stocks are not listed under the ESA, resulting in less consistently updated data. Data availability also varies because some species are difficult to survey effectively and require dedicated efforts. For example, Steller sea lions are challenging to handle and have a short life history stage. Tagging them is not feasible. While some insights come from branding data, gaps remain in understanding their distribution, reproductive success, and mortality rates. Pup counts also provide some data but do not cover all aspects of mortality. There is also a lack of foraging information during the breeding season. Nursing female Steller sea lions are documented to travel approximately 50 miles from rookeries to forage off the continental shelf. Recent observations suggest a possible decline in their population which has prompted efforts to gather more information proactively. Steller sea lions were listed as threatened under the Endangered Species Act (ESA) and was later delisted.

There are significant data gaps regarding pinniped stock abundance in Washington. Abundance data is available for Northern elephant seals, harbor seals, and Guadalupe fur seals, but due to fewer surveys, this data is primarily collected during stock assessments, which are intended to occur every 5-8 years, though they are not always conducted consistently. In contrast, California sea lions and Northern fur seals benefit from a robust monitoring program that has been ongoing for about 50 years, collecting data on abundance, demography (including survival and reproduction rates), distribution, foraging behavior (diet), and health assessments. For Steller sea lions, data is available on abundance, distribution, and some aspects of demography.

Feedback on importance: Addressing this data gap is a high priority. Because many of the listed marine mammals travel long distances, including through Washington waters, understanding their distribution and the drivers of distribution are key to understanding the effects of climate and other changes. Obtaining this information is also a high priority for species that lack baseline data, such as harbor porpoises.

There is also a strong need for seasonal distribution information across various species. Most of the current data pertains to single seasons. This is a relatively easy and low-cost task. Once a general understanding of seasonal distribution is obtained, the need for frequent data collection may decrease. However, due to the transient nature of these species, regular monitoring will likely be necessary. Additionally, currently, there are 4-6 transects, which are sparse. Increasing the number of transects will require additional funding but this is feasible and straightforward. Weather conditions will remain a primary consideration for survey efforts.

WCMAC: Extensive data on marine mammals exists. The National Marine Fisheries Service (NMFS) publishes annual stock assessment reports; however, these often rely on outdated information, undermining the accuracy of policy recommendations. For instance, the current Potential Biological Removal (PBR) metric used for policy decisions is based on survey data from 2018. While some proposals suggest that data up to eight years old is valid for policy decisions, making decisions that impact both human lives and marine species based on such old data is unacceptable. Nonetheless, knowledge of marine mammals is improving, with insights into stock differences, breeding areas, and feeding habits.

For example, the California, Oregon, and Washington strategic stock of ESA listed humpback whales are collectively experiencing significant growth, estimated at an annual rate of 8.2%. The Mexican DPS (Distinct Population Segment) has a broad range that includes parts of Oregon, California, Washington, and Alaska. Based on growth estimates up to 2018, their numbers may have increased to about 4,000-6,000 individuals by 2024. The Hawaiian DPS, which ranges from Hawaii to northern Washington and across the Gulf of Alaska, was delisted and is approaching historical population levels. The Southern Mexican and Central American DPS primarily feeds off Oregon and California and occasionally extends into Washington. While these growths are encouraging, various factors can influence growth rates and it raises concerns about potential interactions with potential new ocean activities. Developments like offshore wind could disrupt population trends, alter whale interactions, affect forage and migration patterns, impact water quality, affect Critical Habitat areas, and generate disruptive acoustic changes. Another example, the population of Southern Resident Killer Whales (SRKW), an endangered species, is declining. The potential effects of activities like offshore wind on SRKW population requires more research. While there is considerable understanding of the dynamics amongst the species, breeding groups, and feeding areas, much of this data is outdated, emphasizing the need for more current information to guide current policy decisions.

Sensitivity of marine mammals to habitat changes. There are no direct studies on many species in Washington, but inferences can be made. Marine mammals respond to changes in ocean conditions and habitats, influencing their distribution and demographics. They also respond to climate which affects their life histories. While this topic is actively researched across different stocks and regions, this data gap mainly applies to pelagic species. Research is also underway concerning predicted oceanographic changes, typically involving predictive models of food web dynamics and impacts of climate change. An upcoming NOAA publication on Pacific and Arctic marine mammal vulnerability to climate change will show which species of marine mammals are sensitive to climate change.

The association of marine mammals with geographic features and some of their aquatic habitat needs are generally understood. Most marine mammals in Washington primarily visit the area to forage. For central place foragers like pinnipeds, specific geographic features are especially important, as they rely on locations such as rocky haul-out sites. Disease outbreaks and fluctuations in prey availability can change habitats. In particular, disruptions in the California Current Ecosystem (CCE) could impact prey resources and alter predator distributions. From 2018 to 2023, an unusual mortality event led to the stranding of hundreds of gray whales along the West Coast, from Alaska to Mexico. Preliminary findings suggest that localized ecosystem changes in the whales' feeding areas led to changes in food, malnutrition, decreased birth rates, and increased mortality.

Feedback on specific species is provided below:

California sea lions, harbor seals, and Steller sea lions: These three species are primarily coastal species. Seals and sea lions use rookeries and may rely on other coastal features. Annual surveys are conducted by WDFW to monitor seal distribution, and updates are regularly made available regarding sea lion rookeries. Disruptions in currents can alter coastal infrastructure and subsequently impact habitat conditions. Specifically for California sea lions, there is a solid understanding of their aquatic habitat requirements. With funding from the Infrastructure for Rebuilding America program, there are plans to propose a terrestrial habitat suitability model, which would be a novel approach as it has not been done for any pinnipeds.

Harbor seals are experiencing habitat loss due to climate change and require suitable areas for pupping and breeding. There is limited understanding of what constitutes optimal terrestrial habitat for them, as most research focuses on their aquatic habitat. Studies on their feeding habits, whether offshore or coastal, will provide insights into their geographic distribution. On land, while associations with prey resources are known, there are likely other factors that contribute to determining what makes a beach suitable for pupping. The impact of broader ecosystem changes on harbor seals remains uncertain.

Northern elephant seals: They are highly pelagic species that spend minimal time on land, primarily coming ashore only for pupping and breeding purposes.

Northern fur seals: Northern fur seals are primarily pelagic and inhabit offshore areas beyond the continental shelf. They migrate through offshore regions, with some venturing into the Pacific Ocean similar to Northern elephant seals, while others remain closer to the coast but still far from shore.

Sea otters: Sea otters, listed as state threatened, typically use kelp beds for pupping. They are not solely dependent on kelp beds but show a preference for these habitats.

Cetaceans: There is limited information available for cetaceans. When considering whales, there are no specific geographic features offshore, nearshore, or alterable that come to mind. Many species breed in distant locations. While some rookeries are used, they are not as heavily relied on in Washington. Critical habitats primarily revolve around prey availability rather than breeding sites. NOAA's Southwest and Northwest Fisheries Centers have been conducting modeling on environmental variables that influence whale movements and distribution. SWFSC is also modeling density and examining water temperature, which helps assess the risk of entanglements.

Researchers have some dietary information on cetaceans, sometimes directly observing their feeding behaviors. However, there are instances when it is unclear why they are present in certain areas. In the case of gray whales, it was traditionally believed they were predominantly on the continental shelf. However, recent observations have documented behaviors deviating from this norm, such as actively pursuing fish rather than their usual bottom-scrounging behavior. The reasons behind this behavioral shift remain unclear, suggesting changes in prey availability or environmental conditions favoring fish as a more profitable feeding strategy. Recent studies involving gray whales employ GPS and drone technology for more precise georeferencing of their movements. Previously, observational methods were limited to photography. Technological advancements are expected to enhance insights into their behaviors and habitats.

Feedback on importance: This represents a critical data gap. Although some information exists, there are still high-priority gaps that need to be addressed. There is a need to understand the habitat requirements of marine mammals given potential redistributions due to climate change. For example, sea otters favor habitats with giant kelp. However, environmental shifts could affect kelp ecosystems. Monitoring sea otters would be essential if there are significant changes in kelp distribution or abundance. Additionally, terrestrial habitat needs are not well understood. For instance, in Grays Harbor, if habitat loss occurs due to rising tides, it is unclear where harbor seals could relocate or if their population might decline. While their current locations are known, the reasons for their absence in other areas remain unclear. Knowledge on their aquatic habitat is more robust, supported by food habits that indicate their preferred locations for foraging and resting. There is also currently a lack of knowledge about the potential threats to Steller sea lions in the future and their effects. Assumptions have been made and models developed, but reliable data is lacking.

There is also interest in identifying species that are environmentally sensitive, prioritizing those that are vulnerable. Sensitivity to environmental changes varies among taxa; some species demonstrate high adaptability, while others are less flexible, or their adaptability is not well understood. For instance, there is a high abundance of seals, while gray whales are experiencing a significant mortality event, resulting in a population decline. Typically, an annual assessment should be adequate for monitoring these dynamics. General abundance and distribution data will provide valuable insights and detecting certain changes will be straightforward. However, detailed investigations will necessitate additional technology and funding. Long-term study sites also play a crucial role in understanding trends and dynamics. Securing funding may be contingent on observing noteworthy findings during monitoring efforts.

> **WCMAC:** Although the Eastern Pacific Gray Whale is not listed under the Endangered Species Act (ESA) and has a robust population, several naturally occurring die-offs have occurred since the 1980s and 1990s, resulting in hundreds of gray whale deaths. This raises questions about whether overpopulation or changes in habitat availability and forage are affecting their access to nutrients. The specific impacts of habitat changes on gray whales are not fully understood. A recognized link exists between acoustic noise and their natural activities. Noise pollution disrupts their communication and orientation, affecting normal behaviors. Additionally, the effects of factors such as foreign materials and warming waters on gray whales remain unclear. There is ample opportunity to enhance understanding of how marine mammals respond to habitat changes and their sensitivities to these shifts.

Effect of biotoxins and other naturally occurring threats on marine mammals. While there is considerable active research, there is limited understanding about naturally occurring toxins that affect species. Certain biotoxins are known to have a detrimental impact on marine mammals. For example, there is generally more information available on domoic acid compared to other biotoxins. Domoic acid, is produced by the microscopic diatom algae *Pseudo nitzschia* spp. Seasonally large concentrations are referred to as harmful algal blooms (HABs) and can have significant effects when ingested by mammals. There have been documented instances of biotoxins entering the ecosystem, from phytoplankton to sardines, ultimately affecting California sea lions with lesions developing on their brains. These affected sea lions exhibited abnormal behavior and resulted with mortality. Approximately 500 deaths over a period of one to two months were directly linked to a domoic acid HABs. This phenomenon can occur with whales but is less understood. Marine mammal rescue centers often become overwhelmed during domoic acid blooms, raising concerns about the potential for more frequent occurrences in the future. These blooms are believed to be influenced by runoff, pesticides, and fertilizers from agricultural areas, which introduce excess nutrients into the marine environment, potentially triggering blooms.

There has also been research on warming oceans and the production of biotoxins, but there is still a significant data gap regarding their impact on marine mammals. Current research tends to focus on individual species and often overlooks cetaceans.

Feedback on importance: This data gap is of high interest due to the potential severe impacts and lethal interactions associated with biotoxins and other naturally occurring threats. Understanding which chemicals marine mammals are sensitive to lays a crucial foundation. This background information is essential for understanding impacts and implementing effective mitigation strategies. Predicting these impacts can be challenging due to the nature and scale of changes, but the potential consequences can be devastating. Having this information can also support the understanding of offshore aquaculture.

> **WCMAC:** There is a growing understanding of the effects of biotoxins and other threats on marine mammals. A poorly understood behavioral phenomenon may be linked to biotoxins like domoic acid. Sea lions along the California coast have experienced significant die-offs, with speculation that ingestion of domoic acid may be a contributing factor. This type of poisoning is particularly severe for marine mammals, which can consume contaminated prey. Sea otters may ingest domoic acid through shellfish consumption. While domoic acid does not directly harm shellfish, it poses significant health risks to its consumers. The impact of domoic acid on fish remains uncertain, but other species that consume contaminated fish species are negatively affected. Ongoing research aims to improve understanding of these interactions and their implications for marine ecosystems.

Offshore wind data gaps

- Effect of offshore wind on marine mammal migration and distribution
- Risk of entanglement or collision with offshore wind

Effect of offshore wind on marine mammal migration and distribution. There is a data gap regarding the potential effects of offshore wind farms on the migration and distribution of marine species. While some studies have been undertaken, unanswered questions remain. Currently, for lease areas, information is provided such as "this area is sensitive to X, please avoid if possible" or "this depth contour is critical for X, please exclude." There is early collaboration with NCCOS to pinpoint sensitive species' locations, assess vulnerability rankings, refine models, and avoid areas critical for species of concern.

Effects will vary depending on species and specific geographical contexts. The exact configuration and spatial extent of future wind farms are also unknown. However, given their offshore location, unless there is substantial noise disturbance, it is believed offshore wind is unlikely to disrupt migration patterns significantly.

Coastal species are expected to have limited interaction with offshore wind farms. However, certain marine mammals will need to navigate around the structures, which remains a significant uncertainty. There is also a potential concern regarding cables between structures that could lead to entanglement issues. The full extent of these challenges won't be understood until the structures are observed. For instance, the primary concern for cetaceans would be navigation obstacles if offshore wind structures obstruct their usual pathways. It is anticipated that cetaceans can navigate detours, as they are known to adapt their routes. However, circumventing offshore wind structures could increase their energy expenditure. If prey is displaced, whales may also need to adjust their movements to locate alternative feeding areas. This concern also applies to pinnipeds. It is believed they can detect and avoid these structures visually and have the capability to either navigate around or pass through them. However, the risk of injury to pinnipeds remains uncertain and the potential energy expenditure and broader impacts are not well understood. Currently, OSW structures have generally been sited outside established pinniped corridors, except for fur seals.

Most marine mammals in Washington are primarily there to forage rather than reproduce. Disruptions in the California Current Ecosystem (CCE) could affect prey availability and lead to changes in predator distribution. For example, a large-scale wind energy project could potentially alter wind patterns, currents, and consequently disrupt the upwelling patterns which could affect prey availability and distribution, as well as migration patterns. If mothers expend more energy navigating the altered conditions, this disturbance could potentially impact the condition of nursing pups. Once they can move away with their pups, the impact is expected to diminish. The consequences of disturbing energetics in marine mammals are still being investigated, with current studies focusing on Steller sea lions.

It is unclear whether the structures will also function like a fish aggregating device (FAD) and how this might affect foraging behavior. The potential effects could be positive or negative, but there is limited knowledge about the attraction of marine species to FAD-like structures. This question has been raised frequently, but there hasn't been a definitive answer yet. If fish were to aggregate around the structures, it might attract predators and facilitate easier prey capture. However, this could also increase the risk of injury from the structures, particularly for pinnipeds, which often feed on aggregating prey. The implications for cetaceans are less understood. There are ongoing studies on the East Coast exploring this aspect.

Feedback on importance: This data gap is crucial. The effect will depend on the placement of wind energy and its potential overlap with species that may be more vulnerable. Most species have well-defined migration routes at a broad scale and information on general abundance, distribution, and migration patterns will provide valuable insights. There has been observed exploitation of structures, although the extent of this with offshore wind structures will be uncertain until it occurs. Certain whale species may not be as attracted to these structures. Continued general monitoring will be necessary until specific issues are observed. Existing methodologies can be relied upon for assessment.

> **WCMAC:** The regulatory impact and regulatory considerations of offshore wind development differs for whales and areas inside and outside Critical Habitat (CH), which is designated for ESA-listed species such as humpback whales, Southern Resident Killer Whales (SRKW), and leatherback sea turtles. It's essential to differentiate between expectations for species within CH and those outside it. Within CH, ocean activities should not disrupt migration patterns or alter habitats through affecting foraging, water quality, or acoustic noise. If turbines alter migration patterns by causing anxiety and deterring whales from swimming through them, this could violate CH regulations and disrupt activities like fishing. This is different from potential behavior changes in whales due to entanglement issues, a risk that can be exacerbated by debris accumulation and increase in anchor scope. Additionally, if offshore wind development alters prey

behavior, forcing whales to seek new foraging grounds, it could impact their migration patterns.

While some expectations exist, there is no conclusive evidence that structures attract marine species or influence behaviors. For example, lights from turbines may attract squid or forage fish, altering predator behaviors like foraging and migration around offshore wind structures. Additionally, electromagnetic fields (EMF) generated by offshore wind turbines can also induce EMF currents that attract or repel certain marine species. If turbines do not induce fear, some species, like whales, may be intrigued. There is a need for further research on EMF effects within turbine arrays and on the seafloor.

Risk of entanglement or collision with offshore wind. Research has addressed entanglement and collision risks to some extent, but definitive answers are lacking. Comparable to the understanding of risks posed by vessel activities, the level of risk varies depending on the species and specific environmental context.

There is limited familiarity with the tethering of floating structures, and it is unknown whether marine animals can adjust their movements to accommodate offshore wind structures or even recognize them. However, it is generally believed that the collision risk would be minimal. Collision risk is acknowledged as an inherent concern associated with offshore wind projects rather than a data gap.

Regarding collision risks with vessels, it is generally believed that pinnipeds can avoid collisions, while whales may face a greater risk as vessel traffic increases. Slowing down is crucial to mitigate these risks. In California, high-resolution geophysical surveys are conducted, and vessels are advised to maintain a speed of 10 knots. Improving understanding of whale migration patterns will help refine scientific assessments of collision risks.

Evaluating entanglement risks requires understanding the specific configuration of cables, anchors, and lines/chains. Although there is existing knowledge from entanglements with fishing gear and buoys, installing new structures in new areas may create and amplify these risks. For offshore wind, secondary and tertiary entanglements pose greater concerns, where debris collected by cables can entangle marine mammals and turtles. Debris will need to be removed to mitigate this issue.

Feedback on importance: This data gap ranks high due to the potential for severe impacts and lethal interactions. The level of risk will depend on factors such as the construction of facilities (materials, location, and structure) and the distribution of animals. While monitoring and reporting by industry would be needed, there can be conflicts of interest; monitoring practices vary among fisheries, with some having robust systems while others may not; and not all industries are required to report or monitor their activities. Additionally, data from observers can be influenced.

Understanding the risk of entanglement takes precedence over collision risk. Despite existing knowledge of entanglement risks, the installation of new structures and potential accumulation of gear around these structures introduce new concerns. Secondary entanglement risks include cables and debris that can collect on cables. Monitoring these risks, particularly sub-surface entanglements, may require methods such as diver or remotely operated vehicle inspections rather than surface or shore observations.

WCMAC: There is a potential risk of collisions between whales and offshore wind turbines, even though whales possess sensitive sonar systems to detect their surroundings. Disruptions from turbine noise or acoustic changes could affect their sonar sensitivity and increase this collision risk. Identifying specific causes and their effects is challenging due to potential interactions among various factors. Cumulative effects from multiple sources may lead to impacts that individual factors alone do not predict, highlighting the difficulty of assessing impacts in isolation. There are also concerns regarding what constitutes an attractive nuisance for marine mammals, potentially increasing collision risks. Even drifting logs or floating debris can significantly alter localized ocean dynamics and create micro-ecosystems. These factors complicate predictions about how offshore wind systems may influence species behaviors.

Vessel strikes on marine mammals are underreported, with many incidents likely going unrecorded. Strikes are more likely from larger vessels than smaller vessels unless they are moving at high speeds. Operating at excessive speeds increases risks to safety at sea, a fundamental concern in the context of offshore wind development. On the East Coast, regulations limit vessel speeds to 10 knots to protect right whale populations. Increased vessel traffic during construction or deployment phases, especially from vessels that are larger than typical fishing boats, could also lead to a rise in vessel strikes. These incidents fall within ESA estimates of marine mammal removals and count against Potential Biological Removals (PBRs), potentially impacting other ocean activities and socioeconomic factors.

Offshore aquaculture data gaps

- Effect of escapees from offshore aquaculture on marine mammals

Effect of escapees from offshore aquaculture. Escapees from aquaculture facilities may not affect marine mammals as significantly as their prey species. During the Atlantic Salmon net pen failure, there were potential impacts on wild salmon. Whales reportedly consumed some farmed Atlantic Salmon, but the potential risks from parasites and other effects of introducing a foreign prey species remain uncertain due to the lack of monitoring or tracking of whales. Hence, escapees could contribute additional food to the environment but also potentially introduce diseases or toxins. While there might be some impact on fitness, it is speculative.

Feedback on importance: This data gap is a high priority due to its potential for severe impacts and lethal interactions. This will require an intensive study with constant monitoring.

WCMAC: Aquaculture has been linked to the introduction of non-native species, such as shellfish and Atlantic salmon, raising significant environmental concerns. The escape of Atlantic salmon into Pacific Northwest and Canadian waters became a notable issue. Despite initial claims that they would not spawn in local streams, evidence now shows they can. Additionally, aquaculture poses risks of disease transmission, the spread of invasive species, and nutrient pollution, which can lead to dead zones and alter nutrient dynamics. Disease outbreaks, including viral toxins in confined aquaculture settings, may also affect surrounding environments. Although native species aquaculture helps mitigate some escape risks, challenges remain regarding feed sustainability and impacts on both mobile and benthic species. The broader impacts on ecosystems and biodiversity remain poorly understood.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Information from foreign countries on the effects of human activities on marine mammals

Information from foreign countries on the effects of human activities on marine mammals. This question encompasses a wide range of potential impacts from various activities, including noise and other disturbances, different forms of fishery-related activities (both direct and indirect effects), vessel strikes, pollution, and changes to habitats due to climate change. The extent of understanding these effects on marine mammals varies depending on the specific activity involved. Along the United States (US) West Coast, there is considerable knowledge about many of these impacts. There aren't any activity-impact interactions on the West Coast that are completely unknown. However, the impacts to some species are better understood than others and uncertainties remain depending on specific research areas.

Impacts on marine mammals can be direct or indirect. Direct impacts include entanglement in fishing gear and collisions with vessels. While these incidents are known to occur, there is limited data on their frequency and extent. Questions remain about the number of individuals affected annually and the population-level or individual effects. It is challenging to ascertain these figures because observations typically involve only those animals that survive such incidents.

Entanglement issues include those arising from fishing gear used for certain groundfish species or the Dungeness crab fishery. These operations can result in the unintentional "take" of marine mammals and sea turtles, which is a significant concern. These fisheries are managed at the state level, and efforts are underway to address this problem. One potential solution being considered is transitioning from fixed gear that remains in the water continuously to on-demand gear that can be deployed and retrieved at predetermined times.

There is data on entanglement risks associated with fisheries and stationary structures such as cables and aquaculture nets. A 2018 paper estimated and extrapolated undetected entanglements based on known incidents and scarring events. The paper "Low Resighting Rate of Entangled Humpback Whales Within the California, Oregon, and Washington Region Based on Photo-Identification and Long-Term Life History Data"[48] delves into the issue of undetected

[48] https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2021.779448/full

entanglements. Washington Department of Fish and Wildlife (WDFW) also conducts periodic status reviews, although these are not consistently performed for common species. Reviews for gray whales and humpback whales were conducted in 2020, while large whales were reviewed in 2018. Status Reviews can be accessed on the WDFW's website under "Publications"[49].

There is a wealth of information available on ship strikes involving marine mammals, particularly large whales. Modeling efforts have been conducted, and there are initiatives involving crowdsourcing, such as Whale Alert[50], which provides information to large ships and tankers about the presence of marine mammals in shipping lanes. This field has emerged relatively recently, over the past 15 years, driven by the recovery of whale populations and an increase in global shipping traffic due to economic growth and international trade interests. There is limited information regarding potential strike risks from other sources.

For less direct impacts, contaminants such as heavy metals and agricultural runoff can enter the marine food chain, affecting the health and lactation of species. While there is some information available for California sea lions, data for other species is scarce due to limited investigation. This issue, significant in the late 1970s and 1980s, remains a concern today. The full extent of its impact is not well understood. Research has linked DDT and PCBs to diseases like herpes and cancer in sea lions, leading to fatalities. This connection between contaminants, disease, and mortality is well-established for sea lions. However, because sampling primarily focuses on genetics, there is a significant gap in understanding low-level accumulation impacts. These impacts can have long-term effects on both marine life and potentially humans exposed over their lifetimes. Another significant impact is ocean noise generated by extensive boat and barge traffic. While there is ample information available on the effects of ocean noise on killer whales, the impacts on other species remain largely uncertain.

Internationally, most of the species under study do not extend beyond national borders. There are a few exceptions. Collaborative efforts with Canada are ongoing to ensure consistent abundance data for gray whales. There are also other similar cooperative programs, particularly concerning disease and contaminants, such as those involving Guadalupe fur seals. There is a data gap regarding international fishery activities on the US West Coast, but this is not currently a priority concern.

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[49] https://wdfw.wa.gov/publications?title=&category=26289&author=
[50] https://whaleaware.org/

Offshore wind data gaps

- Effect of offshore wind on marine mammal breeding and reproduction
- Effect of power transmission cables and electromagnetic fields of offshore wind on marine mammals
- Effect of offshore wind structures on marine mammals
- Effect of vibrations and noise from offshore wind on marine mammals
- Effect of surveying technology and methodology for offshore wind on marine mammals
- Effect of light from offshore wind on marine mammals

Effect of offshore wind on marine mammal breeding and reproduction. This is an active topic that requires better understanding. Currently, there are no dedicated research programs addressing these concerns. However, there are ongoing discussions about designing monitoring programs to gather necessary data to establish baseline information. Many existing programs face funding challenges, which may hinder their ability to conduct pre- and post-installation studies.

While there is some information on marine mammal breeding and reproduction, it remains limited, particularly for species not listed for conservation, such as fur seals and small cetaceans. For example, large whales typically breed in southern waters and migrate northward to feed along the coast, while breeding pinnipeds stay close to their land-based habitat until their pups are reared. Despite the limited knowledge in this area, offshore wind activities are generally not considered a significant direct threat to breeding and reproduction. Rather, potential effects on breeding and reproduction are more likely to arise from the displacement of marine mammals from critical foraging areas or changes in food availability. For example, if a site is selected near harbor seal breeding or pupping grounds, it could have significant implications to seals by disrupting the estuarine environment.

Offshore wind activities are also expected to have a greater impact on migration and distribution than on breeding and reproduction. There are greater concerns with short-term impacts from noise and disturbance during construction and development of offshore wind, as well as long-term entanglement risks. For instance, cetaceans could potentially collide with cables, leading to injuries and disruptions in migration routes. Noise from offshore wind facilities may also interfere with cetaceans' underwater communication. Research on the acoustic effects of offshore wind is still limited.

Effect of power transmission cables and electromagnetic fields of offshore wind on marine mammals. There are data gaps regarding the effects of cables and electromagnetic fields (EMF) on marine mammals. Construction and cable laying for offshore wind development have not yet begun, so it is unclear whether EMF from these activities will be detectable to marine mammals. Generally, EMF does not significantly affect marine mammals, and the risk is further reduced due to their mobility. Unless cables are routed through a rookery, the overall impact of cables and EMF is expected to be minimal and short-term.

While some research has been conducted, it remains uncertain whether marine mammals have interacted with existing cables, and their navigation mechanisms, potentially influenced by electromagnetic fields, are not well understood. The impact of EMF may be more significant for species like sea turtles and sharks, as sea turtles rely on geomagnetic fields for navigation. Additionally, the presence of numerous cables could reduce fish abundance, affecting marine mammals that depend on them. The effects will vary depending on species and environmental context.

Effect of offshore wind structures on marine mammals. The effect of offshore wind structures remains uncertain. Some research has been conducted, but definitive answers are lacking. The outcome depends on the species and the specific environmental context.

Currently, there's limited understanding of marine mammals' ability to adjust their movements around offshore wind structures or their recognition of such structures. However, the potential for offshore wind structures to act as movement barriers is not a significant concern. Based on the effect of permanent structures in bays and estuaries at harbor seal haul-out sites and marine mammal movements, offshore wind structures could potentially have positive effects by creating docking areas marine mammals can use, especially pinnipeds. There is a tendency to focus on potential negatives, but there may be unforeseen positive outcomes. Additionally, offshore wind installations are relatively small within a vast environment. The actual structures are unlikely to exert a significant impact.

For whales, the primary concerns are vessel collisions and entanglement risks. While it is unclear whether vessel activity affects pinniped movement, it is generally believed that pinnipeds can maneuver to avoid vessels. Regarding entanglement risk, offshore wind structures may accumulate marine growth and derelict gear, increasing the potential for entanglement and displacement.

Questions also remain regarding whether offshore installations could create habitat islands, potentially aggregating fish and other species and drawing marine mammals. If the turbines serve as a local prey resource, for instance, it could lead to Steller sea lions frequenting the platforms. The structures may also alter light penetration and could change how sound moves around the structure. The effects of these potential changes are unknown.

Effect of vibrations and noise from offshore wind on marine mammals. The introduction of offshore wind projects will alter the underwater sound environment, potentially affecting marine mammal movement. Given that marine mammals rely heavily on acoustics, effects are expected which will vary by species and local conditions. Limited research has been conducted and data gaps remain.

There is some understanding of how animals respond to various noise levels and types. Cetaceans, which rely heavily on sound, are presumed to avoid noisy areas. For example, blue whales use low frequency calls for long-distance communication, and any disruption to these calls could induce stress. However, the hearing capabilities of large whales are still not well understood. Pinnipeds, in contrast, use sound less frequently than cetaceans. Research has focused on sound thresholds, particularly in relation to Navy activities, but the effects of repeated noise exposure remain unclear. The Marine Mammal Protection Act (MMPA) permits the use of sound-producing devices, though the impacts of such devices require further investigation. For additional insights, Navy literature on the effects of sound on marine mammals would be valuable, given their extensive marine mammal research program.

Understanding proposed offshore wind activities and their potential effects on specific species is a critical data gap. The specifics of offshore wind activities are still unknown, particularly the level and nature of noise, especially during operations, which will involve continuous emissions of noise over the long term. Temporary stressors, such as vessel traffic, construction, and decommissioning, may cause marine mammals to leave an area unless they have a reason to stay. Offshore wind activities may also include mechanical noise sources, such as the clanking sounds from chains observed at an offshore wind test facility off the Oregon coast. However, there are mitigation strategies available to reduce its impact.

Effect of surveying technology and methodology for offshore wind on marine mammals. There is some concern regarding the effect of survey methods and technology on marine mammals. While some studies have been conducted, there are data gaps.

Surveys have been conducted extensively over time in this region. Relevant data comes from other activities including, to a limited extent, oil and gas exploration. For example, a seismic survey funded by the NSF was conducted for earthquake research. Due to their sensitivities, there an understanding on what constitutes marine mammal harassment and how to protect them within safe thresholds. However, gathering additional data to determine whether surveys are causing marine mammals to relocate will be helpful.

The siting requirements for offshore wind remain unclear, and more information is needed about the specifics of these surveys, which may include both aerial and ocean components. For example, seismic surveys will likely be essential for offshore wind projects and other activities that require seabed anchoring, as they help identify suitable substrates for installation. Any geological sampling will require deploying large booms to reflect signals off the seafloor, a method used in oil exploration to locate fault lines. Drones may also be used, although their operational range is limited. Due to their temporary nature, offshore wind surveys are expected to have minimal effects. However, collecting data will still be crucial as these surveys will result in some effects, along with additional impacts from related activities, such as vessel operations. For instance, pelagic surveys, typically conducted with a small boat following transects, may cause slight displacement of bow-riding species. In California, buoy installations are underway and are expected to have minimal impact on marine mammals. No significant effects on cetaceans are anticipated; however, this may change if they shift their distribution toward coastal or offshore areas. For pinnipeds, no impact is expected based on the survey timeframe and the species present.

Effect of light from offshore wind on marine mammals. The effect of light on marine mammals represents a significant knowledge gap. While some studies have been conducted, comprehensive insights are still lacking. The impact on marine mammals will vary depending on species, environmental context, and food resources. Light may attract or repel marine mammals, enhance foraging efficiency, or cause stress. Increased light intensity could also aggregate fish, providing targets for marine mammals. Overall, while light may have some impact, it is expected to be minimal, and this data gap is not a major concern.

Pinnipeds: Pinnipeds may be drawn closer if light used at night causes prey to rise to the surface, a phenomenon known as the scattering layer, which reduces the effort needed to locate prey. Pinnipeds adjust their diving depths based on day and night cycles, diving shallower at night when prey is near the surface and deeper during the day. They follow prey as it moves through the water column. However, their natural behavior is adapted to darkness, and excessive bright light, particularly near rookeries, could have negative effects. Light could also increase their exposure to predators like killer whales or sharks.

Cetaceans: The effects of light on cetaceans remain uncertain and require further study.

Offshore aquaculture data gaps

- Effect of nutrients, waste, and chemicals from offshore aquaculture on marine mammals
- Risk of disease transmission from offshore aquaculture to marine mammals
- Effect of offshore aquaculture on marine mammal migration patterns and distribution
- Risk of entanglement with offshore aquaculture

Effect of nutrients, waste, and chemicals from offshore aquaculture on marine mammals. The potential risk depends on water content, concentration, species present, and scale. In the ocean, extensive dilution is anticipated. The risks to marine mammals will likely be localized.

Processing plants in Puget Sound indicate discarded fish attract harbor seals to the bay. Similarly, if offshore aquaculture facilities discard their products, it could also draw marine mammals. Introducing nutrients can also enhance primary production, influencing the food web and potentially triggering harmful algal blooms (HABs). The effect of nutrients may vary, including affecting water clarity and visibility.

The primary risk lies in ingestion. Marine mammals consuming aquaculture species can heighten the risk of disease and exposure to chemicals. The depth and species of aquaculture are determining factors. Chemical impacts hinge on their composition and potential for bioaccumulation or biomagnification in the food chain. Heavy metals and antibiotics also pose concerns, especially to the food web.

Floating contaminants generally do not affect pinnipeds unless consumed through the food chain.

Risk of disease transmission from offshore aquaculture to marine mammals. Offshore aquaculture operations may affect marine mammals through their prey. Diseases among fish species in aquaculture settings could pose risks, though the likelihood of viruses from fish or invertebrates crossing over to marine mammals is low. Most bacteria and viruses are host-specific and follow particular life cycles, so for a virus to affect marine mammals, it would need to be closely related to them. The risk also depends on the species being raised. The potential for invertebrate diseases to transfer is less clear. While there may be implications if marine mammals consume fish infected with parasites, aquaculture facilities typically manage fish health through treatments. Of greater concern are biotoxins that can bioaccumulate, as well as chemical contaminants, which may pose risks to marine mammals.

Effect of offshore aquaculture on marine mammal migration patterns and distribution. There will be concerns if offshore aquaculture displaces animals from critical foraging areas. This effect will depend on the location and size of the offshore aquaculture operation. Offshore aquaculture could also increase productivity which could lead to marine mammals interacting with the facility, but significant population-level impacts would require a large scale.

In particular, pinniped response to offshore aquaculture will depend on the species being farmed. For example, they are not typically affected by shellfish aquaculture, as they do not consume invertebrates. However, the presence of aquaculture operations may attract other wild species, which in turn could attract pinnipeds. Canadian aquaculture operations may provide insights into this behavior, as pinnipeds have been known to breach or attempt to breach pens.

It is unclear how cetaceans will respond to offshore aquaculture, but they may exhibit similar behaviors. For instance, harbor porpoises could be attracted if the facility aggregates small fish, and other smaller cetaceans may be drawn to prey within aquaculture pens. However, species like gray whales, which primarily consume amphipods and other bottom-dwelling organisms, are unlikely to enter an aquaculture pen.

Risk of entanglement with offshore aquaculture. Yes, there is a potential concern regarding entanglement risk, which has been an issue for pinnipeds. Due to numerous net pens in Puget Sound experiencing problems with sea lions, anti-predator nets were installed to deter them from the fish. There have been a few entanglements associated with these measures.

A global survey reviewed potential entanglements of whales and marine mammals with aquaculture structures, indicating a low but existing risk. The understanding of entanglement risk parallels the understanding of risks from vessel activities. It depends on the size, material, and construction methods of offshore aquaculture structures. These structures themselves can pose entanglement hazards, particularly with fine netting like gillnets or trawl nets. Hanging lateral structures from facilities also increase entanglement risk. For whales, if the facility is large enough, whales may attempt to swim through the facility.

Resources

Table 18. Resources relevant to marine mammals.

NAME	ACCESS	TYPE	DESCRIPTION
A review of climate change effects on marine mammals in United States waters: Past predictions, observed impacts, current research and conservation imperatives	https://www.mmc.gov/wp-content/uploads/Gulland-et-al-2022.pdf	Published article	Assessed whether climate change impacts on marine mammals inhabiting US waters are known, suspected, or just likely to have occurred.
California Current Marine Mammal Assessment Program	https://www.fisheries.noaa.gov/west-coast/science-data/california-current-marine-mammal-assessment-program	Website	Provides information and resources relating to NOAA's assessment of the population status of marine mammals in the California Current.
Climate Vulnerability Assessments	https://www.fisheries.noaa.gov/national/climate/climate-vulnerability-assessments	Website	Information, tools, and resources regarding NOAA Fisheries' assessment of the vulnerability of fish species, protected species, habitats, and fishing communities to changing climate and ocean conditions.
Clinical Signs and Pathology Associated with Domoic Acid Toxicosis in Southern Sea Otters	https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2021.585501/full	Published article	Characterized health effects of domoic acid exposure in southern sea otters.

NAME	ACCESS	TYPE	DESCRIPTION
Impacts of Offshore Wind on Marine Mammals and Seabirds: The Knows & Unknowns	https://www.youtube.com/watch?v=8PiCYmXz1Tw	Webinar	Discussed the state of the science for balancing offshore wind energy development in California with coastal sustainability and biodiversity objectives, focusing on marine mammals and seabirds.
Low Resighting Rate of Entangled Humpback Whales Within the California, Oregon, and Washington Region Based on Photo-Identification and Long-Term Life History Data	https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2021.779448/full	Published article	Used photo-ID images of entangled humpback whales between 1982 and 2017 to examine pre- and post-entanglement sighting histories.
Marine Mammal Stock Assessment Reports	https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-stock-assessment-reports-species-stock	Website	Contains all marine mammal stock assessment reports prepared by NOAA Fisheries.
Predictive mapping of seabirds, pinnipeds and cetaceans off the Pacific Coast of Washington	https://repository.library.noaa.gov/view/noaa/9329	Report	Compiles information on seabirds, pinnipeds, and cetaceans and advances a modeling framework that integrates data sets and develops predictions of relative species density off the Pacific Coast of Washington.

NAME	ACCESS	TYPE	DESCRIPTION
Vulnerability Index to Scale Effects of Offshore Renewable Energy on Marine Mammals and Sea Turtles Off the US West Coast (VIMMS)	https://espis.boem.gov/Final%20Reports/BOEM_2023-057.pdf	Report	Systematic assessment of marine mammal and sea turtle vulnerability to disturbance by population, life history, acoustic, and environmental factors.
Washington Department of Fish & Wildlife: Publications	https://wdfw.wa.gov/publications?title=&category=26289&author=	Website	Search engine for status reports on species in Washington.
Whale Alert	https://whaleaware.org/	Website	Provides information on Whale Alert, an application that shares whale sightings.
Whale Trail Sites	https://thewhaletrail.org/regions/	Website	Provides information on publicly accessible sites in British Columbia, Washington, Oregon, and California that offer a reasonably good chance of seeing marine mammals.

Pacific Whiting

Key Data Gaps

General Data Gaps

- Abundance, distribution, health, and trend of Pacific whiting
- Environmental factors that influence population dynamics of Pacific whiting
- Predator-prey dynamics of Pacific whiting

Offshore Wind Data Gaps

- Effect of offshore wind on early marine survival of Pacific whiting
- Effect of noise and vibrations from offshore wind on Pacific whiting
- Effect of offshore wind on migration of Pacific whiting

Other Data Gaps

Offshore Wind Data Gaps

- Effect of offshore wind structures on Pacific whiting
- Effect of electromagnetic fields from offshore wind on Pacific whiting
- Effect of light from offshore wind on Pacific whiting
- Effect of offshore wind on human activities and subsequent effect on Pacific whiting

Offshore Aquaculture Data Gaps

- Efect of offshore aquaculture on Pacific whiting competition, predation, and other interactions
- Effect of waste products, nutrients, and chemicals from offshore aquaculture on Pacific whiting
- Effect of disease from offshore aquaculture on Pacific whiting
- Effect of offshore aquaculture on migration of Pacific whiting
- Effect of offshore aquaculture on human activities and subsequent effect on Pacific whiting
- Effect of offshore aquaculture on early marine survival of Pacific whiting

Background

Pacific whiting, also known as hake, are among the most plentiful fish species in the California Current. They forage in pelagic waters, preying on items similar to those consumed by salmon, rockfish, and other groundfish species. They inhabit deeper waters during the day and ascend to feed on phytoplankton at night, playing a crucial role in connecting primary production with deeper ocean layers.

The Pacific whiting fishery includes both shore-based and at-sea catcher vessels. The shore-based fishery takes place off Washington and Oregon, with active ports in Westport and Ilwaco, Washington. At sea, key fishing grounds are located on the continental shelf and upper continental slope regions of the Study Area. Between 2004 and 2014, fishing locations were influenced by efforts to avoid salmon and rockfish bycatch. Catch levels off Washington fluctuate annually, especially in the at-sea sector. From 2004 to 2014, landings from the Pacific whiting fishery consistently represented the largest share of total commercial landings on the Washington coast by weight, except for 2012 and 2013.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to Pacific whiting:

General data gaps

- Abundance, distribution, health, and trend of Pacific whiting
- Environmental factors that influence population dynamics of Pacific whiting
- Predator-prey dynamics of Pacific whiting

Abundance, distribution, health, and trend of Pacific whiting. While there are inevitably data gaps and areas for further research, the available data on abundance, distribution, health, and trend for Pacific whiting are relatively comprehensive. Pacific whiting surveys are conducted as part of the Joint United States (US) - Canada Integrated Ecosystem and Pacific Hake Acoustic Trawl Survey. The Pacific whiting assessment is internationally recognized as a leading stock assessment, providing reliable health, trend, and abundance metrics. Acoustic surveys are conducted from spring to fall, spanning from San Francisco, California, to the Canada-Alaska border. These surveys also gauge the size of Pacific whiting schools. Starting in 2025, the US survey will be integrated with the Coastal Pelagic Species (CPS) California Current Ecosystem (CCE) survey. Midwater trawl surveys are also employed to validate acoustic measurements.

When the joint surveys began in 1995, the Alaska Fisheries Science Center conducted surveys triennially. Since NOAA assumed control of the surveys in 2003, they were done every other year. There was one exception. In 2011, a historically low biomass estimate was recorded, prompting an additional survey in 2012 to assess whether this downward trend persisted. Signs of recovery were observed. The decline in Pacific whiting biomass may have been influenced by predation from Humboldt squid which increased in population in 2009.

Distribution: Pacific whiting demonstrates a strong affinity for the continental shelf break, often aggregating near this feature and along the slope before trailing offshore. They also exhibit a wide vertical distribution within the water column, with sightings ranging from shallower depths of 100-150m to deeper regions up to 500m. Surveys conducted by the Department of Fisheries and Oceans Canada (DFO) revealed that Pacific whiting tend to aggregate in concentrated areas during the day but disperse at night without moving in a specific direction. This behavior may be influenced by the movement of krill, which responds to light.

There are several data gaps concerning the distribution of Pacific whiting. For example, the southern and northern extents of their population are not well understood. While there are general estimates of these boundaries, they fluctuate from year to year, and it remains unclear whether specific components of the population are overlooked. There is also limited understanding of the movement patterns and environmental cues that drive Pacific whiting migration, primarily due to the challenges associated with tracking these fish. Recent research, spearheaded by the US, examined environmental factors that may influence their movement such as sea surface temperature, undercurrent strength, and krill distribution. However, additional information is needed to fully grasp these dynamics. Management efforts are increasingly emphasizing the need for a more comprehensive understanding of these factors. Additionally, the spawning locations of Pacific whiting are unknown, though hypotheses suggest that spawning may occur in mid-winter off the coast of California or Oregon.

Health: There is information on age, biomass, and growth. When trawling is conducted to validate the collected acoustic data, data on Pacific whiting length, age, weight, and sex are obtained. Maturity data is collected and reviewed visually as well as through osteology. Other sources of data are also collected. Stomach content analysis is conducted to assess prey composition and while not an ongoing effort, several years ago, blood sample analysis was done to analyze health.

Trend: While joint surveys for Pacific whiting began in 1995, surveys for Pacific whiting began before 1995. A time series of data on abundance, distribution, and trend of Pacific whiting are available. For example, there is biomass and distribution data from 1995 to 2023. In 2023, the biomass estimates for adult Pacific whiting primarily comprised young fish aged 2 to 3 years old.

Feedback on importance: Data on the winter distribution and the full extent of the Pacific whiting's range, both to the north and south, remain unknown. Additionally, there is a need to understand the processes that Pacific whiting use to determine the timing and distance of their migrations.

Environmental factors that influence population dynamics of Pacific whiting. Pacific whiting is adaptable to different environmental conditions. There is a robust environmental sampling effort and access to a long time series of environmental data. For instance, due to physiological and ecological adaptations, Pacific whiting is less sensitive to oxygen levels compared to other species like rockfish. However, there's still much more to learn about how both biotic and abiotic environmental factors influence whiting’s distribution, reproduction, and growth. For example, the relationship between climate and whiting distribution, as well as the climate drivers affecting recruitment, is not fully understood. Traditionally, whiting migrates further north during El Niño years, but recent observations show that while older hake still migrate northward, younger hake are not traveling as far. This suggests that other changing conditions may be influencing their movement. As climate conditions continue to evolve, understanding the long-term effects of climate change on whiting and other groundfish populations becomes increasingly important.

While whiting is remarkably ubiquitous, there is still a lack of comprehensive understanding regarding the effects of environmental factors on their behavior. Further complicating this knowledge gap, studying them in laboratory settings is challenging.

Feedback on importance: In particular, there is an interest in understanding the environmental factors that influence spawning.

Predator-prey dynamics of Pacific whiting. The primary predators of Pacific whiting include squid, adult Pacific whiting (which prey on younger whiting), various finfish, marine mammals, and humans. Pacific whiting plays a significant role in the community and ecosystem dynamics of the California Current Ecosystem (CCE). Conceptual models can be constructed to better understand the predator-prey dynamics within this system. Monitoring is also essential as the effects of other species on Pacific whiting remain unclear. Relevant research has been conducted, including studies on the overlap of krill distribution, stomach content analysis to determine diet composition, and investigations into mortality parameters, such as giant squid predation.

Feedback on importance: There is a tradeoff between mortality and growth. This prompts questions about the natural mortality rate of Pacific whiting and how it evolves over time.

Offshore wind data gaps

- Effect of offshore wind on early marine survival of Pacific whiting
- Effect of noise and vibrations from offshore wind on Pacific whiting
- Effect of offshore wind on migration of Pacific whiting

Effect of offshore wind on early marine survival of Pacific whiting. Their spawning is more likely to occur in California and Oregon, making it less of a significant concern for Washington.

Feedback on importance: No specific feedback provided.

Effect of noise and vibrations from offshore wind on Pacific whiting. The effect of noise or vibrations from offshore wind activities on Pacific whiting is a data gap.

Feedback on importance: No specific feedback provided.

Effect of offshore wind on migration of Pacific whiting. Offshore wind will likely affect migration. This would partially depend on the degree to which these platforms influence oceanographic conditions and undercurrents.

Feedback on importance: No specific feedback provided.

Other Data Gaps

The following are the remaining data gaps:

Offshore wind data gaps

- Effect of offshore wind structures on Pacific whiting
- Effect of electromagnetic fields from offshore wind on Pacific whiting
- Effect of light from offshore wind on Pacific whiting
- Effect of offshore wind on human activities and subsequent effect on Pacific whiting

Effect of offshore wind structures on Pacific whiting. If offshore wind structures function as a fish aggregating device (FAD), there is limited concern about potential impacts on Pacific whiting, as these fish typically inhabit deep waters and the midwater column. However, due to the absence of similar structures for direct comparison, the precise effects of these new developments on Pacific whiting are uncertain. In particular, there is a data gap regarding how offshore will structures will affect Pacific whiting schooling patterns. Oil rigs may serve as the closest proxy for understanding potential impacts.

Offshore wind structures may also have indirect effects on Pacific whiting. If these structures alter ocean dynamics, significant concerns could emerge. Pacific whiting is sensitive to changes in water column properties and tend to target areas with certain water properties favored by their prey.

Stock assessment efforts could shed light on how changes in ocean properties might affect Pacific whiting distribution. Additionally, if the area is designated for an offshore wind farm, acoustic surveys could be conducted to further investigate these effects.

Effect of electromagnetic fields from offshore wind on Pacific whiting. The effect of electromagnetic fields (EMF) on Pacific whiting constitutes a significant data gap. Currently, Pacific whiting's migration patterns are hypothesized to be influenced by either electromagnetic fields or the strength of oceanic undercurrents. Consequently, EMF generated by offshore wind cables may potentially affect Pacific whiting. Further research is required to comprehensively understand the effects of EMF on these species and to determine its implications for their migratory behavior.

Effect of light from offshore wind on Pacific whiting. Pacific whiting exhibits a broad distribution within the water column, ranging from shallower depths (100-150m) to deeper regions, up to 500m. Data collection during transects typically occurs from sunrise to sunset. During a joint survey with Canada, colleagues from the Department of Fisheries and Oceans Canada (DFO) deployed moorings to investigate Pacific whiting migration patterns throughout a diurnal cycle, particularly whether they ascend to the surface at night in search of food sources.

Throughout the day, Pacific whiting was observed to aggregate in concentrated areas. As sunset approached and data collection efforts continued, the fish began to disperse and spread out across the water column. At night, they disaggregated and didn’t display a specific migratory direction. This change in behavior from sunset to nighttime suggested that light may influence their movements. Alternatively, their behavior could be driven by prey dynamics, as krill, a primary food source for Pacific whiting, responds to light. Pacific whiting is known to engage in vertical migration to follow krill and other prey, potentially bringing them closer to the surface during the night. Both of these explanations are possible but are still largely unknown and necessitate additional research.

Effect of offshore wind on human activities and subsequent effect on Pacific whiting. Offshore wind developments may disrupt existing human activities related to Pacific whiting, such as the fishing industry and Pacific whiting surveys. More specifically, offshore wind could interfere with vessel navigation and obstruct access to Pacific whiting schools. It also poses a challenge for conducting surveys in these corridors or near the structures. Using alternative survey methods such as non-cruise systems, sail drones, or other technologies capable of accessing offshore wind areas will be needed to assess and better understand the potential effects.

Offshore aquaculture data gaps

- Effect of offshore aquaculture on Pacific whiting competition, predation, and other interactions
- Effect of waste products, nutrients, and chemicals from offshore aquaculture on Pacific whiting
- Effect of disease from offshore aquaculture on Pacific whiting
- Effect of offshore aquaculture on migration of Pacific whiting
- Effect of offshore aquaculture on human activities and subsequent effect on Pacific whiting
- Effect of offshore aquaculture on early marine survival of Pacific whiting

Effect on offshore aquaculture on Pacific whiting competition, predation, and other interactions. The effect of offshore aquaculture will vary depending on the species being farmed. A major concern is understanding the potential consequences if non-native species escape from aquaculture facilities and the effects on local stocks if native species are raised and interbreed. The location of the offshore aquaculture also plays a critical role in determining the extent of these impacts. For example, at a depth of 500 meters, any potential effects would likely be rapidly diluted. Furthermore, while extensive aquaculture operations could potentially disrupt local ecosystems and affect Pacific whiting, significant impacts on species are unlikely unless regulatory measures are not properly enforced.

Effect of waste products, nutrients, and chemicals from offshore aquaculture on Pacific whiting. There is uncertainty regarding the potential effect, but the prevailing sentiment is this effect may not be significant because Pacific whiting typically inhabit depths of approximately 200 meters below the surface. This issue may apply more to organisms residing closer to the surface.

Effect of disease from offshore aquaculture on Pacific whiting. Rather than the effect of a disease from offshore aquaculture activities, there is a greater concern with disease transmission.

Effect of offshore aquaculture on migration of Pacific whiting. Migration patterns are closely tied to oceanographic conditions and prey availability. Therefore, if a nutrient bloom were to occur, affecting krill populations, Pacific whiting could be impacted as well. This interaction between oceanography and krill concentrations could potentially lead to population-level changes for Pacific whiting.

Effect of offshore aquaculture on human activities and subsequent effect on Pacific whiting. It is difficult to envision that this will have a significant effect on the population. However, it's worth considering the potential effects on the fishing industry.

Effect of offshore aquaculture on early marine survival of Pacific whiting. Pacific whiting spawning is more likely to occur in California and Oregon. Hence, offshore aquaculture is unlikely to pose a major issue on the early marine survival of Pacific whiting in Washington.

Resources

Table 19. Resources relevant to Pacific whiting.

NAME	ACCESS	TYPE	DESCRIPTION
Pacific Fishery Management Council: Groundfish Fishery Management Plan	https://www.pcouncil.org/managed_fishery/groundfish/	Website	Contains information and documents regarding groundfish management.

Salmon

Key Data Gaps

General Data Gaps

- Salmon predators
- Effect of climate change on salmon

Offshore Wind Data Gaps

- Effect of offshore wind structures on salmon
- Effect of offshore wind on early marine survival of salmon
- Effect of electromagnetic fields from offshore wind on salmon

Offshore Aquaculture Data Gaps

- Effect of disease from offshore aquaculture on salmon

Other Data Gaps

General Data Gaps

- Abundance, distribution, health, and trend of salmon

Offshore Wind Data Gaps

- Effect of noise and vibrations from offshore wind on salmon
- Effect of light from offshore wind on salmon
- Effect of offshore wind on salmon migration

Offshore Aquaculture Data Gaps

- Effect of offshore aquaculture on competition, predation, and other interactions involving salmon
- Effect of waste products and chemicals from offshore aquaculture on salmon
- Effect of offshore aquaculture on early marine survival of salmon
- Effect of escapements from offshore aquaculture on salmon
- Effect of offshore aquaculture on salmon migration

Background

Salmonids (salmon and related species) holds deep cultural significance for Washington residents, encompassing both tribal and non-tribal communities, and play crucial roles ecologically and economically. Salmon spawn in freshwater, then migrate to marine areas to feed and grow before returning to freshwater to reproduce. Juvenile salmon rely on estuaries for food and protection from predators. The MSP Study Area hosts several salmonid species whose occurrence can fluctuate yearly due to ocean and environmental changes. There are spatial and temporal variations between populations. Nine of the thirteen anadromous species in the MSP area are federally listed as endangered or are on Washington State's Species of Concern lists. American Shad, introduced in the late 1800s, is an established non-native species in the region.

Salmonids are evaluated for potential listing and recovery under the Endangered Species Act (ESA) based on distinct populations known as Evolutionarily Significant Units (ESUs). Several ESUs such as Puget Sound Chinook, and non-listed ESUs like Washington Coast Chinook, spend parts or all their adult lives in the MSP Study Area. Under the ESA, critical habitat, habitat deemed essential for the conservation of a listed species, has been designated for specific salmon ESUs in streams, rivers, and certain bays or estuaries adjacent to the Study Area. The Magnuson-Stevens Fishery Conservation and Management Act designates Essential Fish Habitat (EFH) for marine salmon (Chinook and Coho Salmon) throughout the Exclusive Economic Zone (EEZ). EFH refers to areas necessary for spawning, breeding, feeding, or growth of federally managed fish. Pink Salmon's EFH is designated in Puget Sound, the Strait of Juan de Fuca, and extends into the MSP Study Area.

Ocean conditions serve as predictive indicators for Chinook and coho salmon returns, such as the Pacific Decadal Oscillation (PDO), sea surface temperature anomalies, coastal upwelling, spring transition dates, and anomalies in copepod biomass. During a positive phase of PDO, salmon stocks in Washington, Oregon, and California typically show reduced production. Conversely, during a negative PDO phase, these areas often experience higher salmon production.

Salmon have been and continue to be impacted by numerous pressures including fishing, habitat loss, hydropower dams, land use activities, predation, and poor ocean conditions, which collectively can include changes in chemical or physical conditions and an accompanying loss of food supply. Salmon recovery efforts in Washington encompass hatchery programs, initiatives for habitat improvement, and rigorous fisheries management practices.

Salmon management is influenced by various factors including oceanic conditions, predation, declines in hatchery programs, habitat degradation, fragmentation, pollution, and overfishing. Given the intricate life histories of salmon and longstanding human interaction, the future of this fishery is expected to be dynamic and uncertain.

Commercial fishery: Salmon are identified as possibly being Washington’s most historic and iconic fish, valued as seafood with the second highest revenue per pound in the MSP Study Area. Low allowable catches limit the fishery. Commercial salmon fisheries have decreased significantly due to factors such as reduced salmon populations. Managed annually by the State and treaty Tribes, salmon fisheries involve two main sectors: ocean troll and gillnet fisheries. The PFMC regulates troll fishing seasons, while WDFW oversees gillnet seasons. Both sectors are part of a larger salmon management process that involve Washington, Oregon, California, Alaska, Idaho, Canada, and numerous tribal entities.

Recreational fishery: Within the MSP Study Area, the recreational salmon fishery in Washington spans Willapa Bay, the Chehalis Basin, and the Pacific Ocean. Ocean salmon are the most popular finfish target species for effort and are the second highest finfish in terms of average catch between 2007 and 2012. Annual catches vary widely. Chinook Salmon dominate Westport catches, while Neah Bay sees the majority of Pink Salmon landings. Grays Harbor dominates coastal estuary salmon fishing. WDFW manages salmon fisheries within three miles of the Washington coast in coordination with PFMC and Tribes, navigating complex management due to salmon's migratory habits and ESA-listed units.

Aquaculture: Beginning in the 1970s, Atlantic salmon were farmed in net pens in Puget Sound, raising public concern over potential impacts on native Pacific salmon, water quality, and ecosystem health. These concerns intensified after a commercial facility collapsed near Cypress Island in August 2017. In response, the 2018 state legislature banned Atlantic salmon and other non-native commercial finfish aquaculture in state waters. State agencies were directed to develop guidance to minimize risk for commercial marine finfish net-pen aquaculture. The Washington Department of Natural Resources (DNR) terminated the leases of all finfish net pen aquaculture on state-owned aquatic lands in 2022.[51]

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to salmon:

General data gaps

- Salmon predators
- Effect of climate change on salmon

Salmon predators. The primary cause of mortality for salmon is predation. However, there's a lack of understanding regarding the identity of their predators. There is a need to understand which predators are most significant and the specifics of when and where predation occurs.

Feedback on importance: No specific feedback provided.

> **WCMAC:** Recent research has focused on the impact of predation on salmon and steelhead populations, highlighting several key studies. The $20 million, five-year early marine survival study by Long Live the Kings and the Pacific Foundation examined predation in Puget Sound and the Salish Sea, providing valuable insights. There is also ongoing work by the Washington Department of Fish and Wildlife to investigate harbor

[51] https://www.dnr.wa.gov/news/commissioner-franz-fight-reinstate-net-pens-washington-over#:~:text=Commissioner%20Franz%20in%202022%20signed,remove%20the%20last%20pen%20from

seal predation on salmon at the Stillaguamish River. Additionally, studies in the Columbia River have explored the effects of California sea lions on salmon populations. There is a new research effort underway. NOAA is launching a three-year project to assess predation on juvenile salmon by marine mammals and avian predators, with the first year dedicated to design and subsequent assessments planned for 2025-2026. Together, these efforts will enhance understanding of predator influences on salmon survival.

Effect of climate change on salmon. The precise mechanisms linking climate change to salmon survival are not fully understood. Salmon survival appears to be influenced by climate patterns such as PDO and the North Pacific Gyre Oscillation (NPGO), which affect marine conditions critical to their well-being. However, it remains uncertain whether researchers have been able to isolate specific environmental factors attributable to climate change that directly impact salmon survival. Studies have explored how temperature changes influence steelhead trout.

Feedback on importance: No specific feedback provided.

WCMAC: Understanding the effects of climate change on salmon encompasses studying a wide range of factors that can influence salmon productivity. One evident impact is the warming of oceans and the occurrence of marine heat waves, which adversely affect lower-level prey that young salmon rely on for food, such as forage fish and copepods. These changes are already negatively impacting salmon productivity in the ocean. Additionally, the implications of ocean acidification (OA) under the climate change umbrella are becoming clearer, particularly regarding how OA affects crustaceans and copepods, which need calcium to thrive. These organisms are crucial for salmon during their early oceanic phase in late spring and early summer.

Efforts to understand climate change impacts on fisheries, especially salmon, have led to collaborative research projects between Canada and the United States (US), focusing on offshore waters off Southeast Alaska. Research cruises, funded by both public and private sources, aim to assess the conditions affecting salmon and steelhead populations and their survival. Institutions like the Northwest Fisheries Science Center (NWFSC) and the Southwest Fisheries Science Center (SWFSC) are also involved, maintaining a dynamic data needs document that is reviewed biennially.

The effects of sea level rise on estuaries, which are vital for the early life stages of salmon, also remain largely unknown and could have profound consequences as sea levels continue to rise.

Offshore wind data gaps

- Effect of offshore wind structures on salmon
- Effect of offshore wind on early marine survival of salmon
- Effect of electromagnetic fields from offshore wind on salmon

Effect of offshore wind structures on salmon. Offshore wind structures are more likely to affect fish in the water column, prompting the fish to aggregate around the structure. In

Hawaii, fish aggregating devices (FADs) are used to attract tuna. It is uncertain whether salmon would respond similarly. In rivers, salmon often gather around rock piles, drawn by the influx of food. Based on salmon behavior, it is reasonable to speculate that they could also aggregate around offshore wind structures. Studies could be done by tethering structures with cameras and hydroacoustic monitors. If there's no evidence of aggregation, it may not pose a significant issue. However, this effect will also depend on scale. Not every effect may be additive.

There are several related considerations to address. The impact of structures on ecosystem patchiness could influence predation dynamics. Structures could also potentially alter migration behavior. Additionally, they may attract predators, and if salmon also congregate around them, their vulnerability to predation could increase. Structures may also interfere with fishing activities in the nearby area, which should be understood in advance. Conducting a modeling exercise would be valuable in assessing these potential impacts.

The effect of structures is a substantial data gap. However, the necessary expertise is available and ready to undertake the task; funding is the remaining requirement.

Feedback on importance: This issue warrants higher priority, as determining whether offshore wind structures attract or repel salmon is crucial. If structures repel salmon over a large area, it could have significant implications. However, dispersal to avoid proximity to the structure would be a less critical concern. Additionally, if these structures attract predators, there could be significant consequences. It is important to assess whether these effects are neutral when compared to background variation, as this will help understand their overall impact.

WCMAC: The effect of offshore wind structures on salmon populations remains uncertain. Once these structures are in place, any adverse impacts on salmon could also affect a wide range of other important natural resources. For example, anchors are likely to attract sedentary groundfish species such as lingcod, Pacific Ocean perch, and canary rockfish, as well as some mid-water dwelling rockfish. These fish can often be observed congregating around weather buoys. Additionally, the impacts of associated infrastructure, supply lines, and power grids on the water column are still unknown. Proceeding without caution may lead to significant negative consequences for various ecosystems. If offshore wind structures adversely affect forage fish such as short belly rockfish, Pacific mackerel, anchovies, sardines, and herring, it raises concerns about the availability of food for other species that depend on them.

Comparing oil rigs to offshore wind structures is not appropriate, as the number, size, and footprint of offshore wind installations will far exceed those of oil rigs. Even in the densest areas of oil platforms, such as by Los Angeles in California, the scale of structures required for offshore wind to generate sufficient electricity will dwarf the existing number of oil rigs.

Salmon are confronting significant challenges for their future, raising concerns about their ability to sustain healthy populations, particularly those that rely on natural spawning. This year, there are no ocean salmon fisheries in the southern regions, where run sizes previously ranged from 600,000 to 700,000. Currently, Chinook stocks are on life support, with natural populations dwindling to fewer than 1,000. The introduction of large-scale wind energy areas off the coast, where salmon migrate, forage, and grow, poses additional risks for future generations. The potential impact on the ocean ecosystem is troubling. Salmon serves as indicators of environmental health, often being the first species to suffer from such changes. The willingness to accept these risks is perplexing, given the stakes involved.

Engaging in offshore wind development quickly and industrially, without adequate research and experimentation, poses significant risks. With only two wind platforms currently in place, there is limited understanding of their impacts. While these projects mention mitigation measures to offset potential losses, it raises ethical concerns about accepting compensation for harm to natural resources that will affect future generations. This is not something that can be owned or sold.

Effect of offshore wind on early marine survival of salmon. There is a lot of information on the critical role early marine survival plays in shaping the trajectory of salmon populations. There's an accepted understanding of the mechanisms involved in this process and there is extensive data on factors like age, size, growth, abundance, and survival. A considerable amount of background information is available to help gauge how different factors may impact salmon survival.

The effects of offshore activities on early marine survival are largely unknown. Since salmon primarily spawn in rivers and do not drift as larvae but swim, direct impacts on spawning are not anticipated. Nevertheless, there are potential consequences for growth through potential inhibition of upwelling, alterations in prey distribution, and changes in prey abundance (such as krill and small fish). In particular, addressing this data gap should involve assessing how offshore wind activities influence food availability for juvenile salmon during critical developmental stages. Juveniles start by eating invertebrates like copepods and smaller invertebrates and eventually graduate to squid, herring, and hake. Understanding these dynamics is crucial for making accurate predictions. Additionally, changes in the California Current Ecosystem (CCE) could affect food availability for adult salmon as well.

Feedback on importance: Understanding this data gap includes understanding the connection between offshore wind projects and the CCE, upwelling dynamics, and food availability.

WCMAC: The potential effects of offshore wind on the early marine survival of salmon are not concerning, particularly since salmon is not associated with larval drift. This concern is more relevant for species like crab and rockfish. However, offshore wind may affect recruitment, which refers to how many fish are produced by spawning adults, influencing early life stage survival. Different salmon species spend varying amounts of time in freshwater before transitioning to saltwater. For instance, chum, Chinook, and sockeye salmon migrate quickly, while coho and pink salmon take longer. The impacts of offshore wind on these early life stages remain uncertain.

The call areas for offshore wind in Oregon were situated near several river systems that support healthy Chinook populations. Any adverse effects on forage fish could negatively impact young salmon as they migrate from rivers in the spring. For Washington, if offshore wind will not extend north of Grays Harbor, the remaining area covers the last 35 miles, which is crucial since the Columbia River, a significant source of salmon on the West Coast, lies nearby. Most salmon from this region migrate offshore and north. Offshore wind projects could be directly in the migratory path of salmon, including those returning to spawn. Given that a substantial percentage of Washington's salmon originate from the Columbia River, any adverse effects could significantly impact the most productive salmon populations on the West Coast. It is essential to conduct thorough research and understand these impacts before investing millions or billions of dollars in infrastructure, ensuring that abundant river systems are protected from potential harm.

Effect of electromagnetic fields from offshore wind on salmon. There is a data gap regarding the impact of electromagnetic fields (EMF) on salmon migration. Salmon uses the earth's magnetic field for orientation in open water. However, the mechanisms by which salmon navigate remain unclear. If offshore wind cables disrupt these magnetic signals, it could potentially interfere with salmon migration patterns, posing a significant issue. The potential for EMF to affect their migration patterns depends on its spatial extent. While there may be existing research on the effects of EMF on animals, there is limited evidence demonstrating how magnetic fields from offshore wind projects specifically affect salmon migration.

Feedback on importance: No specific feedback provided.

WCMAC: It is important to consider that EMF generated by transmission lines and other electrical components on wind platforms could affect salmon, particularly given their migratory nature and their need to return to natal streams. Research to address these data gaps is essential, ideally as part of a test platform.

Offshore aquaculture data gaps

- Effect of disease from offshore aquaculture on salmon

Effect of disease from offshore aquaculture on salmon. Extensive literature addresses the conditions under which diseases and parasites pose significant problems. In British Columbia and Western Europe, there are substantial concerns regarding diseases and parasites, particularly sea lice. When sea lice infestations are severe, they can cause significant harm or mortality to smaller fish. The impact of sea lice varies considerably depending on the size of the fish: a few sea lice can have vastly different effects on a small fish compared to a larger one. Numerous studies have explored these dynamics, highlighting the importance of managing sea lice populations in aquaculture settings.

A substantial body of information exists regarding salmon, diseases, and viruses, revealing that some parasites and viruses are highly host-specific, while others are less so. Viruses can evolve more rapidly than their hosts, which complicates disease management. Salmon are relatively well-studied due to their ecological and economic importance, and their movements—both when they leave and return to freshwater—are well-documented. Juvenile salmon are sufficiently large to be tagged for tracking purposes.

Disease is a significant concern due to the increased transmission rates associated with high-density aquaculture environments. In aquaculture settings, diseases can spread quickly if the density of fish exceeds natural levels found in the open ocean. Additionally, interactions with wild fish that come into contact with farmed fish can facilitate disease transmission. Once a disease outbreak occurs, controlling its spread can be extremely challenging, and the consequences can be long-lasting. This can lead to persistent problems within affected populations, such as the declining numbers observed in certain groups like the California Chinook salmon. While genetic effects might mitigate some impacts over time, the potential for long-term harm remains a significant concern.

Feedback on importance: This is a high priority; however, there is a wealth of information available which may provide a basis for drawing conclusions from those studies.

> **WCMAC:** Disease in offshore aquaculture has long been a concern, particularly when raising salmon in settings where there is potential exposure to wild fish. The magnitude and footprint of the facility, along with production levels, are critical factors. In high-density environments, diseases can spread quickly, posing significant risks to aquaculture operations. For example, hatcheries can experience rapid disease outbreaks that affect the entire facility. Additionally, the escape of Atlantic salmon raises concerns about inbreeding and the potential for these fish to occupy vital spawning habitats for native species. However, it's uncertain whether this issue would be as pronounced in offshore settings.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Abundance, distribution, health, and trend of salmon

Abundance, distribution, health, and trend of salmon. There is a considerable amount of available information. There is extensive scrutiny on the abundance, exploitation, and harvest of various areas, with robust data available on salmon populations compared to other factors. Co-managers are responsible for gathering this information. The Washington Department of Fish and Wildlife (WDFW) and Tribes have established processes in place. Numerous studies also examine survival rates among populations, considering factors such as temperature and other variables.

For distribution, there has been ongoing sampling efforts for many years, providing information on certain salmon stocks. Each stock exhibits its own migration behavior. While broadly understood, the precise location and abundance of many individual stocks are only moderately known. Data collection efforts have focused primarily on listed species under the Endangered Species Act (ESA) or particularly concerning stocks.

In terms of health, multiple metrics are collected for individual fish such as size, length, weight, blood samples, diet, and historically, parasites. Genetic and stress-related assessments are not done. Efforts are underway to identify health metrics that better reflect fish health and implications for marine survival.

As for trends, a clear increase in growth rates has been observed in certain salmon stocks. There is substantial information on specific aspects, such as growth hormones.

There are two sources of data relevant to this data gap: Northwest Fisheries Science Surveys and Fisheries Catch Data:

> **Northwest Fisheries Science survey:** This survey gathers data annually in June on juvenile salmon, their food sources, and phytoplankton. This data collection effort has spanned approximately 20 years, focusing on juvenile fish in the Pacific Ocean. Previously, funding allowed for data collection in September as well. However, the June survey is considered the most critical since it coincides with the period when juveniles enter the ocean. There is currently no funding available to conduct surveys during other times of the year.
>
> **Fisheries Catch Data:** WDFW annually compiles data on the relative abundance of adult salmon across four core areas. While the focus of data collection is limited to these core areas, it provides insight into salmon distribution. This data is readily accessible and allows for trend analysis over time.

The focus of current data collection efforts has predominantly centered on juvenile salmon during their early ocean entry phase, with less emphasis on understanding their entire life history in the ocean. Information on the ocean part of the salmon lifecycle largely relies on fisheries-dependent sources. There is a clear need to obtain data that is not fisheries dependent and to prioritize comprehensive understanding of the salmon's entire life history.

Offshore wind data gaps

- Effect of noise and vibrations from offshore wind on salmon
- Effect of light from offshore wind on salmon
- Effect of offshore wind on salmon migration

Effect of noise and vibrations from offshore wind on salmon. There appears to be a significant data gap regarding the impact of noise and vibration on salmon; however, a substantial effect is not expected. While some species use noise for communication, salmon rely less on auditory cues. They may react negatively to acute noise by moving away but are less sensitive to noise as some other animals. Salmon primarily sense their environment through other sensory mechanisms. Whether a sound falls within the hearing range of salmon can be estimated by analyzing its intensity and frequency. Noise that is continuous or ongoing will have less effect. Indirectly, salmon will also be affected if noise and vibrations affect their predators.

Effect of light from offshore wind on salmon. There is increasing research on artificial light at night (ALAN). Specifically, there is research on fish behavior in both illuminated and unilluminated dock environments. However, there is still a data gap concerning the potential effects of light on salmon behavior. While it's uncertain how light would affect salmon, there's a conjecture that it might repel them. This hypothesis warrants further investigation. Juvenile salmon are typically more active at night, but as adults in the ocean, their behavior is less influenced by the time of day. If salmon are attracted to light, congregating around it could heighten their vulnerability to predation, which would be detrimental.

Effect of offshore wind on salmon migration. Given the extensive research conducted in the coastal ocean, this is not a significant data gap. There is knowledge on the migration patterns of salmon in the ocean. Offshore wind may not have an effect because salmon migration is innate. Additionally, juvenile salmon typically inhabit coastal areas rather than being hundreds of kilometers offshore. The influence of offshore wind will depend on the specific salmon species and the location of the structure. Coho and Chinook salmon typically migrate along the shoreline and northward, while pink, chum, and sockeye salmon migrate to the open ocean and are more commonly found offshore. Steelhead, being more surface-oriented, might be more affected by offshore wind structures. While detailed information is available on individual salmon, the behavior of entire populations is less understood. Insights gained from studying individual fish do not always translate into a comprehensive understanding of population-level dynamics. Regarding the location of offshore wind structures, the presence of structures could potentially affect salmon behavior. Salmon are known to actively forage and avoid predators, so these structures may alter the cues they rely on for migration.

Offshore aquaculture data gaps

- Effect of offshore aquaculture on competition, predation, and other interactions involving salmon
- Effect of waste products and chemicals from offshore aquaculture on salmon
- Effect of offshore aquaculture on early marine survival of salmon
- Effect of escapements from offshore aquaculture on salmon
- Effect of offshore aquaculture on salmon migration

Effect of offshore aquaculture on competition, predation, and other interactions involving salmon. Although the impact varies by species, the effect of offshore aquaculture on the competition and survival of salmon is generally not considered a major concern. This is because it is unlikely that a sufficient number of fish would escape from the aquaculture operations to significantly influence natural populations. Nevertheless, this issue warrants further investigation to ensure comprehensive understanding. For example, while the effect of offshore aquaculture on salmon populations can vary depending on the specific operations and target species, competition with salmon may not be a major concern if the target species for aquaculture is, for example, sablefish. Sablefish have distinct ecological niches and dietary requirements compared to salmon. Offshore aquaculture could also attract predators and create localized nutrient-rich environments. However, it is uncertain whether these shifts will significantly affect salmon competition and predation interactions.

Effect of waste products and chemicals from offshore aquaculture on salmon. Salmon have been raised in net pens for decades. Information on the effects of waste products and chemicals is likely available. However, the full environmental impacts are not yet well understood. The effect of an offshore aquaculture facility will depend on several factors, including its location, scale, water currents, depth, target species, the quantity of fish raised, and substances like antibiotics introduced into the water.

The effects of waste products and chemicals are likely less significant in the open ocean compared to semi-protected coastal due to currents and increased water movement in deep waters. Concerns would be greater in shallow bays and estuaries with reduced circulation. There is a need to fully understand the implications.

Other species may be more affected than salmon. For example, studies in Puget Sound have examined the broader impacts of net pen materials on benthic organisms. These studies suggest that bottom-dwelling species, such as flatfish and crabs, which feed on the seafloor, are likely to be more impacted than salmon.

Effect of offshore aquaculture on early marine survival of salmon. This is likely to be a relatively minor issue. The potential use of offshore aquaculture is unlikely to coincide with juvenile salmon habitats, but it may intersect with sub-adult salmon populations in the ocean. The effect of offshore aquaculture on salmon populations will vary depending on the species involved. If aquaculture operations act as an attractive nuisance, they could disrupt migration patterns, attract predators, and increase salmon vulnerability. There is information regarding the size (ranging from 6 to 14 centimeters) of salmon when they enter the sea and their dietary habits. Plausible connections between offshore aquaculture operations and salmon feeding habits can be made. However, unless implemented on a large scale, the overall impact would likely be minimal compared to other sources of mortality such as pathologies and genetic effects.

Effect of escapements from offshore aquaculture on salmon. The primary concern is not that escaped fish will overwhelm local populations numerically, but rather that they may compromise genetic integrity. When escaped aquaculture fish intermingle with wild populations, they can introduce diseases and genetic changes to native fish. Aquaculture fish, being subject to domestication selection, are often genetically inferior to their wild counterparts. This genetic disparity can dilute the gene pool of native populations, as domesticated fish may carry traits that are less suited to survival and reproduction in natural environments. Even if a native strain is used in aquaculture, the potential genetic impact remains.

One significant concern is the escape of non-native fish into rivers, which can adversely affect the fitness of native populations. This issue is particularly relevant for species such as rainbow trout which is already experiencing population declines along the coast. Any additional negative impacts could be detrimental. As these fish mature, they may attempt to spawn in inappropriate locations, further exacerbating the issue. Careful management and monitoring will be essential to mitigate these risks and protect the genetic health of native fish populations.

Effect of offshore aquaculture on salmon migration. Offshore aquaculture seems relatively unlikely to significantly affect salmon migration. From central California to Alaska, salmon typically migrate northward over time, supported by available data and fish tagging studies that provide insights into population dispersal distances. Salmon that survive typically return to the river they spawned in, with juveniles moving toward feeding areas and retracing these paths as adults. There are variations in migration timing. Chinook salmon spend more time at sea (often 2-3 years) and exhibit more variability in their migration periods. Coho spend approximately 1.5 years in saltwater. If salmon linger around net pens, there may be effects on migration. Information from regions like Chile or British Columbia may offer insights.

Resources

Table 20. Resources relevant to salmon.

NAME	ACCESS	TYPE	DESCRIPTION
Coast Salmon Partnership	https://www.coastsalmonpartnership.org/	Website	Provides information and resources regarding the Coast Salmon Partnership's work to guide the long-term protection and restoration of Washington's salmon and steelhead populations.
Pacific Fishery Management Council: Salmon Fishery Management Plan	https://www.pcouncil.org/managed_fishery/salmon/	Website	Contains information and documents regarding salmon management.

Sea Turtles

Key Data Gaps

General Data Gaps

- Abundance, distribution, status, and trend of sea turtles
- Sensitivity of sea turtles to habitat changes
- Effect of biotoxins and other naturally occurring threats on sea turtles

Offshore Wind Data Gaps

- Effect of temporary and permanent offshore wind structures on sea turtles
- Entanglement and collision risk from offshore wind on sea turtles

Other Data Gaps

General Data Gaps

- Information from foreign countries on the effects of human activities on sea turtles

Offshore Wind Data Gaps

- Effect of offshore wind on sea turtle breeding and reproduction
- Effect of offshore wind on sea turtle migration and distribution
- Effect of offshore wind power transmission cables and electromagnetic fields on sea turtles
- Effect of vibration and noise from offshore wind on sea turtles
- Effect of surveying methods and technology for offshore wind on sea turtles
- Effect of light from offshore wind on sea turtles

Offshore Aquaculture Data Gaps

- Efect of added nutrients, waste, and chemicals from offshore aquaculture on sea turtles
- Risk of disease transmission from offshore aquaculture on sea turtles
- Effect of offshore aquaculture on sea turtle migration patterns and distribution
- Effect of escapees from offshore aquaculture on sea turtles
- Risk of entanglement from offshore aquaculture on sea turtles

Background

Three sea turtle species—leatherback, loggerhead, and green sea turtles—are present in the MSP Study Area, feeding and migrating through its waters. All three species are listed under the federal Endangered Species Act (ESA) and on the Washington State Species of Concern list. None nest within Washington State. Loggerhead and green sea turtle sightings are rare off Washington's coast. There were four green sea turtle strandings between 2002 and 2012.

Leatherbacks are regularly found in Washington waters, feeding primarily on jellyfish in the upper water column during summer and fall. They concentrate in areas like the Columbia River Plume, attracted by favorable oceanographic conditions that support jellyfish aggregations. NOAA's Critical Habitat Designation identifies an area from Cape Flattery, WA, to Cape Blanco, OR as being crucial for leatherback foraging on key prey species. Within the MSP Study Area, leatherback sea turtles are affected by pollution, primarily from plastic bags mistaken for jellyfish. Entanglement in fishing gear can also be a stressor, but this risk was reduced with the prohibition of drift gillnet and pelagic longline fishing gears within the Study Area.

Table 21. Sea turtles within the MSP Study Area and their federal and state status (MSP Table 2.1-6).

COMMON NAME	SCIENTIFIC NAME	FEDERAL STATUS	STATE STATUS
Green sea turtle	*Chelonia mydas*	Threatened	State Threatened
Leatherback sea turtle	*Dermochelys coriacea*	Endangered	State Endangered
Loggerhead sea turtle	*Caretta caretta*	Endangered	State Threatened

The MSP addressed the probable effects of three potential activities on sea turtles:

Offshore aquaculture: The primary concern with sea turtles and offshore aquaculture is entanglement in gear. There have been documented cases of entanglement in shellfish aquaculture. Recommendations include using rigid netting, taut mooring lines, and removing loose equipment to minimize interactions.

Offshore dredging: The primary concern with the East Coast's offshore dredging is the entrainment and mortality of sea turtles, particularly loggerhead, Kemp's ridley, and green sea turtles due to their benthic foraging habits. While mitigation efforts addressed some concerns, information on other impacts like habitat alteration, noise, turbidity, vessel strikes, and sediment deposition is limited. Biological impacts are likely species-specific, influenced by their life history, prey, habitat preferences, and behavior.

Offshore oil and gas activities: Sea turtles face potential impacts from offshore oil and gas activities, including collisions with vessels, toxicity from discharges, and noise disturbances from seismic surveys and construction.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to sea turtles:

General data gaps

- Abundance, distribution, status, and trend of sea turtles
- Sensitivity of sea turtles to habitat changes
- Effect of biotoxins and other naturally occurring threats on sea turtles

General abundance, distribution, status, and trend. Leatherbacks are mesothermic, capable of maintaining a body temperature higher than their environment. They are a constituent of the ecosystem along the Washington coast.

Abundance and Status: There is limited information on current abundance. Leatherbacks are critically endangered with a threat of extinction. They have faced significant declines over the past three decades. As a highly endangered species, NOAA has designated them as a "species in the spotlight," facing a high risk of extinction within the next 30 years. From 1990 to 2017, there was an 80% decline, primarily observed in California. This decline mirrors a similar decrease in nesting beaches in Indonesia, which support approximately 75% of the global population. Those nesting beaches have also experienced an 80% decline over the same period with an annual decline rate of 5.5%. This downward trend in population continues. Research is needed to understand reproductive success on nesting beaches, particularly how beach conditions influence hatching outcomes. Typically, natural reproductive success yields a 50-60% hatch rate, but there are efforts aiming to improve this to 70-80%. Global change in environmental conditions may also affect reproductive output.

Figure 9. A leatherback sea turtle on a beach.

Improving abundance estimates requires additional information, such as the migration intervals and how they change over time. Leatherbacks have remigration intervals of approximately 3-5 years, which are believed to depend on their ability to acquire resources for growth and reproductive output while on the West Coast. Changes in ocean productivity could lengthen these intervals to 5-7 years, potentially reducing reproductive output and recruitment to the population. The distribution of different proportions of the population on either side of the ocean complicates the identification of individual observations.

Distribution: Leatherbacks found along the Pacific Northwest coast are part of the Western Pacific meta-population. They originate from beaches in the Western Pacific but are observed in waters off the West Coast of the United States (US). Nesting occurs on beaches in Indonesia from May to August, while they forage on jellyfish from July to November. Critical habitat areas were identified in 2012, with one area off the Washington and Oregon coasts, and another off the coast of California, particularly concentrated in the Gulf of San Francisco.

Information specific to the Pacific Northwest (PNW) is relatively limited. There is information from satellite tag data, although the available information dates back approximately 20 years and is limited. This data includes observations of leatherbacks, particularly in the Columbia River Plume area and from other identified hotspots. Between 2003 and 2010, three leatherback sea turtles tagged in Indonesia undertook transpacific migrations, remaining beyond the 200-meter isobath.

The NOAA Southwest Fisheries Science Center (SWFSC) conducts leatherback sea turtle research in Washington waters, with a focus on tagging to track their movements and behaviors. However, surveying leatherbacks is challenging, requiring calm weather for aerial observations. As a result, winter data is currently lacking, and this research is costly with limited results. SWFSC's program is the only in-water leatherback sampling effort on the Pacific Coast. While colleagues on the East Coast focus on tagging efforts, there is no comparable population monitoring. Funding from the Bureau of Ocean Energy Management (BOEM) supports ongoing aerial surveys conducted during August and September. The primary goal is to identify areas where leatherbacks are reliably found and deploy transmitters to gather more information on their use of PNW waters. From 2021 to 2023, 90-100 aerial surveys were conducted, yielding the observation of just one leatherback. Funding is secured through 2025 to continue this work.

Separately, off the coast of Washington, there are also occasional sightings of green turtles or loggerheads, which are ectothermic species (their body temperature varies with the environment). However, due to the consistently cold waters in this region, individuals found here are often in poor condition. The local ecosystem does not provide the necessary conditions for these turtles to thrive. Stranding events have been documented.

Feedback on importance: Before assessing impacts, it is necessary to establish a baseline of the species present. Given that many of the listed species travel long distances, including through Washington waters, understanding their distribution—along with the factors influencing it—is crucial for evaluating the impacts of any changes, whether climatic or otherwise.

Sensitivity of sea turtles to habitat changes. Sea turtles are highly sensitive to changes in marine productivity. As mega-planktivores, there is a bottom-up influence via jellyfish blooms. Leatherback turtles are specialized feeders on jellyfish, adapted specifically for consuming gelatinous zooplankton. Some jellyfish species that leatherbacks target have a life cycle that includes a benthic stage, where polyps strobilate and bud off tiny jellyfish that mature over time. Critical habitat assessments have highlighted that disturbances to areas where polyps occur could have a negative impact. If climate change results in warmer waters and suppressed upwelling, polyps may remain on the seabed without strobilating, affecting food availability for leatherbacks. Disruption of a polyp bed would be particularly detrimental.

Given the changing ocean conditions, it is certain that the distribution of all species, including leatherback sea turtles, will undergo changes. Currently, there is collaborative work with modelers to study habitat changes within the context of climate change. There are modeling projects that are gaining attention and providing valuable insights. Researchers are investigating how these habitat changes will impact the distribution of animals in the future. They are examining whether species will have more or less habitat compared to present conditions. Recent research included those originating from marine sanctuaries. They examined whether sanctuary boundaries would remain valid in the future, a concern also shared by proponents of Marine Protected Areas (MPAs). In addition to habitat changes, current species distribution patterns may also shift over time.

Feedback on importance: Understanding the effects of ocean warming, shifts in ecology, and other changes is crucial to understand this data gap.

Effect of biotoxins and other naturally occurring threats on sea turtles. It is known that biotoxins have caused mortality in marine turtles. The extent to which this would be an issue in colder climates is uncertain. Substances like domoic acid or toxic algal blooms could potentially intensify in a changing ocean environment. While it is unclear how quickly biotoxins pass through jellyfish, but the likelihood of a sea turtle consuming a contaminated jellyfish is low. Some studies on biotoxins are currently underway. Studies have also been conducted on heavy metal accumulation in leatherbacks, revealing levels below fatal doses.

Feedback on importance: Due to the nature and scale of environmental changes, predicting the effects of biotoxins and other naturally occurring threats can be challenging, but their impacts can be devastating.

Offshore wind data gaps

- Effect of temporary and permanent offshore wind structures on sea turtles
- Entanglement and collision risk from offshore wind on sea turtles

Effect of temporary and permanent offshore wind structures on sea turtles. The effect of offshore wind structures is unknown. This effect may have been studied on the East Coast. These structures can serve as substrates for settlement, potentially creating ecosystems that attract species like jellyfish polyps. Furthermore, offshore structures are associated with significant entanglement risks and the potential to snag other gear, including nets that could ensnare additional marine life, represents a major concern. The impact on biological communities, fish aggregation, and the accumulation of marine debris in these areas are not well understood.

Feedback on importance: No specific feedback provided.

Entanglement and collision risk from offshore wind on sea turtles. The challenge primarily arises from the limited understanding of sea turtle distribution. Sea turtles are thought to generally inhabit areas farther offshore than where offshore wind activities may be sited. The main concern is not direct entanglement with cables, but rather secondary entanglement caused by cables picking up marine debris. Regular cleaning of debris will be crucial to mitigate this risk.

There is a higher likelihood of ship collisions than entanglement. However, collisions are less of a concern because boats are not expected to travel at high speeds for offshore wind and sea turtles are small.

Feedback on importance: The biggest issue for sea turtles will likely be derelict gear and ghost nets, rather than the offshore wind structures themselves. However, this effect will depend on factors such as the construction of the facilities (materials, location, structure) and the distribution of the animals.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Information from foreign countries on the effects of human activities on sea turtles

Information from foreign countries on the effects of human activities on sea turtles. The US provides significant protection for protected species by regulating industries and fisheries, such as implementing quotas on take. However, leatherbacks, originating from the western Pacific, lose these protections once outside the US Exclusive Economic Zone (EEZ). In international high seas or other countries' waters, similar protective measures may not be available.

The decline of leatherback turtles is primarily driven by fishery bycatch on the high seas, where fisheries use drift gillnets or longlines to target swordfish and tuna. There is knowledge of these impacts. Efforts by foreign fisheries in this regard are not as visible. However, recently, there have been increased commitments to preserving safe nesting habitats. Egg harvesting and adult turtle mortality are also now prohibited on larger beaches, though these activities may still occur on secondary beaches. While there is still some cleanup work to be done, the situation has improved compared to previous conditions. Lastly, entanglement in fixed gear fisheries and the Dungeness crab fishery are understood as significant impacts.

Offshore wind data gaps

- Effect of offshore wind on sea turtle breeding and reproduction
- Effect of offshore wind on sea turtle migration and distribution
- Effect of offshore wind power transmission cables and electromagnetic fields on sea turtles
- Effect of vibration and noise from offshore wind on sea turtles
- Effect of surveying methods and technology for offshore wind on sea turtles
- Effect of light from offshore wind on sea turtles

Effect of offshore wind on sea turtle breeding and reproduction. Offshore wind is unlikely to affect sea turtle breeding or reproduction because there is no such activity in the Washington region.

Effect of offshore wind on sea turtle migration and distribution. The effect of offshore wind activities on sea turtle migration and distribution remains uncertain, with limited available information on this aspect.

A populated industrial wind operation could either create a sanctuary or cause displacement. The static structures are unlikely to directly affect sea turtles as these animals can avoid them. However, if offshore wind changes upwelling dynamics, this may cause displacement. Furthermore, offshore wind projects may disrupt existing human activities, including long-term scientific surveys and fisheries. If both sea turtles and human activities shift in their spatial distribution, offshore wind development could redirect sea turtles to areas with higher human presence, potentially increasing the likelihood of interactions between the two.

Effect of offshore wind power transmission cables and electromagnetic fields on sea turtles. There is still a lack of data on this issue. Cables have the potential to entangle animals, though this would not be a concern unless they are in the midwater column. However, the creation of electromagnetic fields (EMF) could affect animals such as leatherbacks and sharks that use EMF for navigation. Significant signals would be needed to influence their navigation.

Effect of vibrations and noise from offshore wind on sea turtles. The effect of vibrations and noise on sea turtles is currently not well understood. It could be a concern, particularly at lower frequencies. The specific frequencies of offshore wind operations are uncertain and should be investigated further.

Effect of surveying methods and technology for offshore wind on sea turtles. While temporary, sea turtles have been observed to react to certain surveys. The National Science Foundation conducts surveys and may be able to provide information on the effects of surveys.

Offshore wind operations could potentially affect aerial surveys for leatherback turtles, necessitating survey aircraft to fly at higher altitudes or avoid certain areas altogether.

Effect of light from offshore wind on sea turtles. The effect of light from offshore wind operations depends on how these activities affect food resources, with uncertainty regarding whether they will attract or repel species. Leatherbacks are less of a concern in this regard, while other species, such as hard-shelled turtles, may be impacted. However, since sea turtles are rarely found in Washington waters, the effects of light from offshore wind operations do not require significant consideration.

Offshore aquaculture data gaps

- Effect of added nutrients, waste, and chemicals from offshore aquaculture on sea turtles
- Risk of disease transmission from offshore aquaculture on sea turtles
- Effect of offshore aquaculture on sea turtle migration patterns and distribution
- Effect of escapees from offshore aquaculture on sea turtles
- Risk of entanglement from offshore aquaculture on sea turtles

Effect of added nutrients, waste, and chemicals from offshore aquaculture on sea turtles. The effect of nutrients, waste, and chemicals from offshore aquaculture on sea turtles depends on water composition, substance concentration, and the species being farmed. Changes in trophic dynamics, such as shifts in tide patterns and jellyfish populations, may indirectly affect leatherback turtles, which feed on jellyfish.

Risk of disease transmission from offshore aquaculture on sea turtles. This risk is unknown and may not be a concern.

Effect of offshore aquaculture on sea turtle migration patterns and distribution. Offshore aquaculture is unlikely to directly affect sea turtle migration. Alterations in local marine productivity or the promotion of jellyfish blooms could potentially have some influence. Nonetheless, an effect to migration or distribution remains a low probability.

Effect of escapees from offshore aquaculture on sea turtles. These factors are unlikely to have an effect as sea turtles do not consume shellfish, finfish, or kelp.

Risk of entanglement from offshore aquaculture on sea turtles. Understanding sea turtle distribution is crucial, as they are typically found far offshore. Sea turtles can navigate around offshore aquaculture facilities, though this largely depends on the size of the facility. Due to the potential overlap of sea turtle distribution with aquaculture operations, concerns with the risk of entanglement remains.

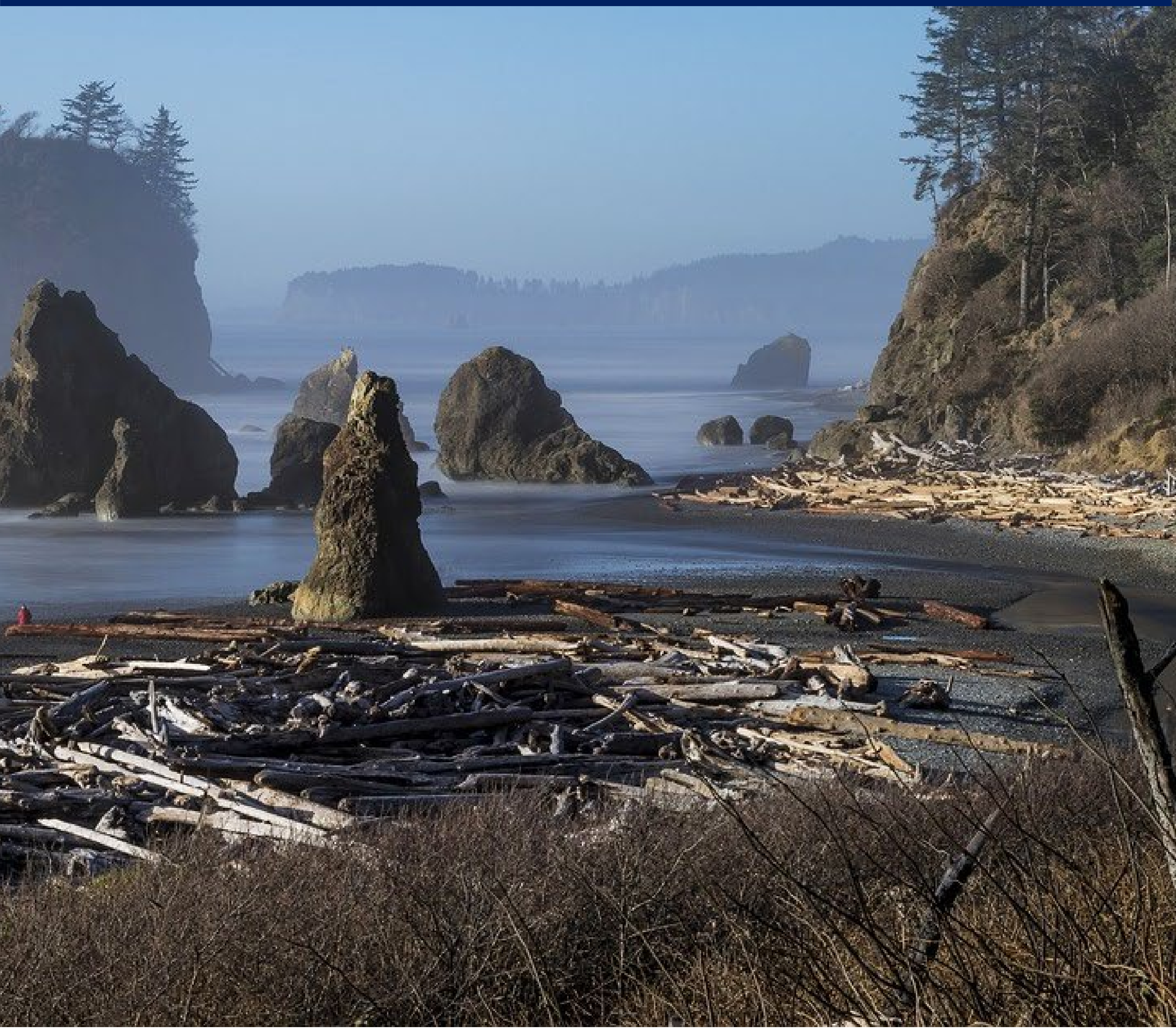
Resources

Table 22. Resources relevant to sea turtles.

NAME	ACCESS	TYPE	DESCRIPTION
A long-term decline in the abundance of endangered leatherback turtles, Dermochelys coriacea, at a foraging ground in the California Current Ecosystem	https://www.sciencedirect.com/science/article/pii/S2351989420309124	Published article	Analyzes the trend in leatherback abundance off central California using 28 years of aerial survey data from coast-wide and adaptive fine-scale surveys.
BOEM: Vulnerability Index to Scale Effects of Offshore Renewable Energy on Marine Mammals and Sea Turtles Off the US West Coast (VIMMS)	https://espis.boem.gov/Final%20Reports/BOEM_2023-057.pdf	Report	Evaluates the relative vulnerability of protected marine species on the US West Coast to disturbances associated with offshore alternative energy development.

NAME	ACCESS	TYPE	DESCRIPTION
California Marine Sanctuary Foundation: Impacts of offshore wind on sea turtles & fish: The Knowns and Unknowns	https://www.youtube.com/watch?v=nKEpeeMbqgg	Webinar	Focusing on sea turtles and fish, discusses research gaps in addressing vulnerability impacts from offshore wind.
California Marine Sanctuary Foundation: Impacts of Offshore Wind on Marine Mammals and Seabirds: The Knows & Unknowns	https://www.youtube.com/watch?v=8PiCYmXz1Tw	Webinar	Discusses the state of the science for balancing offshore wind energy development in California with coastal sustainability and biodiversity objectives, focusing on marine mammals and seabirds.

Ecology



Coastal Estuaries

Key Data Gaps

General Data Gaps

- Effect of climate change on coastal estuaries

Offshore Wind Data Gaps

- Effect of offshore wind on waves and its effect on coastal estuaries
- Effect of offshore wind on upwelling and its effect on coastal estuaries
- Effect of offshore wind cables on coastal estuaries
- Effect of port and infrastructure development for offshore wind on coastal estuaries

Offshore Aquaculture Data Gaps

- Effect of nutrient addition from offshore aquaculture on coastal estuaries

Other Data Gaps

Offshore Aquaculture Data Gaps

- Effect of offshore aquaculture on waves and its effect on coastal estuaries

Background

Willapa Bay and Grays Harbor are the two largest coastal estuaries in the MSP Study Area. Estuaries are crucial ecosystems, hosting a variety of species vital for commercial, recreational, and conservation purposes. These areas are recognized as Ecologically Important by the state due to their significance for both wildlife and human activities. While some estuarine species and habitats are well-documented in the MSP, up-to-date spatial data is lacking for many.

Estuaries serve as vital habitat for diverse marine and terrestrial organisms. Phytoplankton, benthic diatoms, and micro- and macroalgae thrive alongside eelgrass, kelp, and salt marsh plants, with distribution influenced by salinity and tidal elevation. Invertebrates like insect larvae, amphipods, and polychaetes; shellfish such as Olympia oyster, Pacific oyster, and Dungeness crab; and fish populations like salmon, herring, and sturgeon are also present. Estuaries also provide crucial nursery grounds for juvenile fish and crabs and are also important foraging areas, attracting migratory shorebirds and terrestrial animals. Harbor seals also reside in estuaries, hauling out on rocks, reefs, beaches, and docks and feeding on invertebrates and fish. Grays Harbor and Willapa Bay also have biogenic habitats. Eelgrass beds and oyster reefs are prevalent, covering thousands of hectares. Eelgrass plays a vital role in the estuarine food web, providing habitat, slowing water currents, trapping sediment, and supporting various species of birds, invertebrates, and fish. Oysters form three-dimensional habitats in lower intertidal and subtidal zones and improve water quality by filtering nutrients and reducing hypoxia.

Washington's coastal estuaries face various natural and human pressures. Coastal estuaries are shaped by wave exposure, salinity fluctuations, and tidal mixing. With over 50% of Willapa Bay and Grays Harbor being intertidal, tidal mixing is a major habitat influencer. Other physical drives that affect estuaries include ocean upwelling and downwelling, sediment dynamics, river plumes, large-scale climate patterns, and weather. In particular, climate change affects coastal estuaries through alterations in precipitation patterns, sea levels, winds, and runoff, potentially leading to flooding, erosion, coastal inundation, and saltwater intrusion into freshwater aquifers. Loss of estuarine habitats like tidal flats and wetlands will impact forage fish and shorebirds and acidification will harm shellfish. Shifts in hypoxic and anoxic conditions will affect zooplankton, and sea level rise will alter estuarine habitat, affect overall habitat composition, and impact species. Additionally, habitat-forming species like eelgrass and kelp face mixed impacts from temperature and carbon dioxide (CO_2) increases, storm events, and benthic nutrient cycling.

Human activities and management efforts have also significantly altered habitats and functions of these estuaries. These activities include fishing, dredging, aquaculture, introducing non-native species, watershed activities, port development, shipping, and pollution. Activities that do not occur directly on coastal estuaries like dike construction, logging and damming, and the introduction of species also effect estuaries.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to coastal estuaries:

General data gaps

- Effect of climate change on coastal estuaries

Effect of climate change on coastal estuaries. Climate change effects in coastal estuaries have not manifested as strongly in these regions compared to other thus far. Understanding these impacts involves addressing two key considerations. First, it is important to identify how climate change physically manifests in coastal estuaries and what observable changes are caused by climate change in these areas. The magnitude of climate change varies globally, and its effects will not be uniform across all regions. Data has been collected and predictions made regarding sea level rise, pH and aragonite saturation, and upwelling.[52] Second, if these estuaries are changing due to climate change, it is essential to understand how the organisms inhabiting them will respond. There is some information available regarding both aspects.

a. Physical manifestations

On the implications of climate change for coastal estuaries, for example, marine heat waves are increasing in intensity and duration as a result of climate change, a trend that is well-established and will affect estuaries. However, the specific impacts on estuaries remain complicated and difficult to predict. While the timing of heat waves cannot be forecasted, and the effects on estuaries are not fully understood—especially in comparison to their impacts on coastal areas—existing models typically stop at the boundaries of estuaries. This is due to the more complex circulation patterns in these areas. To gain a clearer understanding of the dynamics in coastal estuaries, there is a need for more tailored models that account for these unique conditions.

Coastal estuaries are susceptible to temperature changes at the sea surface but receive a buffering effect from the land. However, there is a significant gap in understanding how much this buffer shifts temperature in these areas. There is a lack of published data on this matter; however, estuarine water temperature records dating back to the mid-1940s suggest that warming has been less pronounced along the coast compared to other parts of the state and western North America. The Climate Impacts Group may have more detailed analyses of this data. The ocean serves as a buffer against warming in two ways. First, estuarine temperatures are influenced by the coastal ocean. Except during phenomena like the Blob heatwave, marine temperatures typically warm more slowly than those on land due to thermal mass. Second, the coastal region of Washington remains predominantly cloudy and rainy throughout most of the summer which buffers the coast from rising air temperatures. Relative to inland areas of Washington, the coast maintains a cooler and often overcast climate year-round. The "heat dome" experienced in 2021 was not evident on the coast.

[52] *See* https://link.springer.com/article/10.1007/s12237-022-01060-2; https://link.springer.com/article/10.1007/s12237-016-0136-7; https://www.researchgate.net/publication/5574954_Emergence_of_Anoxia_in_the_California_Current_Large_Marine_Ecosystem

As climate change progresses, the total precipitation is expected to remain relatively consistent. However, warmer temperatures will result in less snow accumulation during winter. This change may influence the environmental conditions and ecosystem dynamics of coastal estuaries. For instance, the Fraser River is primarily supplied by snowpack and experiences its peak flow in June. With less snow, this may shift the river's flow pattern, resulting in a reduced spring peak and a more pronounced winter peak.

There is some understanding of other climate change effects on coastal estuaries. In comparison to the open ocean, coastal estuaries exhibit a distinct response to decreasing pH levels associated with ocean acidification. The dynamics of carbon cycling differ significantly in these more enclosed environments compared to open ocean settings. Willapa Bay and Grays Harbor are examples of open estuaries. Acidification poses far less of a concern in estuaries that are closed off from the ocean compared to those that are open. There is a lack of comprehensive studies quantifying these differences.

b. Effect to organisms

Temperature variations can be used to explore potential responses of species under warming conditions. For instance, warmer temperatures could initially benefit the wild settlement of non-native Pacific oysters. Willapa Bay, positioned near its lower temperature limit, can provide more favorable conditions for the reproductive stage with even a slight increase in temperature. Two publications "Changes in oyster condition index with El Niño-Southern Oscillation events at 46°N in an eastern Pacific Bay"[53] and "The Willapa Bay Oyster Reserves in Washington State: Fishery Collapse, Creating a Sustainable Replacement, and the Potential for Habitat Conservation and Restoration"[54] addressed the variability in non-native Pacific oysters. There is also evidence suggesting that seagrasses are sensitive to the temperature range experienced in Willapa. However, significant warming would be required to reach a critical point where survival becomes compromised.

Corrosive waters driven by climate change could impact bivalve larvae, affecting their survival and development. There was a study[55] focusing on oyster reproduction across estuarine regions with varying carbonate chemistry. Pacific oyster larvae were observed to be thriving in the more acidified parts of the bay. These areas are likely naturally acidified due to freshwater input and terrestrial organic matter decomposition.

If climate change affects upwelling, this effect is crucial as upwelling facilitates the transport of larvae into estuaries. This process relies on advection and is time-sensitive, as larvae are passively drifting offshore and are subject to ocean circulation patterns. This is essential for species like crabs to access coastal estuaries or to remain close to the shore. There is a narrow window during which they must settle into an estuary before reaching a certain developmental stage; otherwise, their survival is at risk.

[53] https://agupubs.onlinelibrary.wiley.com/doi/10.1029/JC092iC13p14429
[54] https://sites.evergreen.edu/terroir/wp-content/uploads/sites/134/2015/12/WillapaBay_Oyster_Reserves.pdf
[55] https://repository.library.noaa.gov/view/noaa/59989

Harmful Algal Blooms (HABs) are also anticipated to rise with climate change. Estuaries harbor filter feeders that can uptake toxins from these blooms, subsequently transferring them up the food web. The effect of HABs on flora and fauna within estuaries is expected to intensify.

Reason for priority: While it is certain that climate change will occur, how it will manifest is unknown. The potential effects are expected to be substantial.

Offshore wind data gaps

- Effect of offshore wind on waves and its effect on coastal estuaries
- Effect of offshore wind on upwelling and its effect on coastal estuaries
- Effect of offshore wind cables on coastal estuaries
- Effect of port and infrastructure development for offshore wind on coastal estuaries

Effect of offshore wind on waves and its effect on coastal estuaries. Coastal estuaries rely on a specific balance of wave action and sand transport to maintain their ecosystems. Habitat heterogeneity shapes the community. Hydrodynamics are crucial in determining this balance because they influence the grain size of soft sediments and. Any alteration in wave size or intensity could disrupt this balance and impact the estuarine environment

Any potential impacts of offshore wind on wave patterns are unlikely to pose a significant concern for coastal estuaries. While offshore wind farms do harness energy from winds that contribute to wave formation, given that estuaries already attenuate waves, the influence of offshore wave energy is relatively minor compared to the local waves generated by estuarine winds. However, the extent of their influence on coastal estuaries will depend on the magnitude of the change. A 1% alteration in local wind patterns due to offshore wind is unlikely to produce a measurable difference in estuarine conditions. In contrast, the complete absence of local wind would have a more noticeable impact.

Reason for priority: No specific feedback provided.

Effect of offshore wind on upwelling and its effect on coastal estuaries. Willapa Bay is influenced by water properties originating from the continental shelf, with a clear upwelling signal observed within the bay.[56] This upwelling is most noticeable in areas with lower water residence times, typically within 20 km of the mouth. During the summer, upwelling brings deeper water properties closer to the bay's mouth. In addition, the Columbia River plume, flowing from the south, introduces water with distinct properties that can negatively impact the aragonite saturation state. Any changes in the characteristics of the plume water could pose concerns, particularly in light of observed shifts, such as altered river flow timing due to dam construction.

[56] https://www.researchgate.net/publication/276322104_Variability_in_Carbon_Availability_and_Eelgrass_Zostera_marina_Biometrics_Along_an_Estuarine_Gradient_in_Willapa_Bay_WA_USA

While research on coastal upwelling exists, its interaction with estuaries remains unexplored. As a result, the effects of upwelling changes on estuarine ecosystems are poorly understood. However, any shift in upwelling is expected to significantly impact estuarine function.[57] Changes in upwelling could alter salinity, chlorophyll levels, and dissolved oxygen, all of which are crucial to estuarine health. Given that salinity is a defining characteristic of estuaries, such changes would directly influence the estuarine community.

A shift in chlorophyll will also affect existing aquaculture operations in estuaries by influencing primary production, food supply, nutrient dynamics, and water quality. The shellfish industry relies on plankton blooms, driven by upwelled nutrient-rich waters, to support the growth and fattening of oysters within the bay.

Additionally, estuaries are vital nursery areas and play a key role in supporting commercial fisheries. If offshore wind development disrupts upwelling and, in turn, alters the movement of species in and out of estuaries, it could affect the survival and growth of adults emerging from these vital nursery habitats.

Reason for priority: There is interest in this data gap due to the strong relationship between coastal estuaries' productivity and upwelling. Any changes in upwelling could significantly affect estuaries.

Effect of offshore wind cables on coastal estuaries. Offshore wind cables could introduce physical changes by adding a hard substrate to soft sediment areas, potentially hindering species' movement and affecting local communities. They may also generate electromagnetic effects. However, concerns about these impacts on coastal estuaries are minimal. Moreover, laying cables across an estuary is unlikely to be economically beneficial, further reducing concerns about their installation. An existing electricity cable in Willapa Bay may provide insight into the potential effects of offshore wind cables.

Reason for priority: No specific feedback provided.

Effect of port and infrastructure development for offshore wind on coastal estuaries. The development of ports and infrastructure for offshore wind can significantly affect estuaries. For instance, Willapa Bay is the sole bay where the entrance remains undredged and lacks jetties. Its dynamic nature allows the mouth to shift over several miles. Increased port capacity, heightened boat traffic navigating in and out of the estuary, and any accompanying development can exert substantial influence. Communities and sections of Highway 101 on the north side, such as North Cove, have already been affected by erosion.

Reason for priority: Shoreline development has been shown to pose challenges to the water quality and health of coastal estuaries. Similarly, offshore wind port and infrastructure development could introduce similar or new stressors to these sensitive ecosystems.

[57] https://www.researchgate.net/publication/235995558_Wind-Induced_Plume_and_Bloom_Intrusions_into_Willapa_Bay_Washington

Offshore aquaculture data gaps

- Effect of nutrient addition from offshore aquaculture on coastal estuaries

Effect of nutrient addition from offshore aquaculture on coastal estuaries. Considering the extensive presence of shellfish aquaculture within the bays, the addition of nutrients from an offshore facility is likely to have comparatively minor effects. However, there is currently a lack of available data on this matter. The effect of nutrient addition will likely vary based on the species cultivated and the proximity of the facility to the estuary mouth.

Reason for priority: No specific feedback provided.

Other Data Gaps

The following are the remaining data gaps:

Offshore aquaculture data gaps

- Effect of offshore aquaculture on waves and its effect on coastal estuaries

Effect of offshore aquaculture on waves and its effect on coastal estuaries. A "carpet effect," a dense aggregation of aquaculture structures, could potentially lead to wave attenuation around aquaculture facilities depending on where they are situated. However, the overall effect may not be significant. Coastal estuarine waves are typically locally generated and less influenced by coastal ocean dynamics. There is a lack of available data on this matter.

Resources

Table 23. Resources relevant to coastal estuaries.

NAME	ACCESS	TYPE	DESCRIPTION
Changes in oyster condition index with Niño-Southern Oscillation events at 46°N in an eastern Pacific Bay	https://agupubs.onlinelibrary.wiley.com/doi/10.1029/JC092iC13p14429	Published article	Investigates the relationship between sea level fluctuations and the condition index of temperate northeast Pacific oysters.
Emergence of anoxia in the California Current Large Marine Ecosystem	https://www.whoi.edu/cms/files/Chanetal_anoxia_science2008_51503.pdf	Published article	Reports on the intensification of severe inner-shelf hypoxia and rise of water-column anoxia in the California Current Ecosystem.

NAME	ACCESS	TYPE	DESCRIPTION
Predicted Changes in Seagrass Cover and Distribution in the Face of Sea Level Rise: Implications for Bivalve Aquaculture in a United States (US) West Coast Estuary	https://link.springer.com/article/10.1007/s12237-022-01060-2	Published article	Develops a model to determine the relationship between seagrass presence and seven predictor variables which was then used to predict eelgrass distribution in Willapa Bay in 2030, 2050, and 2100.
Similar oyster reproduction across estuarine regions differing in carbonate chemistry	https://repository.library.noaa.gov/view/noaa/59989	Published article	Examines oyster reproduction by conducting a coupled chemical-biological study of water properties, oyster larval densities, and settlement at stations on two sides of Willapa Bay.
The Carbonate Chemistry of the "Fattening Line," Willapa Bay, 2011-2014	https://link.springer.com/article/10.1007/s12237-016-0136-7	Published article	Provides measurements of aqueous CO_2 partial pressure and total dissolved carbonic acid within Willapa Bay that has been identified as optimal for larval oyster retention and growth and collocated with larval settlement.
The Willapa Bay Oyster Reserves in Washington State: Fishery Collapse, Creating a Sustainable Replacement, and the Potential for Habitat Conservation and Restoration	https://sites.evergreen.edu/terroir/wp-content/uploads/sites/134/2015/12/WillapaBay_Oyster_Reserves.pdf	Published article	Provides an update on the status of Willapa Bay oyster reserves. Describes information on the Pacific oyster fishery on the reserves and its management, including shell return to the reserves and an annual assessment of oyster settlement.

NAME	ACCESS	TYPE	DESCRIPTION
Variability in Carbon Availability and Eelgrass (*Zostera marina*) Biometrics Along an Estuarine Gradient in Willapa Bay, WA, USA	https://link.springer.com/article/10.1007/s12237-014-9933-z	Published article	Examines within-estuary variation in biometrics of intertidal eelgrass during summer production.
Willapa-Grays Harbor Estuary Collaborative	https://wghec.org	Website	Provides information on the Collaborative's work to increase the resilience of communities and ecosystems in Washington's southwest coastal estuaries.
Wind-induced plume and bloom intrusions into Willapa Bay, Washington	https://aslopubs.onlinelibrary.wiley.com/doi/10.4319/lo.2002.47.4.1033	Published article	Measures the physical oceanography and chlorophyll distribution in Willapa Bay and the adjacent coastal ocean during an upwelling-downwelling wind cycle in May 1999.

Kelp and Eelgrass

Key Data Gaps

General Data Gaps

- Abundance, distribution, health, and trend of kelp and eelgrass
- Relationship of kelp and eelgrass with environmental parameters
- Community associated with eelgrass
- Resilience of eelgrass to disturbance

Offshore Wind Data Gaps

- Effect of shift to flow and local circulation from offshore wind on kelp and eelgrass
- Effect of offshore wind on survival and recruitment of new kelp and eelgrass plants

Other Data Gaps

General Data Gaps

- Factors that influence flowering rates of eelgrass
- Effect of eelgrass on carbon dioxide dynamics

Offshore Wind Data Gaps

- Effect of offshore wind on sedimentation and organisms associated with kelp and eelgrass
- Effect of offshore wind on the ability of kelp and eelgrass to remove carbon dioxide
- Effect of offshore wind structure on kelp and eelgrass
- Effect of electromagnetic fields from offshore wind on kelp and eelgrass
- Effect of potential shift in upwelling from offshore wind on kelp and eelgrass
- Effect of light from offshore wind on kelp and eelgrass

Offshore Aquaculture Data Gaps

- Effect of shift in flow and local circulation from offshore aquaculture on kelp and eelgrass
- Effect of offshore aquaculture on sedimentation and organisms associated with kelp and eelgrass
- Effect of offshore aquaculture on survival and recruitment of new kelp and eelgrass
- Effect of offshore aquaculture on the ability of kelp and eelgrass to remove carbon dioxide
- Effect of offshore aquaculture structure on kelp and eelgrass

Background

Eelgrass: Seagrass beds are a biogenic habitat, particularly common in Grays Harbor and Willapa Bay. Native (*Zostera marina*) (*Z. marina*) and non-native (*Zostera japonica*) seagrass species form extensive, continuous meadows or patchy beds covering thousands of hectares. Seagrass beds serve as primary producers, providing essential structure to mudflats, slowing water flow, reducing wave energy, trapping sediments, and providing fish and invertebrate spawning substrate and refugia. They are integral to the estuarine food web, supporting diverse species including birds, invertebrates, and fish.

Brant Geese (*Branta bernicla*) depend directly on *Zostera spp.* as a major food source during their biannual migrations along the Pacific flyway. Seagrass also hosts epiphytes, microalgae, macroalgae, and invertebrates, forming a vital prey base for marine life. Commercially important species like Dungeness Crab, Pacific Herring, salmonids, shrimp, and flatfish rely on eelgrass habitats at various stages of their life cycles.

This section will focus on *Z. marina*. The non-native seagrass *Z. japonica* is discussed in the "Invasive Species and Pests" section, under the "Data Gaps for Plants" subsection.

Kelp: Kelp forest habitat in the MSP Study Area includes floating canopies of bull kelp (*Nereocystis luetkeana*) or giant kelp (*Macrocystis pyrifera*), submerged kelp beds (e.g., *Laminaria* spp. and *Pterogohora californica*), and rocky reefs up to 30 meters deep. This diverse habitat supports over 20 species of kelp, creating one of the world's most diverse kelp communities. It spans the northern coast primarily, with scattered patches along the central coast and estuaries.

Kelp forests are vital ecosystems that provide habitat for diverse marine life and energy to the food web. They act as nurseries, refuges, and foraging grounds for various fish species, including those listed on Washington's Species of Concern list[58]. Floating kelp also helps to dampen wave energy, creating semi-protected foraging habitats for seals and birds. Sea otters, too, rely on kelp for both feeding and resting. In addition, kelp and other macroalgae contribute significantly to the food chain by supplying organic matter. As kelp decomposes, it supports bacterial communities that fuel phytoplankton and benthic filter-feeders in nearshore environments. Storm-dislodged kelp also supports coastal scavengers such as small crustaceans and insects.

Seasonal and inter-annual variations in kelp populations are influenced by reproductive cycles, ocean conditions, and herbivore activity. For instance, strong El Niño events with nutrient-poor waters can reduce kelp coverage, while La Niña events with cold, nutrient-rich waters promote growth. Years with suppressed cold-water upwelling negatively impact kelp forests, as bull kelp is particularly sensitive to temperature increases and changes in nutrient availability. Additionally, heavy rains and landslides can decrease bull kelp due to increased sediment runoff, which impacts light penetration. Conversely, storm-driven waves can promote the recruitment of bull kelp and other macroalgae. Changes in the extent, area, and density of the

[58] https://wdfw.wa.gov/species-habitats/at-risk/listed

kelp canopy directly influence species composition. Monitoring these trends offers valuable insights into ecosystem health and informs the dynamics of fish and invertebrate populations.

Predators like sea otters, sea stars, humans, and crabs control sea urchin populations. In the northern hemisphere, herbivorous sea urchins are the primary drivers of widespread kelp deforestation. In Washington, red (*Mesocentrotus franciscanus*), purple (*Strongylocentrotus purpuratus*), and green (*S. droebachiensis*) sea urchins graze on kelp. Sea otters can enhance the growth of kelp and kelp-associated communities by reducing sea urchin numbers. The reintroduction of sea otters in Washington decreased sea urchin densities and increased algal abundance. This trophic interaction between sea urchins, sea otters, and kelp has been well documented in the Pacific Ocean.

Other pressures on kelp forest habitat in the MSP include recreational fishing, pollutants, excess nutrient inputs, as well as climate change. Climate change is expected to have detrimental effects on kelp. Rising ocean temperatures are likely to impact kelp in multiple ways, affecting its physiology, growth, reproduction, and competitive dynamics. Warming waters may also drive non-native species to move northward. Ocean acidification could enhance marine algae productivity by increasing carbon dioxide (CO_2) availability. Research in Puget Sound is exploring whether large, healthy kelp forests might help mitigate increased CO_2 levels by absorbing the additional carbon. However, it remains uncertain whether the benefits of higher CO_2 concentrations will outweigh the negative effects of rising ocean temperatures. Furthermore, more frequent and intense storms may reduce the complexity and diversity of kelp forest food webs by altering substrate availability and damaging seagrasses through wave action.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to the kelp and eelgrass:

General data gaps

- Abundance, distribution, health, and trend of kelp and eelgrass
- Relationship of kelp and eelgrass with environmental parameters
- Community associated with eelgrass
- Resilience of kelp and eelgrass to disturbance

Abundance, distribution, health, and trend of kelp and eelgrass.

Eelgrass: Eelgrass distribution is well understood. It is primarily found in nearshore areas and can grow up to 20 feet in length. The Department of Natural Resources (DNR) provides robust data across Puget Sound and major bays, offering comprehensive insights into abundance, distribution, and trends. DNR primarily uses towed cameras for surveys. Depth distribution assessments are conducted by dragging cameras during low tide.

In coastal Washington, *Z. marina* is primarily found in Grays Harbor, Willapa Bay, and to a lesser extent in the Columbia River Estuary. Eelgrass in coastal estuaries exhibit high productivity.

Particularly in Willapa Bay, seagrass shows exceptionally robust summer growth rates, with a remarkable increase of 3% in biomass per day (approximately 2 inches per day), surpassing global standards. DNR is working on protecting Grays Harbor.[59] Maps on the distribution and density of *Z. marina* and *Z. japonica* at Grays Harbor and Willapa Bay are available from 2013.[60] Smaller rivers along the coast may not provide suitable habitat for *Z. marina*. The Olympic Coast National Marine Sanctuary's Olympic Coast 2008-2019 Condition Report[61] does not mention eelgrass.

There is substantial knowledge regarding the factors influencing eelgrass distribution, including intertidal elevation (exposure to cold and hot air), and disturbance from shellfish aquaculture within estuaries. Light availability is a critical factor influencing their distribution. Insufficient light limits eelgrass growth at certain depths; however, estuaries generally offer extensive shallow areas that are highly suitable for eelgrass.

There is also an understanding of the incompatibility between eelgrass and high densities of burrowing shrimp. Eelgrass exhibits seasonal patterns independent of burrowing shrimp; however, it may appear otherwise due to the reduced activity of burrowing shrimp in winter, which coincides with eelgrass dormancy during that period. As a result, eelgrass's ability to respond during this window of opportunity is limited. Additionally, an emerging issue is wasting disease (*Labyrinthula*), which caused significant losses of *Z. marina* in the Atlantic during the 1930s. While it has been detected on eelgrass in coastal estuaries, it does not appear to significantly affect population levels. This contrasts with findings from studies in the San Juan Islands, where it has reduced shoot density. Ongoing research is exploring this disease, including the development of remote sensing approaches.

While some changes in distribution over time are expected due to the dynamic nature of species and their environments, there is currently no evidence of significant losses. Historical habitat assessments include potential eelgrass habitats from the 1800s and 1900s[62], productivity changes in the 1990s linked to introduced species[63], and aerial surveys of eelgrass habitat conducted in 2006[64].

Kelp: Although kelp can reach heights of up to 20 feet, the majority of it is concentrated in a limited area, typically extending only to 10 meters deep.

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59 https://www.dnr.wa.gov/kelp-and-eelgrass-plan

60 https://www.dnr.wa.gov/publications/aqr_aamt_zjproject_summary.pdf

61 https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/2008-2019-ocnms-condition-report.pdf

62 https://www.researchgate.net/publication/227059049_Geospatial_habitat_change_analysis_in_Pacific_Northwest_Coastal_estuaries

63 https://www.researchgate.net/publication/236027531_Change_in_productivity_associated_with_four_introduced_species_ecosystem_transformation_of_a_pristine_estuary

64 https://www.researchgate.net/publication/276137381_Effect_of_oyster_aquaculture_on_seagrass_Zostera_marina_at_the_estuarine_landscape_scale_in_Willapa_Bay_Washington_USA

Beyond Puget Sound, the coastline is poorly monitored for kelp. Data collection is infrequent and often insufficient in scale. Comprehensive monitoring efforts should be made to gather data on abundance, distribution, health, and trends. Valuable insights can be gained from both robust outer coast populations and declining Puget Sound populations. However, data quality is improving.

Various groups are conducting extensive sampling to determine the presence of kelp using different survey methods. Studies include surface-based surveys of bull kelp, giant kelp, and other species; underwater surveys of all kelp types, including floating kelp that have not reached the surface yet; and transboundary collaboration with Canada under the UN Decade of Ocean Science. Remote sensing data is limited. Aerial surveys are preferable due to their ease compared to deploying scuba divers, who, while able to observe prominent species in detail, must also identify others on the spot which may be challenging. DNR has conducted extensive studies across various coastal regions. Detailed distribution information can be accessed through the Washington State ShoreZone Inventory[65] and the Floating Kelp Forest Indicator for Washington State[66]. Substantial research efforts are also ongoing to understand the magnitude of kelp loss. Significant efforts have been made over the past decade through initiatives led by the DNR and the Northwest Straits Commission.

Progress is also being made to understand kelp stressors. There are some systematic evaluations. The coast exhibits a temperature gradient that affects giant kelp and bull kelp distribution. While there is some overlap in their ranges, bull kelp tends to thrive in cooler temperatures, particularly in northern regions. However, much of the information remains correlative; for example, observations show that kelp decline correlates with warmer temperatures and increased runoff from roads into shallow bays. There is a notable lack of laboratory work investigating specific physiological impacts.

The understanding of different kelp species and types are also uneven, with canopy-forming kelp receiving the most attention due to its vital role as a habitat, providing refuge, foraging grounds, cultural significance, and economic value. In contrast, understory kelp often goes underexplored, despite being the least understood and having significant data gaps.

At a broader level, floating kelp is relatively easy to survey as long as it is conducted during the growing season when they are at the surface and under suitable tide and current conditions. This timing is optimal for assessing their abundance and distribution accurately. Giant kelp and bull kelp are species of floating kelp. There is a solid understanding of giant kelp, which thrives in areas with significant wave action and larger waves. It does not propagate in Puget Sound. For bull kelp, DNR and NOAA use various survey methods to gather data, providing a strong understanding of its historical and current distribution as well as the relative sizes of kelp beds. While there is a good grasp of their changes over time, historical data can sometimes be inconsistent. Additionally, the significant population variability of bull kelp makes it challenging to identify long-term trends across coastlines, as some populations show stability or growth while also exhibiting considerable fluctuations. However, population density is closely linked to

[65] https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-inventory
[66] https://wadnr.maps.arcgis.com/apps/webappviewer/index.html?id=f10864050bf14f57ba751ae53bc061f5

the effect and intensity of shared environmental pressures. In Vancouver, Canada, bull kelp density increases as one moves northward, possibly due to reduced human impact or differing temperatures.

For subcanopy kelp, underwater surveys are essential for improving data collection, particularly regarding abundance and distribution where significant gaps exist. While there are some surveys and datasets available, speciating kelp remains challenging, especially from towed sled videos. Accurate identification often requires physically handling the kelp. WDFW uses herring rake surveys, which include the identification of submerged aquatic vegetation (SAV) but are limited to herring spawning grounds. As a result, while general patterns can be described, a comprehensive understanding is lacking. Some trend analysis can be conducted using available historical data.

These disparities highlight the challenges of studying a multispecies ecosystem. Additional data needs include identifying the biodiversity within kelp and eelgrass forests, conducting long-term time series studies, and surveying the use of both kelp and eelgrass.

For both kelp and eelgrass, additional information is expected to become available in the future. DNR developed a Statewide Kelp Forest and Eelgrass Meadow Health and Conservation Prioritization Plan[67] (Prioritization Plan). The plan provides a process to identify at least 10,000 acres of native kelp and eelgrass habitat for conservation and recovery by 2040. A companion document, the Statewide Kelp Forest and Eelgrass Meadow Health and Conservation Monitoring Plan[68] guides tracking the implementation of the Prioritization Plan. Additional information is available on DNR's website[69].

Feedback on importance: Monitoring is essential, as trends can change over time, requiring continuous data collection. It establishes a baseline from which the potential effects of various activities can be assessed and helps fill other critical data gaps.

Relationship of kelp and eelgrass with environmental parameters.

Eelgrass: *Z. marina* is globally distributed in temperate latitudes of the northern hemisphere, making it a well-studied estuarine species. Research conducted outside of Washington State provides valuable insights. Locally, DNR has conducted extensive studies in Puget Sound, gathering data on distribution, abundance, density, and stressors.

Eelgrass requires stable surfaces to attach to and cannot anchor in areas like rocky substrates. It thrives in more protected, calmer waters, such as those found in embayments, rather than in exposed areas. Notable eelgrass habitats in Washington include Puget Sound, Padilla Bay, Grays Harbor, and Willapa Bay, with Padilla Bay accounting for about 20% of the state's eelgrass. Its distribution is influenced by factors such as depth and wave action. Eelgrass is highly sensitive to light, temperature, and sediment conditions. Additionally, understory species exhibit growth

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67 https://app.leg.wa.gov/ReportsToTheLegislature/Home/GetPDF?fileName=2023_KelpAndEelgrassHealthAndConservation_Prioritization%20Plan_196dcf40-a44c-47f2-b973-7c11f578a5b0.pdf

68 https://deptofnaturalresources.app.box.com/s/0hc5a2l0las517yjcq1auau3b8fmehmk

69 https://www.dnr.wa.gov/kelp-and-eelgrass-plan

during spring and summer, driven by light and nutrient availability. In many regions, submerged aquatic vegetation (SAV) dies back almost entirely during the late fall and winter but becomes an important nutrient source for upland systems in the form of beach wrack.

The relationship between stressors and ecological responses has been studied extensively, yet there remain uncertainties, particularly concerning local ecotypes and specific environmental conditions. The cause of occasional declines and recoveries are not always known. Feedback was provided for the following environmental parameters:

Light: Eelgrass requires more light compared to other submerged photosynthetic organisms.

CO_2: Eelgrass obtains its dissolved inorganic carbon directly from water rather than from the air. Because gases diffuse more slowly in water, eelgrass can potentially be limited by carbon availability. Modeling suggests that eelgrass may tolerate higher temperatures and lower light levels under conditions of elevated carbon dioxide. However, under field conditions in Willapa Bay, eelgrass did not exhibit clear performance advantages in areas where dissolved inorganic carbon (DIC) concentrations were higher. Theoretical expectations suggest that the concentration of DIC should be significant, but empirical findings indicated it did not have the predominant effect. Elevated CO2 levels result in lower pH conditions. Low pH was traditionally considered beneficial for seagrasses due to increased DIC availability, particularly in the form of CO2 rather than bicarbonate or carbonate.

Desiccation: Eelgrass can withstand certain amount of time out of water. Eelgrass lacks a cuticle or stomata, making it vulnerable to desiccation. As a result, the conditions it experiences during low tides matter. Hot or cold, dry conditions can be particularly damaging. Intertidal distributions can have higher-elevation patches on wide tidal flats that hold pools of water.

Temperature: Seasonal acclimation to light and temperature has also been well-documented. The general thermal performance curve suggests that eelgrass can photosynthesize effectively within water temperatures ranging from 10°C to 20°C. While local adaptation is likely, it remains an area that requires further exploration. Eelgrass distribution is declining due to climate change. Reports indicate that the southern limit of *Z. marina* is shifting northward in China and the eastern United States (US), with potential losses observed in the Gulf of California.

Hydrodynamic energy: Hydrodynamic energy can uproot plants or alter sediment, making it unsuitable for eelgrass. Separate from eelgrass, *Phyllospadix*, a surfgrass species, is well-adapted to high water energy environments, growing on rocks and rocky intertidal areas where it anchors itself by connecting its roots firmly to the substrate.

Sediment: Eelgrass is rarely found above 5% organic matter in sediment. Muddiness challenges anchoring and high organic matter accelerates decomposition, creating a low-oxygen environment that stresses eelgrass. This condition leads to the production of toxic sulfides harmful to plant roots.

Salinity: Euryhaline species are well-adapted to varying salinities. They can tolerate salinities as low as 5 parts per thousand (ppt) for a period and thrive in salinities around 10 ppt. Marine salinity is typically around 33 ppt.

Kelp: Different kelp species have varying ecological requirements; for example, giant kelp (*Macrocystis*) and bull kelp (*Nereocystis*) have distinct needs that influence their distribution. There is a scarcity of remotely sensed data, and buoys do not collect nearshore data, creating uncertainty about the environmental conditions that kelp and benthic invertebrates experience. However, factors such as depth and wave action are critical in determining kelp location patterns, and understory species show seasonal growth driven by light and nutrient availability. A strong correlation also exists between water temperature and kelp distribution, with known temperature thresholds for species like bull kelp and giant kelp. Some data also exist on salinity, pH, and ocean acidification, and research on marine heatwaves has examined their effects on kelp growth and presence.

There is a significant gap between understanding the physiological limits of kelp and predicting the impacts of climate change. The effects of climate change, particularly ocean acidification, vary widely by region and specific site and kelp typically thrives in dynamic environments with high mixing rates. However, these conditions can also lead to localized losses of kelp. Widespread kelp loss is occurring, but the causes are often unique to each region, making large-scale modeling difficult to apply.

Feedback on importance: No specific feedback provided.

Community associated with eelgrass and kelp.

Eelgrass: Publications document that eelgrass supports a unique nekton community comprising fish, crabs, and shrimp, including species like saddleback gunnels, pipefish, and sticklebacks that are disproportionately found within eelgrass habitats. Of particular concern are migratory salmonids, which are difficult to sample in the field to assess their distribution and habitat suitability. Additional data on habitat associations would greatly benefit managers dealing with this group. Currently, a University of Washington study is investigating whether nonnative eelgrass provides functionally redundant habitat for associated organisms.

Kelp: At a statewide level, numerous data gaps persist. If there is no kelp undergrowth, important species are missing. Focusing solely on larger kelp species like bull kelp and giant kelp overlooks the essential role of understory kelp that support diverse ecosystems crucial for commercial species. Species associated with the understory kelp include juvenile stages of Dungeness crab, various flatfish, and numerous rockfish species. Kelp serves as a vital nursery ground for numerous species and specific life history stages.

Feedback on importance: Understanding this data gap helps assess the value of these habitat types. These structures are three-dimensional; disrupting them can have wide-reaching impacts.

Resilience of eelgrass to disturbance. This knowledge gap is actively being addressed. Eelgrass resilience arises from both clonal branching and sexual reproduction through seeds. Seedlings thrive in sparse meadows, and with adequate water quality, eelgrass typically compensates for shoot loss by increasing new shoot production.

Eelgrass' resilience to climate change will be crucial because of its importance as a habitat. As temperatures and environmental conditions shift beyond normal ranges, they may surpass eelgrass' tolerance, especially during extreme events, posing challenges to its long-term persistence and resilience.

Feedback on importance: This is a critical question to understand the importance of allowing this habitat type to persist.

Offshore wind data gaps

- Effect of shift to flow and local circulation from offshore wind on kelp and eelgrass
- Effect of offshore wind on survival and recruitment of new eelgrass and kelp

Effect of shift to flow and local circulation from offshore wind on kelp and eelgrass.

Eelgrass: If wind patterns diminish, it is likely to affect upwelling, subsequently impacting water temperature. Both kelp and eelgrass are sensitive to temperature increases. Changes in upwelling patterns could also alter their distribution. However, based on the location of eelgrass, such as in Puget Sound and river estuaries, the consequence of this potential shift is harder to discern for eelgrass. Additionally, offshore wind is expected to have minimal impacts on eelgrass within estuaries.

Kelp: Kelp growth is limited by depth, so the effect of offshore wind will depend on how offshore the facilities are located. Changes in upwelling patterns could affect water temperature, potentially leading to adverse effects such as thermal stress on kelp. A shift in upwelling could also change distribution. This effect will depend on scale and location of offshore wind facilities. However, if they are sufficiently distant and do not hinder the kelp's ability to anchor to the bottom, effect would likely be minimal. Offshore wind farms can also be strategically located to minimize impact on flow dynamics from transmission lines.

Feedback on importance: There is interest in understanding potential changes offshore wind may cause at the local region.

Effect of offshore wind on survival and recruitment of new eelgrass and kelp.

Eelgrass: Offshore wind activities are unlikely to impact estuaries where eelgrass thrives. Additionally, eelgrass requires sand or mud substrates, making it unlikely to grow on offshore wind structures. Similarly, surfgrass, which typically roots to hard substrates in biogenic habitats, is unlikely to thrive in the open ocean environment provided by offshore wind structures.

Kelp: There is some understanding of survival and recruitment dynamics of kelp, though this knowledge does not extend to the context of offshore wind installations. Algal spores have the capacity to disperse over long distances, yet many settle near existing beds. If the installation and operation of offshore wind structures affect local beds, upwelling, or water circulation patterns, it could significantly reduce the settlement and survival rates of new individuals. Cables running onshore may potentially provide substrates for attachment, depending on whether offshore wind activities impact sedimentation, habitat, disturbance, and environmental conditions. Predicting these effects is challenging without a comprehensive understanding of the scale of offshore wind, local flow dynamics, and other variables. The location of offshore wind facilities is also critical. Proximity to critical habitats or hard rock formations is crucial information. For example, in Grays Harbor, where hard substrate is limited, kelp growth is minimal.

Feedback on importance: There is interest in understanding potential changes offshore wind may cause at the local region.

Other Data Gaps

General data gaps

- Factors that influence flowering rates of eelgrass
- Effect of eelgrass on CO_2 dynamics

Factors that influence flowering rates of eelgrass. Efforts are currently underway to investigate the factors influencing flowering rates in eelgrass. Seed production is vital for recovery from significant disturbances, promoting genetic diversity, and ensuring survival under extreme conditions. Flowering rates typically range from 1% to 20%, but the reasons for variability across spatial and temporal scales remain unclear. In coastal estuaries, *Z. marina* includes both annual and perennial life history types. The annual form germinates, flowers, and dies between March and October, regenerating from seed the following year.

Effect of eelgrass on CO_2 dynamics. It is crucial to distinguish the role of *Z. marina* in CO_2 dynamics, which can be substantial due its CO_2 uptake during daylight and release at night, and its role in carbon sequestration, which remains uncertain. There is a clear data gap for coastal estuaries, although numerous publications exist on this topic in other regions. Scientists consider blue carbon sequestration a promising area for research. Discussions about seagrass and blue carbon typically focus not on the carbon stored by individual plants, but on the sustaining perennial beds and the ability of these plants to modify sediment conditions, which in turn enhances carbon storage within the sediment.

Offshore wind data gaps

- Effect of offshore wind on sedimentation and organisms associated with kelp and eelgrass
- Effect of offshore wind on the ability of kelp and eelgrass to remove carbon dioxide
- Effect of offshore wind structure on kelp and eelgrass
- Effect of electromagnetic fields from offshore wind on kelp and eelgrass
- Effect of potential shift in upwelling from offshore wind on kelp and eelgrass
- Effect of light from offshore wind on kelp and eelgrass

Effect of offshore wind on sedimentation and organisms associated with kelp and eelgrass.

Eelgrass: If wind projects are located far enough offshore, they are unlikely to have a substantial effect on eelgrass within estuaries.

Kelp: If kelp is present in the area, macroalgae can grow on infrastructure such as cables and anchor chains, potentially benefiting marine species. Offshore wind facilities can serve as hard substrates in areas where the seafloor consists of mud and sand, promoting algal and vegetative growth. Sedimentation resulting from the infrastructure could also impede kelp attachment, potentially covering areas crucial for young kelp to establish and grow. However, offshore wind is unlikely to cause significant sedimentation effects.

The impact of these factors will vary depending on the scale of the offshore wind project. A single project is unlikely to have a significant effect, but with multiple projects, the cumulative impact could be substantial. The location of offshore wind facilities will also be crucial. For instance, in Grays Harbor, where hard substrate is scarce, kelp growth is limited.

Effect of offshore wind on the ability of kelp and eelgrass to remove carbon dioxide.

Eelgrass: There can be carbon uptake within eelgrass beds. Eelgrass, a flowering plant with robust root structures, stabilizes sediment and acts as a carbon sink. Offshore wind activities are unlikely to affect carbon uptake because they will most likely not affect estuaries where eelgrass thrives. However, if there are disturbances to eelgrass meadows, stored carbon will be reintroduced into the environment.

Kelp: Carbon sequestration involves removing CO_2 from the atmosphere. There is existing data on kelp's capability to sequester CO_2. However, there are unanswered questions about the duration of carbon storage and its fate once sequestration efforts are complete. Similarly, the fate of kelp after capture raises concerns about long-term storage solutions. If the carbon remains in the ecosystem rather than being permanently removed, challenges arise.

Offshore wind activities are unlikely to directly affect kelp's ability to remove carbon dioxide. However, if these activities lead to an increase in kelp populations, their carbon sequestration potential could improve. The impact of offshore wind on kelp will largely depend on its location, as kelp are typically found at depths exceeding 20 meters, while other species thrive in shallow waters where strong water movement supports their growth.

Effect of offshore wind structure on kelp and eelgrass.

Eelgrass: Placing an offshore wind structure on top of eelgrass would indeed affect it. Such structures can alter water flow patterns and create shading, both of which can influence the health and growth of eelgrass.

Kelp: The impact of offshore wind structures on kelp remains uncertain. Kelp requires adequate light to grow, so it typically thrives only in nearshore areas where light penetration is sufficient. In nearshore areas where kelp can anchor to shore-based structures, offshore wind infrastructure could potentially provide additional habitat. The location of the offshore wind site will be crucial, particularly in relation to critical habitats or hard rock formations. While the specific materials used for these structures are unclear, it is possible that kelp could attach and grow on them, though studies specific to this activity are currently lacking. In deeper waters, kelp settlement becomes more challenging. Notably, while these structures might offer a substrate for kelp, they could also become heavily fouled, potentially negating any positive effects.

For underwater cables, if they sway with wave action, they may interfere with kelp's ability to remain securely attached. Ensuring stability will be crucial. Additionally, as the cable extends to shore, any movement could also potentially disrupt kelp attachment in nearshore areas. The extent of impact will depend on factors including reach, area coverage, size, material composition, and depth. While long-term effects remain uncertain, short-term impacts from construction and installation are expected.

Effect of electromagnetic fields from offshore wind on kelp and eelgrass.

Eelgrass: The effect of electromagnetic fields (EMF) on eelgrass represents a data gap; currently, there is no definitive knowledge, but believe it's unlikely to affect eelgrass.

Kelp: There is no information available regarding the effect of EMF on kelp.

Effect of potential shift in upwelling from offshore wind on kelp and eelgrass.

Eelgrass: Estuaries, as a whole, will be sensitive to shifts in upwelling. While these shifts may impact eelgrass to some extent, they are generally less influential on eelgrass compared to their effect on oyster productivity.

Kelp: Currently, there is a scarcity of publications regarding offshore wind activity in this context. It is crucial to differentiate between large-scale processes and small-scale impacts. It is unknown whether offshore wind will decrease upwelling indices or stabilize upwelling patterns. Changes may lead to a loss of seasonality or a reduction in its intensity, affecting organisms reliant on upwelling dynamics. The outcome depends significantly on the scale of the changes involved.

The site location is also crucial, especially near critical habitats or hard rock formations. However, this situation may be more pertinent to soft sediment communities.

Effect of light from offshore wind on kelp and eelgrass.

Eelgrass: Light from offshore wind is unlikely to affect eelgrass.

Kelp: Lighting would primarily involve artificial light, specifically designed for visual aid rather than broad-spectrum lighting. Therefore, its direct impact is unlikely. However, there could be indirect effects such as altering the behavior of fish and invertebrates that use submerged aquatic vegetation, potentially affecting grazing rates and other ecosystem processes.

Regarding the shading effect from structures, most research has focused on large over-water structures like bridges and docks. It is well established that kelp require specific light and temperature to thrive. Reduced light levels can directly inhibit photosynthesis, which is well-documented. However, there is a lack of literature on these topics. The effect will depend on the specific site where activities are planned. This situation may be more relevant to soft sediment communities in the area.

Offshore aquaculture data gaps

- Effect of shift in flow and local circulation from offshore aquaculture on kelp and eelgrass
- Effect of offshore aquaculture on sedimentation and organisms associated with kelp and eelgrass
- Effect offshore aquaculture on survival and recruitment of new kelp and eelgrass
- Effect of offshore aquaculture on eelgrass and kelp's ability to remove carbon dioxide
- Effect of offshore aquaculture structure on kelp and eelgrass

Effect of shift in flow and local circulation from offshore aquaculture on kelp and eelgrass.

Eelgrass: Offshore aquaculture is unlikely to have an effect within estuaries and is therefore, unlikely to affect eelgrass.

Kelp: The potential effects are expected to vary depending on the specific site. They primarily involve localized impacts on flow patterns and the distribution of spores, depending on factors such as scale, nutrient releases, cultivated species, and feed composition. Despite some evaluation in certain aquaculture contexts, there are still numerous uncertainties.

While aquaculture placement is unlikely to eradicate kelp because these submerged aquatic species are generally robust and adaptable, there are kelp life cycle distribution patterns that must be considered. For instance, kelp relies on chemical cues for settling. Different species exhibit variations in their duration in the water column and the specific chemical cues they respond to. Nearly all marine propagules have a limited time frame for settling. Therefore, it's crucial to site aquaculture activities in a way that minimizes impact. The factors that could disrupt settlement need to be identified. The Puget Sound Restoration Fund has found that despite understanding the historical presence of kelp and what appear to be suitable habitats, attempts made to re- introduce kelp have not always been successful.

Additionally, many spores and larvae settle more effectively when other species are present in the area. This indicates interspecies relationships where chemical attributes signal favorable growing conditions. Furthermore, when cultivating species in a facility with hard infrastructure, other species that graze on kelp may settle on this infrastructure over time, forming a diverse community. Predicting the impact on kelp may involve tracing a complex chain of logical relationships.

Some information is known about the effect of offshore aquaculture on kelp, but much of it is derived from Asia, where aquaculture operations are larger in scale. While there are some shared species, significant differences exist as well. Therefore, it's essential to study the local dynamics.

Effect of offshore aquaculture on sedimentation and organisms associated with kelp and eelgrass. Depending on its location, offshore aquaculture may influence sedimentation and affect the organisms that rely on kelp or eelgrass. Sedimentation typically has negative effects, impacting various life stages, like reducing eelgrass blade photosynthesis and hindering the attachment of understory kelp. Sedimentation rates can be altered by any factor that disrupts circulation.

Eelgrass: Offshore aquaculture is unlikely to have an effect within estuaries and is therefore, unlikely to affect eelgrass.

Kelp: Large-scale aquaculture operations can introduce bacterial pathogens, potentially causing adverse effects. If kelp requires a solid substrate for attachment, any impediment from offshore aquaculture, such as a covering film, could be detrimental. However, offshore aquaculture operations may be located far enough offshore that their impact on kelp is minimal.

Effect of offshore aquaculture on survival and recruitment of new kelp and eelgrass.

Eelgrass: Offshore aquaculture is unlikely to have an effect within estuaries and is therefore, unlikely to affect eelgrass.

Kelp: There is considerable uncertainty regarding the effect of offshore aquaculture on the early survival and settlement of kelp, making predictions challenging and highlighting the need for site-specific studies. While some positive impacts may occur, evidence also suggests potential harm. Although offshore aquaculture is likely too distant to have a significant impact, the effect will depend on various factors, including water circulation, which can either promote or prevent the settlement of spores, and the level of nutrient availability. Increased nutrients could reduce water clarity, limiting the suitable habitat for kelp to thrive. Additionally, if a solid substrate is necessary for attachment, any obstruction, such as a film covering, would be detrimental.

Effect of offshore aquaculture on the ability of kelp and eelgrass to remove carbon dioxide.

Eelgrass: Offshore aquaculture is unlikely to have an effect within estuaries and is therefore, unlikely to affect eelgrass.

Kelp: This issue largely depends on the scale of nutrient inputs. Increased nutrients could reduce water clarity, limiting the area where kelp can thrive. Additionally, pathogens from offshore aquaculture could potentially impact kelp's ability to uptake CO_2. While the transfer of disease agents to kelp is not a primary concern, it is important to consider how disrupting the food web might affect the broader ecosystem. Nevertheless, the impact of offshore aquaculture on kelp's ability to remove CO_2 is minimal, as kelp primarily redistributes carbon within the ecosystem rather than sequestering it permanently.

Effect of offshore aquaculture structure on kelp and eelgrass.

Eelgrass: Offshore aquaculture is unlikely to affect eelgrass because it is unlike to have an effect within estuaries, and eelgrass, which prefers sandy substrates, would not thrive on aquaculture structures.

Kelp: Kelp could potentially grow on offshore aquaculture structures if spores are able to settle there, but they are unlikely to thrive or may be removed. The growth of kelp on these structures depends on how they are managed, such as scraping off settled organisms. For example, piers and marinas often have understory growth due to marine biofouling, which is typically controlled with anti-fouling paint. For kelp to thrive on aquaculture structures, they would need to be left undisturbed. Maintenance practices and responses to potential structural failures are key factors in determining kelp's ability to grow. Existing rules, recommendations, and policies are in place to address these concerns.

Resources

Table 24. Resources relevant to kelp and eelgrass.

NAME	ACCESS	TYPE	DESCRIPTION
A comparison of epifaunal invertebrate communities in native eelgrass *Zostera marina* and non-native *Zostera japonica* at Tsawwassen, BC	https://www.tandfonline.com/doi/abs/10.1080/17451000.2014.985230	Published article	Investigated whether the non-native *Zostera japonica* provides habitat for eelgrass-dwelling invertebrates similar to its native congener, *Zostera marina*.
Bacterial abundance and aerobic microbial activity across natural and oyster aquaculture habitats during summer conditions in a northeastern Pacific estuary	https://www.researchgate.net/publication/43265056_Bacterial_abundance_and_aerobic_microbial_activity_across_natural_and_oyster_aquaculture_habitats_during_summer_conditions_in_a_northeastern_Pacific_estuary	Published article	Studied sediment properties and the abundance and aerobic metabolism of microbes in Willapa Bay, Washington, USA, to assess their response to oyster aquaculture.
Beyond light: Physical, geological, and geochemical parameters as possible submersed aquatic vegetation habitat requirements	https://link.springer.com/article/10.2307/1352808	Published article	Summarized the effect of physical, geological, and geochemical parameters on the habitat suitability of submerged aquatic vegetation.

NAME	ACCESS	TYPE	DESCRIPTION
Blue Carbon Storage Capacity of Temperate Eelgrass (Zostera marina) Meadows	https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018GB005941	Published article	Provided an estimate of the magnitude and variability of carbon stocks within a widely distributed marine foundation species across its temperate Northern Hemisphere distribution area.
Change in productivity associated with four introduced species: ecosystem transformation of a "pristine" estuary	https://www.researchgate.net/publication/236027531_Change_in_productivity_associated_with_four_introduced_species_ecosystem_transformation_of_a_pristine_estuary	Published article	Examined the changes in ecosystem function associated with introduction of non-native species into Willapa Bay.
Congener comparison of native (Zostera marina) and introduced (Z. japonica) eelgrass at multiple scales within a Pacific Northwest estuary	https://www.researchgate.net/publication/45500577_Congener_comparison_of_native_Zostera_marina_and_introduced_Z_japonica_eelgrass_at_multiple_scales_within_a_Pacific_Northwest_estuary	Published article	Conducted a comparative study of native (*Zostera marina*) and introduced (*Zostera japonica*) eelgrass in Willapa Bay.
Department of Natural Resources (DNR): Outer coast estuary *Zostera japonica* 2013 mapping and monitoring	https://www.dnr.wa.gov/publications/aqr_aamt_zjproject_summary.pdf	Report	Surveyed Willapa Bay and Grays Harbor to assess the presence and abundance of *Zostera japonica* and the density of *Zostera marina*.

NAME	ACCESS	TYPE	DESCRIPTION
Disease surveillance by artificial intelligence links eelgrass wasting disease to ocean warming across latitudes	https://aslopubs.onlinelibrary.wiley.com/doi/full/10.1002/lno.12152	Published article	Assessed wasting disease sensitivity to warming temperatures.
DNR: Nearshore Habitat Inventory	https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-inventory	Website	Contains data and information for the Washington State ShoreZone Inventory along with other intertidal habitat data.
DNR: Statewide Kelp and Eelgrass Health and Conservation Plan	https://www.dnr.wa.gov/kelp-and-eelgrass-plan	Website	Provides information on DNR's plan to conserve and restore at least 10,000 acres of kelp forest and eelgrass meadow habitat by 2040.
Effect of oyster aquaculture on seagrass *Zostera marina* at the estuarine landscape scale in Willapa Bay, Washington (USA)	https://www.int-res.com/articles/aei2015/7/q007p029.pdf	Published article	Quantified impacts of oyster aquaculture on *Z. marina* in Willapa Bay.
Effects of irradiance, temperature, and nutrients on growth dynamics of seagrasses: A review	https://www.researchgate.net/publication/248248296_Effects_of_irradiance_temperature_and_nutrients_on_growth_dynamics_of_seagrasses_A_review	Published article	Reviewed the effects of light, temperature, and nutrients on seagrasses.

NAME	ACCESS	TYPE	DESCRIPTION
Expected limits on the ocean acidification buffering potential of a temperate seagrass meadow	https://www.researchgate.net/publication/326738724_Expected_limits_on_the_ocean_acidification_buffering_potential_of_a_temperate_seagrass_meadow	Published article	Developed a biogeochemical box model to enhance understanding of how a temperate seagrass meadow could potentially mitigate the effects of ocean acidification locally.
Factors influencing spatial and annual variability in eelgrass (Zostera marina L.) meadows in Willapa Bay, Washington, and Coos Bay, Oregon, estuaries	https://www.researchgate.net/publication/225723175_Factors_influencing_spatial_and_annual_variability_in_eelgrass_Zostera_marina_L_meadows_in_Willapa_Bay_Washington_and_Coos_Bay_Oregon_estuaries	Published article	Investigated environmental factors affecting annual variability and spatial differences in eelgrass meadows (*Zostera marina L.*) within Willapa Bay, WA and Coos Bay, OR over 4 years.
Floating Kelp Forest Indicator for WA State	https://wadnr.maps.arcgis.com/apps/webappviewer/index.html?id=f10864050bf14f57ba751ae53bc061f5	GIS	Interactive map for the Floating Kelp Indicator.
Form–function relationships in a marine foundation species depend on scale: a shoot to global perspective from a distributed ecological experiment	https://stachlab.wordpress.com/wp-content/uploads/2018/08/ruesink_et_al_2018.pdf	Published article	Examined form and function of Zostera marina at 14 sites spanning a wide biogeographic range, by experimentally establishing a mesograzer deterrence and fertilizer treatment.
Geospatial Habitat Change Analysis in Pacific Northwest Coastal Estuaries	https://www.researchgate.net/publication/227059049_Geospatial_habitat_change_analysis_in_Pacific_Northwest_Coastal_estuaries#full-text	Published article	Assessed the historical changes in the location and amount of potential estuarine habitat in Grays Harbor, Willapa Bay, and Coos Bay.

NAME	ACCESS	TYPE	DESCRIPTION
Habitat effects of macrophytes and shell on carbonate chemistry and juvenile clam recruitment, survival, and growth	https://www.researchgate.net/publication/329342270_Habitat_effects_of_macrophytes_and_shell_on_carbonate_chemistry_and_juvenile_clam_recruitment_survival_and_growth	Published article	Measured (1) recruitment, survival, and growth of juvenile clams (*Ruditapes philippinarum*) and (2) local water chemistry in response to experimental manipulations at Fidalgo Bay and Skokomish Delta, Washington, USA.
Habitat structure influences the seasonality of nekton in seagrass	https://www.researchgate.net/publication/333029835_Habitat_structure_influences_the_seasonality_of_nekton_in_seagrass	Published article	Surveyed nekton and predation intensity at five sites in distinct oceanographic areas in Washington.
Habitat use patterns and edge effects across a seagrass-unvegetated ecotone depend on species-specific behaviors and sampling methods	https://www.researchgate.net/publication/324767882_Habitat_use_patterns_and_edge_effects_across_a_seagrass-unvegetated_ecotone_depend_on_species-specific_behaviors_and_sampling_methods	Published article	Studied patterns in mesopredator densities (aggregate and per-taxon) and behaviors across a seagrass-unvegetated ecotone in WA.
Impacts of CO_2 Enrichment on Productivity and Light Requirements of Eelgrass	https://academic.oup.com/plphys/article/115/2/599/6071252	Published article	Studied the long-term effects of increased CO_2 availability on light requirements, productivity, and carbon allocation in eelgrass (*Zostera marina L.*)

NAME	ACCESS	TYPE	DESCRIPTION
Life history and morphological shifts in an intertidal seagrass following multiple disturbances	https://ir.library.oregonstate.edu/concern/articles/2801ph55w?locale=en	Published article	Characterized gap recovery after complete removal of eelgrass (*Zostera marina*) in Willapa Bay, Washington, USA.
Nearshore Habitat Inventory	https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-inventory	Website	Department of Natural Resources' inventory of data and information on the intertidal and shallow subtidal areas along WA's saltwater shorelines.
Nekton Community Responses to Seagrass Differ with Shoreline Slope	https://www.researchgate.net/publication/332449542_Nekton_Community_Responses_to_Seagrass_Differ_with_Shoreline_Slope	Published article	Sampled nekton in naturally occurring eelgrass habitat mosaics using a crossed design: unvegetated, edge, and interior eelgrass habitat in flats and fringes.
Nekton use of co-occurring aquaculture and seagrass structure on tidal flats	https://www.researchgate.net/publication/373290114_Nekton_use_of_co-occurring_aquaculture_and_seagrass_structure_on_tidal_flats	Published article	Studied the impact of various oyster culture methods on nekton communities and abundance across a range of seagrass habitats, spanning multiple seasons.
Olympic Coast National Marine Sanctuary Condition Report: 2008-2019	https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/2008-2019-ocnms-condition-report.pdf	Report	Assesses the condition and trends of national marine sanctuary resources and ecosystem services, including kelp forests.

NAME	ACCESS	TYPE	DESCRIPTION
Projected cross-shore changes in upwelling induced by offshore wind farm development along the California coast	https://www.nature.com/articles/s43247-023-00780-y	Published article	Examined changes to upwelling using atmospheric and ocean circulation numerical models with a hypothetical turbine buildout scenario across three areas of interest.
Reversal of intraspecific interactions by an ecosystem engineer leads to variable seedling success along a stress gradient	https://www.int-res.com/articles/meps2016/543/m543p163.pdf	Published article	Conducted an empirical test of the stress gradient hypothesis for *Zostera marina L.*, an important marine ecosystem engineer, across a hydrodynamic gradient.
Taxonomic and functional assessment of mesopredator diversity across an estuarine habitat mosaic	https://esajournals.onlinelibrary.wiley.com/doi/full/10.1002/ecs2.1792	Published article	Evaluated functional redundancy as a proxy for ecosystem resistance and resilience by using multiple response variables emphasizing taxonomic and functional diversity in seagrass habitats.
Temporal variation in intertidal habitat use by nekton at seasonal and diel scales	https://www.researchgate.net/publication/334142788_Temporal_variation_in_intertidal_habitat_use_by_nekton_at_seasonal_and_diel_scales	Published article	Examined nekton abundances and community structure in eelgrass, unvegetated habitats, and edges in Willapa Bay, focusing on how seasonality, habitat, and diel period influenced these patterns

NAME	ACCESS	TYPE	DESCRIPTION
Tradeoffs in life history investment of eelgrass Zostera marina across estuarine intertidal conditions	https://www.int-res.com/abstracts/meps/v686/p61-70/	Published article	Evaluated intraspecific life history patterns of eelgrass *Zostera marina*.
Variability in carbon availability and eelgrass (Zostera marina) biometrics along an estuarine gradient in Willapa Bay, WA, USA	https://doi.pangaea.de/10.1594/PANGAEA.869866	Published article	Examined the variation in biometric measurements of intertidal seagrass (*Zostera marina*) within an estuary during peak summer growth.
Warming sea surface temperatures fuel summer epidemics of eelgrass wasting disease	https://par.nsf.gov/servlets/purl/10373338	Published article	Monitored eelgrass wasting diseases (EWD) and correlated prevalence of EWD with seawater temperature metrics before, during, and after the 2015-2016 marine heatwave.
Washington Marine Vegetation Atlas	https://wadnr.maps.arcgis.com/apps/webappviewer/index.html?id=d0ccc569e1cd4b5189b492c0ba0297c5	GIS	Provide spatially referenced information and data about vegetation growing in nearshore areas in WA.

Protected Areas

Key Data Gaps

General Data Gaps

- Relative effect of a disturbance to habitat resilience within protected areas
- Monitoring and assessment of the health of species communities within protected areas

Offshore Wind Data Gaps

- Effect of preclusion of existing uses by offshore wind and the effect on protected areas
- Effect of offshore wind on critical habitat and their associated species
- Method to assess the scale of offshore wind effects on protected areas
- Effectiveness of existing regulations in mitigating offshore wind effects on protected areas

Other Data Gaps

General Data Gaps

- Spatial data of protected areas

Offshore Aquaculture Data Gaps

- Method to assess the scale of offshore aquaculture effects
- Effect of offshore aquaculture on critical habitat and their associated species
- Effectiveness of existing regulations in safeguarding protected areas from offshore aquaculture effects

Background

In this report, the term “protected areas” is being broadly applied to areas protected by state or federal designations. Specifically, within the MSP Study Area, there are various such designations, each providing differing levels and forms of protection for habitats and resources.

a. State Designations

1. Important, Sensitive, and Unique Areas (ISUs)

The Marine Spatial Plan, mandated by RCW 43.372.040(6)(c), designates Important, Sensitive, and Unique Areas (ISUs) in state waters to areas with high conservation value, historic value, or has key infrastructure. There are standards to maintain the high values for these areas and provide protection from adverse effects of offshore development while balancing existing uses like fishing. ISU maps are available to serve as informational tools to aid state agencies, local governments, and applicants in identifying known ISU locations. However, these standards apply to all designated habitats or resources that occur in state waters, regardless of whether they have been mapped or not.

Coastal estuaries are vital ecological areas that also support a range of existing uses and associated infrastructure. However, coastal estuaries like Grays Harbor and Willapa Bay themselves are not an ISU. Rather, the estuaries host numerous ISUs. Because the resolution of existing data is insufficient for detailed siting, proposed projects must undergo a finer-scale analysis to “provide special protection to the marine life and resources of the estuaries and to ensure all reasonable steps are taken to avoid and minimize impacts to the habitats, species, and uses in estuaries” (RCW 43.143.030(2)(d) and RCW 43.143.030(2)(e)).

2. Washington State Seashore Conservation Area and State parks

The Washington State Seashore Conservation Act of 1967 recognized the significance of the pristine Washington shoreline for recreational activities, sports, nature observation, and relaxation (RCW 79A.05.600). To ensure public access and enjoyment, the Act designated a substantial portion of the southern coast as the Seashore Conservation Area (SCA). The SCA spans 62 miles of the coastline and is divided into three sections.[70] 10 state parks are located within the conservation area.

The Washington State Parks and Recreation Commission oversees the SCA, numerous state parks, and ocean beach access points along the coastline within Grays Harbor and Pacific Counties. Many parks offer overnight camping facilities, while others are designated for day use only. Public access is vital for promoting and enabling coastal recreation.

In 2013, Pacific Coast state parks, the SCA, and ocean beach approaches collectively attracted over 9.2 million visitors, generating approximately $3.3 million in revenue.

[70] https://parks.wa.gov/find-parks/state-parks/seashore-conservation-area

b. Federal Designations

1. Olympic Coast National Marine Sanctuary

Established in 1994, the Olympic Coast National Marine Sanctuary (OCNMS) covers about 41% of the MSP Study Area. The Sanctuary spans 2,408 square nautical miles off Washington's Olympic Peninsula, extending seaward 22 to 39 nautical miles with depths exceeding 4,500 feet. Its shoreline spans 141 nautical miles, encompassing bays, inlets, and points. The OCNMS is located in the California Current Large Marine Ecosystem and connected to the Big Eddy Ecosystem. The Sanctuary is one of North America's most productive marine regions with pristine, undeveloped shorelines. It is home to large seabird colonies, at least twenty-nine marine mammal species, various fish species, deep-sea corals, and a diverse seaweed community. The Sanctuary also supports a range of ocean activities, including shipping, commercial fisheries, and research.

The Sanctuary borders the Olympic National Park and overlaps with the Usual and Accustomed Areas (U&As) of four coastal treaty Tribes. The Sanctuary also enhances the protection of the Washington Maritime National Wildlife Refuge Complex which includes over 600 offshore islands and rocks.

The Sanctuary aims to safeguard the Olympic Coast's natural and cultural resources through responsible stewardship and research and promote public outreach and education. In 2007, the four coastal treaty Tribes, Washington State, and the National Sanctuary Program created the Olympic Coast Intergovernmental Policy Council (IPC), fostering information exchange, policy coordination, and resource management. The Sanctuary collaborates with a Sanctuary Advisory Council (SAC), comprising representatives from treaty Tribes, government agencies, and interested or affected parties. The SAC advises the Sanctuary's superintendent on management, operations, education, regulations, enforcement, and marine policy. There is an Olympic Coast National Marine Sanctuary Management Plan which includes Action Plans on oil spill prevention, marine debris, education and outreach, research coordination, and community involvement.

2. Critical Habitat

Under the Endangered Species Act (ESA), critical habitat may be established for threatened or endangered species. 16 U.S.C. §1532(5)(B). This habitat is a geographical area that is essential to the conservation of specific species and may require special management considerations or protection. 16 U.S.C. §1532(5)(A)(i).

Critical habitats have been designated for various species which include, but are not limited to specific salmon species, bull trout, green sturgeon, and leatherback sea turtles.

3. Essential Fish Habitat

The Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act) requires fishery management plans developed by Regional Fishery Management Councils or the Secretary of Commerce to describe and identify essential fish habitat (EFH), minimize adverse effects on these habitats caused by fishing to the extent practicable, and identify actions to promote the conservation and enhancement of the habitat. 16 U.S.C. §1853(a)(7). EFH refers to the waters and substrate that are necessary to fish for spawning, breeding, feeding, or growth to maturity. 16 U.S.C. §1802(10).

Fishery management plans identified EFH for coastal pelagic species, highly migratory species, groundfish, and salmon. For salmon, EFH was designated for Chinook and Coho salmon across the EEZ. EFH for pink Salmon was designated in Puget Sound, the Strait of Juan de Fuca, and extends into the MSP Study Area.

4. National Parks and National Wildlife Refuges

The Olympic National Park (ONP) was established in 1938 by President Roosevelt and is managed by the National Park Service. This park is located on the Olympic Peninsula, primarily within Clallam and Jefferson Counties, and encompasses three park districts adjacent to the MSP Study Area. Covering a substantial area of the northern coastline, ONP serves as the region's primary destination for recreation and tourism, attracting approximately 3 million visitors annually.

The United States (US) Fish and Wildlife Service manages National Wildlife Refuges (NWRs). The Study Area contains five NWRs. Flattery Rocks, Quillayute Needles, and Copalis NWRs are located offshore, with public access prohibited but wildlife viewing permitted from boats. In contrast, Grays Harbor and Willapa NWRs are situated on the mainland and are open to visitors. A 2011 study estimated that Willapa NWR attracted 114,680 visitors that year, resulting in approximately $1.8 million in associated spending.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to protected areas:

General data gaps

- Relative effect of a disturbance to habitat resilience within protected areas
- Monitoring and assessment of the health of species communities within protected areas

Relative effect of a disturbance to habitat resilience within protected areas. Resilience is studied frequently in ecological research and there is a decent understanding of different disturbances that occur, including human-induced activities such as discharges and oils spills.

Habitat resilience can be categorized into resilience to extreme events and resilience to sublethal effects. More observations have focused on sublethal effects. For example, in California, kelp forests were seen to decline rapidly when water temperatures reached 16°C. Further research is needed to better understand the thermal tolerance of kelp forests.[71]

[71] *See* https://www.int-res.com/articles/meps_oa/m703p047.pdf

A multi-stressor project[72] is examining lethal and sublethal thresholds on the continental shelf, exploring how combinations of stressors like temperature increases, marine heatwaves, hypoxia, ocean acidification (OA), and harmful algal blooms (HABs) affect marine species such as Dungeness crab and krill. While research has been conducted on other species, many sublethal thresholds, such as those for hypoxia, remain poorly established. These thresholds vary across different life stages. For example, the standard threshold for dissolved oxygen is 2 mg/L (milligrams per liter). However, species such as juvenile and adult salmon require higher levels of dissolved oxygen, typically ranging from 4 to 5 mg/L. Additionally, young salmon smolts in streams and nearshore areas necessitate even greater concentrations, exceeding 10 mg/L. Efforts by the EPA are underway to address these threshold discussions.

The effects of disturbances vary depending on factors like habitat type and whether the disturbances are episodic or chronic. For example, a disturbance can be brief, such as a hypoxic bubble in a pelagic zone that dissipates quickly, or it can persist as a prolonged disturbance, like hypoxic conditions that affect deep-sea corals for several months. The nature of the disturbance is also paramount, with episodic events like oil spills having defined durations ranging from days to years, while chronic disturbances such as climate change exert continuous pressure. Some events can manifest as having both episodic and chronic traits such as hypoxia which intensifies during upwelling seasons, subsides during downwelling, and now occurs annually during summer months. Similarly, marine heatwaves are transitioning from an episodic disturbance to a more chronic one.

The effects of human interventions aimed at mitigating disturbances also remain uncertain. For instance, the effect of dispersants deployed during oil spills on aquatic organisms remains uncertain.

Protected areas have differing reasons on their importance and level of protection, with recovery processes for each representing a significant data gap. Legal safeguards within sanctuaries and other protected zones can help mitigate impacts, such as those enforced in the OCNMS. Human-induced disturbances are minimized within OCNSM boundaries due to the prohibition of discharges of substances or pollutants and activities that cause seafloor impacts. Understanding the potential effect of disturbances is important, particularly for some EFH conservation areas where historically permitted activities like bottom contact fishing or bottom trawling were ceased and habitats were allowed to recover. There is a need to better understand recovery timelines and influencing factors such as latitude, depth, circulation, habitat and community composition, substrate type, and nature of impacts. Crafting a monitoring plan with specific metrics tailored to each area's needs will help answer these questions.

Feedback on importance: No specific feedback provided.

> **WCMAC:** Most protected areas, if not all, were established for specific purposes such as the groundfish Essential Fish Habitat conservation area. Understanding the relative

[72] https://coastalscience.noaa.gov/project/science-to-support-a-climate-ready-dungeness-crab-fishery-in-the-northern-california-current/

impact of disturbances on habitat resilience will require these protected areas to be exposed to and affected by such disturbances.

Monitoring and assessment of the health of species communities within protected areas. Monitoring and assessment efforts are conducted by various entities, including communities, Tribes, states, and federal agencies and depends on jurisdiction. For example, sanctuaries operate their own monitoring programs, which may not be standardized across all locations. Within the OCNMS, monitoring of biological communities encompasses annual kelp surveys, intertidal monitoring, biodiversity surveys, and ocean water sampling for Harmful Algal Blooms (HABs) near moorings. In contrast, there is currently no specific monitoring system in place for EFHs. Monitoring and assessment of species also occur through fisheries-independent surveys conducted across the entire West Coast, covering locations accessible by net dragging. However, these surveys do not prioritize areas based on an area's protection status.

Additionally, to assess species health, the National Oceanic and Atmospheric Administration's (NOAA) Pacific Marine Environmental Laboratory (PMEL) is studying changes in biological communities under varying ocean conditions. PMEL is tracking biodiversity using eDNA, integrating this data with information from a long-term coastal mooring at Teahwhit Head. Autonomous samplers collect eDNA samples at both noon and midnight to capture diurnal variations in these communities, primarily at Teahwhit Head, with occasional deployments at Cape Elizabeth.

Certain habitats require greater monitoring and assessment efforts. The nearshore sandy habitat, home to significant species like Dungeness crab, remains poorly understood.[73] There is a lack of information regarding the early life history of these species and the influence of ocean conditions on their development and growth. Presently, efforts are underway to address these questions through a NOAA-funded four-year multi-stressor project[74]. Monitoring of the deep-sea benthic community is also challenging and limited. Due to their long lifespan and slow growth rates, deep-sea species, particularly corals, exhibit slow recovery from impacts. However, regular monitoring is rare, with efforts primarily focused on exploring and characterizing new areas. This is largely due to the high costs and uncertain availability of ship time. While some monitoring occurs, it is often driven by permit requirements or the willingness of permit holders to finance surveys. For instance, a research cruise recently studied the recovery of benthic habitats following the installation of telecom cables.

Additionally, certain phenomena such as spillover effects have not yet been studied in protected areas like EFHs. Particularly observed in Marine Protected Areas (MPAs), the spillover effect refers to the increased abundance and larger average size of fish, often cited as a benefit of fishery closures. These benefits can extend beyond the MPA, spilling over into adjacent areas and becoming available to nearby fisheries. Research on this effect has been conducted within the California MPA network.

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[73] https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/2008-2019-ocnms-condition-report.pdf

[74] https://coastalscience.noaa.gov/project/science-to-support-a-climate-ready-dungeness-crab-fishery-in-the-northern-california-current/

Feedback on importance: No specific feedback provided.

WCMAC: The monitoring and assessment of the health of various biological communities represent significant data gaps. Numerous protected areas exist, yet there is little to no monitoring or baseline data regarding the conditions within these areas.

Offshore wind data gaps

- Effect of preclusion of existing uses by offshore wind and the effect on protected areas
- Effect of offshore wind on critical habitat and their associated species
- Method to assess the scale of offshore wind effects on protected areas
- Effectiveness of existing regulations in mitigating offshore wind effects on protected areas

Effect of preclusion of existing uses by offshore wind and the effect on protected areas. The coastal area sees significant human activity. Offshore wind my restrict certain activities, like seabird monitoring and vessels conducting whale watching or seabird tours. There may also be tradeoffs with scientific research activities. During the Okeanos Explorer cruise in April 2023, ROV pilots were reluctant to operate within 2 miles of submarine cables. In particular, the potential placement of offshore wind facilities outside the OCNMS raises concerns about the increased risk of concentrating people in certain areas. This effect could result from the displacement of existing vessel and fishing activities by offshore wind, resulting in a concentration of ocean use in specific regions. However, sanctuary regulations may provide some protection against these effects as they dictate permissible activities, requiring site-specific permits for certain actions. Seafloor disturbances, discharges, and low overflights causing wildlife disturbance are prohibited.

The coastal area experiences significant human activity, and the development of offshore wind facilities may restrict certain activities, such as seabird monitoring and whale watching. These projects could also present trade-offs with scientific research. For example, during the Okeanos Explorer cruise in April 2023, ROV pilots were hesitant to operate within 2 miles of submarine cables. There are also concerns about the potential displacement effects caused by precluding certain activities. For instance, the potential placement of offshore wind facilities outside the OCNMS raises concerns about displacing existing ocean uses, which could concentrate human activity in other areas, including adjacent to or within the sanctuary. However, sanctuary regulations provide some protection against these effects by governing permissible activities. These regulations require site-specific permits for certain actions and prohibit seafloor disturbances, discharges, and low overflights that could disturb wildlife.

Feedback on importance: No specific feedback provided.

WCMAC: The potential preclusion of offshore uses due to offshore wind development and its impact on protected areas will depend on the cumulative effects of offshore wind activities, proximity, and other factors. Displacement of existing offshore activities is certain; however, the specifics of where these activities will relocate and how this will affect other areas, including protected zones, remain to be determined. This data gap is regarded as a lower priority because there are currently no available methods to study this effect.

Effect of offshore wind on critical habitats and their associated species. Various federally and state-listed species possess critical habitat designations, including Southern Resident Killer Whales (SRKW), humpback whales, state-listed sea otters, sturgeons, and seabird species such as the short-tailed albatross and marbled murrelet. The presence of offshore wind facilities within these critical habitats could have an effect, the severity of the impact contingent upon the specific species involved. The effect of offshore wind development will not be homogenous. Potential outcomes may range from displacement or disruption to more significant effects, including harm, harassment, or mortality. Indirect effects may also result. For example, shifts in human responses to offshore wind, such as changes in vessel traffic and fishing effort, may also affect critical habitats and their species. Offshore wind projects may also affect upwelling and migratory patterns. Any effects on upwelling could lead to cascading impacts.

Risks from offshore wind farms can be extrapolated if the effect on a particular species is understood. Surveying areas with windfarms can provide valuable insights. Recently, environmental DNA (eDNA) techniques were used to study and compare species distribution within and outside windfarm areas.

Feedback on importance: No specific feedback provided.

WCMAC: The method for assessing the impacts of offshore wind on protected areas will remain a data gap until offshore wind activities are initiated and a comprehensive scaling plan is established. Consequently, this data gap is considered a lower priority, as the necessary information cannot be obtained until such activities take place.

Method to assess the scale of offshore wind effects on protected areas. To assess the scale of offshore wind effects, it is essential to incorporate a risk assessment which evaluates both vulnerability and exposure of protected areas. The exposure to the effects of offshore wind will vary across different regions and exhibit significant heterogeneity. For areas like sanctuaries where offshore wind developments are not expected to occur, these areas may still be subject to indirect effects if offshore wind facilities are nearby. For example, historical trends have seen fishing activity move southward out of OCNMS. If offshore wind development restricts access to fishing grounds, fishing efforts may be pushed back into the sanctuary. Evaluating the scale of offshore wind effects will need to involve understanding how decisions regarding offshore wind influence user behavior, as this could have substantial implications for the management of the protected area.

There are various approaches to do risk assessments, ranging from data-intensive methods to expert assessments. Collaboration with various partners will be necessary to attain a comprehensive understanding of this data gap. Existing resources may also provide insight. For example, OCNMS evaluates the vulnerability, sensitivity, and exposure of resources such as species, habitats, and ecosystem services to climate change. Creating a guide for offshore wind, akin to OCNMS's Marine Protected Area Climate Vulnerability Assessment Guide[75], could prove beneficial.

Feedback on importance: No specific feedback provided.

> **WCMAC:** The method for assessing the impacts of offshore wind on protected areas will remain a data gap until offshore wind activities are initiated and a comprehensive scaling plan is established. Because the necessary information cannot be obtained until offshore wind activities take place, this data gap is considered a lower priority.

Effectiveness of existing regulations in mitigating offshore wind effects on protected areas. There are regulations under statutes such as the Marine Mammal Protection Act (MMPA) and the Endangered Species Act (ESA) which provide robust protection of certain species from the effects of developments like offshore wind, as activities must avoid causing harm or "take." Species not listed under these acts may not enjoy the same level of protection. Other regulations, including those related to critical habitats and those requiring consultations on the impacts to habitats and species, allow projects to move forward once compliance is confirmed.

Protected areas may have their own specific regulations. For example, sanctuaries are intended to protect designated areas while also allowing for compatible uses. Typically, sanctuaries regulate activities within their boundaries, unless a clear nexus of impact is demonstrated beyond those boundaries. There are concerns if existing protections will adequately protect sanctuaries once offshore wind facilities are established. BOEM is unable to issue leases in specific protected areas such as national marine sanctuaries. Permit requests may still be submitted, but they would not undergo the typical BOEM leasing process. For example, offshore wind installations would likely be positioned outside of OCNMS boundaries. However, offshore wind cables may pass through OCNMS which may have an effect. Alternatively, if development occurs outside the sanctuary, it's important to assess whether it will negatively affect sanctuary resources and whether there are pathways for recourse. It will be essential to determine who is responsible for demonstrating these effects.

Feedback on importance: No specific feedback provided.

> **WCMAC:** The regulatory effectiveness of protected areas in mitigating the effects of offshore wind is likely a significant data gap, and it probably varies by the type of protected area. For instance, national marine sanctuaries are excluded from BOEM's offshore wind call areas, while other protected areas, such as rockfish conservation areas managed by the Pacific Fishery Management Council or state-managed MPAs, are included.

[75] https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/2023-mpa-climate-vulnerability-assessment-guide.pdf

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Spatial data of protected areas

Spatial data of protected areas. Monitoring is an integral part of the management of protected areas and can provide valuable insights into what is happening within. However, inadequate funding poses a challenge to conduct regular data collection both inside and outside these areas and across different seasons. There is also a significant gap in various types of information, necessitating the use of diverse approaches and technologies. Collaboration with entities such as NOAA and, when feasible, Tribal entities can help gather various information such as on fishing activity and the risk of whale entanglement. Although distribution is not inherently linked to protected areas, analyzing fishing data can identify hotspots of species distribution.

In particular, understanding how species use different habitats in different protected areas is really important. Some knowledge of marine mammals is based on sound recordings and vocalizations. Despite abundant acoustic data, much of it remains unanalyzed due to the specialized nature of bioacoustics data analysis, which requires hiring expert analysts. It's anticipated that factors like time scales, seasonality, and hotspots may change over time, prompting concerns about the potential northward and offshore shift of these hotspots. Efforts are also underway to document hotspots for seabirds.

Another approach is collecting data on the movement of fish. Since 2018, VEMCO receivers have been deployed on moorings, enabling the detection of signals from tagged fish. This method significantly enhanced knowledge of how sturgeons and other tagged species, such as salmon, move within OCNMS. Data on fish movements also has a broader application. The likely locations of Southern Resident Killer Whales (SRKW) can be estimated based on the distribution of their Chinook salmon prey. Given the inability to tag killer whales directly, researchers rely on tracking their prey or listening for their vocalizations to infer their behavior. However, there are still gaps in understanding the distribution of SRKW along the coast, particularly during the winter months. The Northwest Fisheries Science Center of NOAA Fisheries is conducting studies to improve this understanding.

Other data sources are also important for addressing this data gap. Within OCNMS, moorings are positioned along the coast, with 10 moorings at 5 locations. Between 2019 and 2022, up to four sound moorings were deployed, and the sound mooring at the entrance of the Strait of Juan de Fuca is still maintained. In total, 11 sites are planned to operate indefinitely. Additionally, oceanographic buoys are scattered across the region, including the National Data Buoy Center’s Cape Elizabeth buoy and NANOOS’s Cha’ba buoy. However, most of these sites lack the VEMCO acoustic receivers used on OCNMS moorings to track tagged fish presence.

There are also Tribal data resources. The Quinault Indian Nation and Quileute Tribe have partnered with NANOOS to deploy buoys as part of the Backyard Buoys[76] initiative. These buoys collect real-time surface data, including temperature and wave height, with the goal of supporting Indigenous communities. Additionally, the Makah Tribe is exploring the potential installation of a mooring further offshore, near Nitinat Canyon.

Offshore aquaculture data gaps

- Method to assess the scale of offshore aquaculture effects
- Effect of offshore aquaculture on critical habitat and their associated species
- Effectiveness of existing regulations in safeguarding protected areas from offshore aquaculture effects

Method to assess the scale of offshore aquaculture effects. Risk assessment involves evaluating both vulnerability, sensitivity, and exposure, with exposure being variable across locations. There are various approaches to conducting risk assessments, ranging from data-intensive methods to expert assessments. However, risk assessments will be challenging to perform without a clear understanding of the impacts of offshore aquaculture. Assessing the impact would also depend on the type of aquaculture—whether it involves finfish, shellfish, or kelp. Currently, there is a lack of monitoring infrastructure tailored to this specific activity.

The Pacific Fishery Management Council (PFMC), in collaboration with NOAA Fisheries and, if in state waters, the state of Washington, holds the authority to regulate offshore aquaculture, with consultation from the treaty Tribes. Developing a framework similar to MPA Climate Vulnerability Assessment Guide[77] for aquaculture could prove beneficial.

Even if located outside a protected area, offshore aquaculture activities can still have an impact. Issues such as water quality, materials used, anchoring, maintenance, and biofouling highlight the potential risks associated with net pens. For instance, discharge from offshore aquaculture operations could be classified as a prohibited activity within the OCNMS. Permitting for such activities would be evaluated on a case-by-case basis, taking into account various factors such as the size and scale of the facility, potential impacts on state waters, and the need for Tribal consultations.

Effect of offshore aquaculture on critical habitat and their associated species. Understanding the effects of offshore aquaculture on critical habitat and species' growth and recovery poses a data gap, with the outcome varying based on the aquaculture operation’s siting and scale. If an offshore aquaculture farm intersects with critical habitat and the effects on species are understood, risks can be extrapolated. Survey efforts should begin with established aquaculture farms. Additionally, specific areas like the Juan de Fuca eddy serve as hotspots for harmful algal bloom (HAB) formation. Introducing nutrients in this region may exacerbate HAB occurrences

[76] https://backyardbuoys.org/
[77] https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/2023-mpa-climate-vulnerability-assessment-guide.pdf

and affect critical habitats. There is a need to carefully consider potential cascading impacts of offshore aquaculture on the food web and human populations.

Effectiveness of existing regulations in safeguarding protected areas from offshore aquaculture effects. Unlike offshore wind activities, offshore aquaculture leasing may not be outright prohibited within a sanctuary. The OCNMS does not have a direct role in fisheries management and is not currently structured to be fully protected from such activities. However, any installation, anchoring, or mooring that results in seafloor disturbance or discharge may require a permit or be subject to prohibition. Additionally, certain species receive robust protection measures from statutes such as the MMPA and the ESA. These acts mandate the avoidance of "take" and harm.

Resources

Table 25. Resources relevant to protected areas.

NAME	ACCESS	TYPE	DESCRIPTION
Backyard Buoys	https://backyardbuoys.org/	Website	Provides data, information, and resources for the Backyard Buoys project, which empowers Indigenous and coastal communities to collect and utilize wave data.
National Centers for Coastal Ocean Science (NCCOS): Science to Support a Climate-Ready Dungeness Crab Fishery in the Northern California Current	https://coastalscience.noaa.gov/project/science-to-support-a-climate-ready-dungeness-crab-fishery-in-the-northern-california-current/	Website	Provides information on a project that aims to understand how multiple stressors interact and affect Dungeness crabs and the communities dependent on them.
NOAA: The West Coast Region (WCR) Species and Habitat App	https://maps.fisheries.noaa.gov/portal/apps/webappviewer/index.html?id=e8311ceaa4354de290fb1c456cd86a7f	GIS Map	Presents spatial data for species listed under the Endangered Species Act, as well as habitat areas protected by the Magnuson-Stevens Fishery Conservation and Management Act.

NAME	ACCESS	TYPE	DESCRIPTION
Olympic Coast National Marine Sanctuary Condition Report: 2008-2019	https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/2008-2019-ocnms-condition-report.pdf	Report	Using the best available information, provides information on the status and trends of various components of the sanctuary's ecosystem and maritime heritage resources.

Key Data Gaps

General Data Gaps

- Seafloor surveys
- Data on bottom environmental factors

Offshore Wind Data Gaps

- Effect of offshore wind cables and cable installation on the seafloor
- Effect of offshore wind anchors on the seafloor
- Effect of offshore wind on the ecological productivity of the seafloor
- Effect of offshore wind on seafloor communities

Other Data Gaps

General Data Gaps

- Effect of disturbance on the seafloor

Offshore Wind Data Gaps

- Effect of offshore wind structures on the seafloor

Offshore Aquaculture Data Gaps

- Effect of nutrients, waste, and chemicals from offshore aquaculture on the seafloor
- Effect of offshore aquaculture structures on the seafloor

Background

The MSP Study Area includes the Pacific Ocean adjacent to Washington's coastline from the intertidal zone out to the continental slope. It extends from ordinary high water on the shoreward side out to a water depth of 700 fathoms (4,200 feet) offshore. Washington's continental shelf widens northward, ranging from 15 to 78 nautical miles wide. A 330-foot water-depth contour lies within 22 nautical miles from shore. It comprises primarily soft sediments, glacial deposits, and rocky outcrops. The continental shelf break and slope rapidly increases in depth towards the abyssal plain. There are also submarine canyons that cut into the slope and shelf. These canyons act as channels for sediment movement to the deep seafloor and enhance coastal upwelling.

There is limited empirical seafloor mapping data in the MSP Study Area. Past modeling efforts attempted to create regional maps of geology and habitats to estimate seafloor features. Maps of limited areas suggest the majority of seafloor habitat is soft/mixed substrates with rocky/mixed seafloor substrates mainly occurring in the northern area. Previous projects include a 2011 lidar coastal survey by the United States (US) Army Corps of Engineers National Coastal Mapping Program; the Washington State Outer Coast Seafloor Atlas of the OCNMS; and the coastal treaty Tribes' classification of substrate, geoform, and ecological units using the Habitat Framework Initiative. This Habitat Framework applies NOAA's Coastal and Marine Ecological Classification Standard[78] (CMECS) which provides a catalog of ecological terms to describe coastal and marine environments and a framework to interpret, classify, and inter-relate observation data. A 2014 study[79] by BOEM that assessed the physical properties of the seafloor and species-habitat associations of Washington, Oregon, and northern California recommended site specific mapping to accurately assess substrate and habitat features. Additionally, in 2015, NOAA assessed priority seafloor mapping areas for the MSP. Evaluating seafloor data and important areas identified by interested or affected parties for future management decisions, two offshore and three nearshore priority areas were identified. The most important management issues for these areas were ecosystem-based management, living resources, coastal hazards, sediment management, and research needs.

Various species and resources are part of the seafloor habitat. Based on a conceptual model of the seafloor that was prepared to assist with the development of the MSP, seafloor habitat was characterized to represent all bottom habitats in water up to 30m (98 feet) depth in Washington State waters. This depth was chosen because it was often cited as the lower depth limit for most local kelps and other structure-forming algae due to light limitations. The seafloor habitat includes biogenic habitat made up of deep-sea corals, sponges, and anemones observed throughout the Study Area. The highest density was observed in the canyon areas, such as the northernmost region in the Juan de Fuca Canyon area.

Large zooplankton such as krill are vital in the seafloor habitat food web, serving as a major food source for groundfish. Their abundance fluctuates with upwelling conditions. "Marine

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[78] https://repository.library.noaa.gov/view/noaa/27552
[79] https://www.boem.gov/sites/default/files/environmental-stewardship/Environmental-Studies/Pacific-Region/Studies/BOEM-2014-662-Vol-1.pdf

snow," which consists of sinking organic and inorganic particles like bacteria, phytoplankton, detritus, and bio-minerals, nourishes detritus-feeding invertebrates and deposit feeders on the seafloor, particularly after diatom blooms. Deposit feeders, including benthic invertebrates like amphipods, isopods, small crustaceans, snails, sea cucumbers, worms, polychaetes, sea slugs, and hermit crabs, sustain the ecosystem by consuming detritus. These species are prey for economically important species such as Dover sole and Pacific halibut. Other benthic invertebrates, including bivalves, sea urchins, and sea stars, form part of the diet of flatfish and rockfish. The seafloor also provides essential habitat for commercially valuable species like Dungeness crab, spot prawn, and pink shrimp. Groundfish, which include a variety of species, also rely on the seafloor habitat and feed on various benthic invertebrates and fish.

The seafloor is susceptible to various stressors. In particular, low dissolved oxygen events stress and can kill seafloor organisms, especially immobile or slow-moving ones, impacting the food web and groundfish. Additionally, seafloor and deep-water habitats face threats from climate change, including ocean temperature rise, ocean acidification, hypoxia, and altered productivity. Deep-sea corals and shellfish are particularly vulnerable to these threats. Any decline in the quality or extent of habitat would affect associated species. Other species that inhabit the seafloor are also likely to be affected. Shellfish species may experience slower growth rates, thinner shells, and higher mortality rates and deep-water fish may lose habitat and experience population declines due to expanding hypoxic or anoxic zones or increased frequency of those events. Furthermore, the decrease of benthic fish populations may alter food webs and potentially benefit invertebrates.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to the seafloor:

General data gaps

- Seafloor surveys
- Data on bottom environmental factors

Seafloor surveys.

a. Survey methods

Seafloor surveys encompass a range of techniques, including multibeam surveys, side-scan sonars, and photographic surveys conducted from ships, Remotely Operated Vehicles (ROVs), Autonomous Underwater Vehicles (AUVs), and other platforms. These surveys play a crucial role in habitat mapping and monitoring. Determining the specific type of data required (e.g., seafloor surface versus sub-bottom profiling) depends on the research question.

There are three main types of data used for seafloor surveys. The first type of data is obtained through side scan sonar, which provides information on the texture of the seafloor. By analyzing acoustic signatures, researchers can infer the type of bottom (e.g., muddy or sandy) and categorize it into soft, medium, or hard substrates. The second involves collecting and analyzing core samples, which provide detailed information on the geology of the seafloor, including sediment composition and rock type. This method is a more detailed survey than a side scan sonar. The third type of data comes from visual surveys conducted by AUVs. AUV-based surveys of the seafloor offer exceptionally high resolution. However, these high-resolution data are often integrated with coarser spatial layers, resulting in a patchwork of absurdly detailed information in small areas and much coarser data elsewhere. This poses challenges for spatial analyses. While the level of detail available in small patches may be exciting, it is important to recognize its limited applicability across larger areas.

Recent high-quality digital multibeam sonar surveys conducted within the last 10-20 years are needed to produce detailed seafloor bathymetric and habitat maps. Bathymetric data stem from surveys dating back to 1927, employing rudimentary methods such as lowering a string to measure depth. Converting bathymetric data into habitat maps is a distinct process that requires specialized expertise. While there are experts capable of creating habitat maps from seafloor data, this step must be intentionally pursued.

NOAA oversees mapping endeavors, ensuring that all collected information is reviewed and approved. There is a desire for a fully integrated and regularly updated master bathymetry file for the region. While the NOAA bathymetric data viewer serves as a repository for individual data collection efforts, it lacks integration. The National Centers for Coastal Ocean Science (NCCOS) integrated all available data up to 2019 for a BOEM project; however, this data is not available publicly as it was considered an intermediate product. Since then, more mapping was done. Regular updates are essential because new areas are mapped, new data is collected to update areas with low resolution, or new technology is used. For data to be used in creating nautical maps, it must meet the standards set by the International Maritime Organization (IMO), a key criterion in mapping efforts. Data from extensive mapping for shipwrecks and other purposes could not be integrated into official nautical charts because they didn't adhere to these standards.

b. Mapped areas

Although many areas on the continental margin have been mapped, significant gaps remain in habitat coverage. While substantial progress has been made in mapping offshore areas, nearshore seafloor surveys continue to be a major gap. Data for nearshore areas are often fragmented, resulting in a patchwork of information. Certain nearshore waters have been well mapped, such as Hecate Bank and the Olympic sanctuary. Priority areas for future mapping efforts include unmapped fishing zones and offshore regions, such as those at the depths of oil platforms. In California, there is an ongoing initiative to map the entire state's waterways. Similar comprehensive mapping efforts are lacking for Washington.

Geological models were prepared for the Pacific Northwest. The Pacific Marine and Estuarine Fish Habitat Partnership (PMEP) prepared a report[80] with information on the state of nearshore habitat and contains habitat maps. Additionally, there has been an update to a 2012 map commissioned by NMFS, providing an inventory of current data layers for the seafloor within

[80] https://honu.psmfc.org/media/PMEP/Documents/PMEP_Nearshore_FishInvert_Habitat_Report.pdf

the Exclusive Economic Zone (EEZ) from Mexico to Canada. This inventory encompasses bathymetry, side scan, and backscatter data.

There are ongoing efforts focused on developing the Habitat Framework[81], a comprehensive seafloor atlas aimed at consolidating all available data within the sanctuary. This initiative interprets data to identify various substrate types, such as sand, mud, and mixed compositions. CMECS was created as a standardized method for analyzing marine habitats. The substrate information was transformed into a habitat framework, representing a step towards comprehensive habitat mapping. The framework was development through a collaboration between the Sanctuary, Tribal entities, and interested or affected parties from the state. The framework consists of four key components: geoform (encompassing broad landscape categories like submarine canyons and continental shelves), substrate (detailing variations in composition such as cobble, boulder, sand, and mud), biological layers (representing the distribution of flora and fauna across different landforms and substrates), and the pelagic component (describing oceanographic properties such as temperature and oxygen levels throughout the water column). The geoform and substrate layers have been successfully developed. Efforts to complete the biological and pelagic layers are currently being led by the Northwest Fisheries Commission.

c. Areas that need to be mapped

The existing surveyed areas are often biased and opportunistic, with many data layers extending beyond 1300m. This highlights the need for a consistent dataset covering larger areas at shallower depths. Such a dataset would enable more accurate and comprehensive analyses of seafloor conditions.

Two recent prioritization efforts identified areas in need of seafloor surveys. First, in 2015, the National Centers for Ocean and Coastal Science outlined areas in the West Coast where survey efforts were most needed.[82] Similarly, a Washington-focused effort was conducted in 2014.[83] Progress on mapping priorities reviewed in 2018 to guide additional mapping efforts. Second, the NOAA Integrated Ocean and Coastal Mapping Program conducted its own prioritization study.[84]

The central southwest area of the Washington coast is identified as having the most urgent need for seafloor surveys. Limited mapping and ROV work were conducted in this region, notably during Nautilus cruise NA072 and surveys conducted by the NOAA Ship Rainier in 2016 and 2017. NOAA's National Centers for Environmental Information (NCEI) Bathymetric Data Viewer[85] offers a data quality map that can be used to pinpoint areas requiring updated surveys. The following data is needed: multibeam data collection, bathymetry, shaded relief, and CMECs habitat/biotopes, and induration. Additionally, along the shoreline, other than floating kelps, there is little biotic habitat data. Habitats such as seagrass, surfgrass, or other

[81] https://nwifc.maps.arcgis.com/apps/Cascade/index.html?appid=8ee7967fbb5f43948a803438b07938b8
[82] https://repository.library.noaa.gov/view/noaa/22029
[83] https://pmc.ncbi.nlm.nih.gov/articles/PMC5421661/
[84] https://iocm.noaa.gov/
[85] https://www.ncei.noaa.gov/maps/bathymetry/

submerged vegetation lack comprehensive data coverage. There is little information on the extent of these habitats, particularly in shallow and nearshore areas. As a result, these areas are hard to map.

There are other resources that identify data needs. The Geographic Information System (GIS) team for PSFMC manages and creates GIS datasets by consolidating diverse datasets and making them accessible to the public. The Pacific Marine & Estuarine Fish Habitat Partnership (PMEP) has an inventory and maps fish habitat within estuaries and the nearshore, encompassing depths deeper than the traditional -200 meters.[86] Substrate data will be updated in the fall, including data beyond -200m and a data quality layer. PMEP also prepared a state of knowledge report[87] on nearshore habitats used by fish assemblages and certain marine invertebrates, which included habitat maps. Habitat data were standardized using CMECS where possible. The substrate and biotic habitat data layers provide valuable insights into kelp, macroalgae, and seagrass habitats. While the focus has primarily been on substrate type, there is a recognized need for additional data on environmental factors crucial for distribution modeling. These factors include velocity direction, occurrence consistency (e.g., oxygen and temperature levels on the seafloor), and other parameters essential for assessing productivity. The effectiveness of modeling is closely linked to the availability of this data.

Another area of interest is the biotopes that support fish species. Fish may prefer specific substrate types, such as rocky substrates at certain depths, flat seafloors, elevated areas, or combinations of various terrain features. To pinpoint potential fish habitats, layers of habitat information are needed. This requires examining how biotic habitats and substrates intersect, while also incorporating oceanographic data to better understand fish habitat preferences. However, the spatial overlap of these habitats remains poorly understood. A valuable resource to address this data gap is the USGS maps on benthic habitats, which adhere to biotope standards.

Feedback on importance: Seafloor surveys provide essential baseline information for all ocean uses. While many seafloor areas have been surveyed, there is still a need to understand what lies beneath the surface. Additionally, updated bathymetric maps that synthesize data collected over the past decade are needed. These maps will be crucial for developing accurate habitat maps. This task is both feasible and straightforward, with well-established methods available to accomplish it.

> **WCMAC:** A clearer understanding of the current state of the seafloor is essential, including its composition and the locations of corals, sponges, essential fish habitats, and unique or sensitive areas. While seafloor surveys and habitat area descriptions are available, assessing the current conditions is crucial. Various ocean uses can introduce stressors to both the seafloor and the species that depend on it.
>
> Additionally, conducting additional surveys will help evaluate the potential impacts of new ocean uses, such as offshore wind energy, on the seafloor and its ecosystems.

[86] *See* https://www.pacificfishhabitat.org/data/
[87] https://honu.psmfc.org/media/PMEP/Documents/PMEP_Nearshore_FishInvert_Habitat_Report.pdf

Recent findings indicate localized seafloor warming can occur from high energy transmission cables. Additional considerations include the physical interaction of transmission lines with the seafloor, as well as the impacts of anchoring systems, scouring, and sediment disturbance. Some of these physical effects could be mitigated by, for example, identifying areas with soft sediments for cable burial. Soft sediments may provide more suitable pathways for crossing transmission cables with less disruption to the seafloor and benthic habitats.

Data on bottom environmental factors. There is limited seafloor data compared to the more abundant sea surface information. Seafloor environmental data is primarily collected using human-occupied vehicles (HOVs), remotely operated vehicles (ROVs), and some autonomous underwater vehicles (AUVs), though tools like gliders often don’t approach the seafloor closely enough. NOAA moorings provide detailed monitoring data, operating at various times throughout the year in specific monitoring areas. While most moorings are active from May to October, some, such as the Cha'Ba and the Ocean Observatories Initiative’s (OOI) Washington Endurance Array, operate year-round. Fisheries' bottom trawl surveys also collect environmental data through sensors attached to the trawl gear. Additionally, several initiatives are underway, including the exploration of sensors for more frequent monitoring in localized coastal areas, though these efforts do not cover all the desired sampling locations. One notable project is a multi-stressor research initiative focused on Dungeness crab and krill, which consolidates ocean observations from Oregon and Washington to create a comprehensive dataset on dissolved oxygen levels on the seafloor.

Despite the spotty nature of the data, extrapolation and modeling efforts across the Washington coast heavily rely on these datasets, such as with LiveOcean[88] and J-SCOPE[89]. Many collaborators, including modelers, are working to provide a broader understanding of seafloor conditions, with some focusing specifically on forecasting ocean acidification and dissolved oxygen levels. Where observational data is limited, particularly for winter conditions, experienced professionals can make informed predictions based on available information.

Additionally, crucial factors like velocity direction, consistency occurrence (e.g., oxygen and temperature of the seafloor), and productivity measurements are often overlooked. There is a need for more data on these environmental factors to model distribution. There is also currently no monitoring of the deep ocean seafloor. While measurements are taken on the Cascadia subduction zone, there is insufficient monitoring of ocean conditions at the bottom of the Quinault or Juan de Fuca Canyon, as these areas are challenging to access. Consequently, they represent some of the least understood habitats in terms of seafloor conditions. For example, the oxygen minimum zone is a significant feature of the Washington coast. This zone remains deep but expands during specific times of the year. Tracking its extent would provide valuable insights into how oxygen levels affect community conditions, abundance, and various life stages.

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[88] https://faculty.washington.edu/pmacc/LO/LiveOcean.html
[89] https://www.nanoos.org/products/j-scope/

The condition of the ocean is constantly changing, making it difficult to determine which data products are most useful. A key challenge is identifying additional locations and types of equipment that can enhance the understanding of these changes. There is growing recognition of the need for more real-time monitoring of benthic conditions, particularly with regard to hypoxia, which is crucial for Dungeness crab fishers.

Feedback on importance: Limited knowledge is available. There is a need to better understand the conditions of different areas, including variations in currents, fluctuations in conditions during downwelling and upwelling, periods of stratification, and low water exchange. If seafloor depth data is available, addressing other significant data gaps may take priority.

> **WCMAC:** Data on bottom environmental factors represent a significant gap in knowledge. Understanding the current seafloor conditions that impact dependent species, as well as the dynamic factors that could alter these conditions, are crucial. These environmental factors are influenced by currents, including coastal currents and eddies, the California Current Large Marine Ecosystem (CCLME), and upwelling. A thorough comprehension of oceanographic processes, such as seasonal and tidal currents, wind-driven currents, and occasional storm currents, is essential for this assessment.

Offshore wind data gaps

- Effect of offshore wind cables and cable installation on the seafloor
- Effect of offshore wind anchors on the seafloor
- Effect of offshore wind on the ecological productivity of the seafloor
- Effect of offshore wind on seafloor communities

Effect of offshore wind cables and cable installation on the seafloor. Numerous cables already exist on the ocean floor, including submarine cables extending across continental margins. For offshore wind, these cables will serve to link offshore turbines with substations and terrestrial electrical grids. Existing submarine cables can serve as valuable reference points. However, energy cables and fiber optic cables involve different installation procedures and maintenance requirements.

The installation of cables is expected to impact the seafloor, but once in place, the effects are likely to be minimal due to the vastness of the ocean. Installation will inevitably cause some disturbance, particularly at the shoreline where cables connect, potentially flushing or burying species. Anything within the installation footprint could be affected, leading to displacement or mortality. Timing will be crucial to avoid disrupting fish migration or spawning. Additionally, the installation process may generate significant noise, and the long-term impacts of maintenance and dredging remain uncertain. Careful planning will be needed to avoid and minimize impacts to, for example, important groundfish habitats such as submerged aquatic vegetation, seagrass beds, and rocky reefs. These areas may also serve as important nursery grounds to numerous fishes.

Once installed, cables will become a new physical structure, likely remaining undisturbed thereafter. They may even serve as beneficial habitat, potentially enhancing fish aggregation. Over time, organisms may colonize the cables, forming a hard bottom community. Unless the cables shift or disturb sediment, they should not pose significant issues, as ecosystems are expected to recover. However, installations could act as vectors for invasive species, as seen with oil and gas platforms in the Gulf of Mexico. Additionally, many cables are not buried, raising concerns about fishing interactions, as snags could damage both the cable and fishing gear.

As a tectonically active region, there are questions on whether vibrations from cable installations will have an impact. There may also be effects to structures and cables installed along the Cascadia subduction zone. The potential repercussions of increased vibrations across landscapes are unprecedented and remain unknown. There are ongoing studies on sediment flows in canyons. Recently a seabed recovery survey was completed that focused on assessing the response of various habitat types to the reburial of PCL submarine fiber optic cables. Analysis of the data is currently underway. The effect of the cables varies depending on the habitat type where they are installed, with some habitats showing more resilience than others. Burying cables over boulders is impractical, and it's crucial to avoid suspending cables over rocky reefs and boulder fields.

Additionally, electromagnetic fields (EMF) from offshore wind cables may have an effect. Surveys conducted off Rialto Beach revealed volcanic formations with magnetic fields on one of the islands. The potential effects of EMF on volcanic rock or other rocks with high iron content is unknown.

Feedback on importance: Offshore wind cables could present significant challenges, potentially driving out marine life depending on installation methods. A phased approach to installation, allowing areas to recover before moving forward, might mitigate issues. Cable installation creates plumes, and mobile cables can be disruptive. Assessing physical impact, durability, and likelihood of breakage is crucial. Lessons may be learned from offshore oil and offshore structures in Europe where community surveys may be available. Insights from similar projects, such as PCL submarine cables, can also inform challenges with cable burial, seafloor disruption, and habitat recovery.

WCMAC: The impact of cables and their installation from offshore wind developments on the seafloor represents a significant data gap. These installations can disturb sediment, potentially conflicting with other ocean uses and affecting species behavior and seafloor physiology. Factors such as sediment movement and scouring must be carefully assessed, especially at the specific depths of cable deployment. Frequent storm events in Washington can also disturb the seafloor, potentially leading to cables becoming exposed. Observations indicate that bottom disturbance impacts can extend up to 15 miles offshore during severe storms. In addition to developing effective management strategies for exposed cables, determining the optimal burial depth is crucial to mitigate potential interactions with seafloor characteristics. Historical issues in Washington and Oregon, where depths as shallow as three feet have proven inadequate, underscore this need. The appropriate depth to prevent exposure, benthic disturbance, and entanglement with fishing gear for Washington's coast remains undetermined. Cables must also avoid Essential Fish Habitats (EFH), corals, sponges, and rocky areas.

Separately, electromagnetic field (EMF) effects should also be considered.

Effect of offshore wind anchors on the seafloor. The effect of anchors varies depending on factors like anchor type, depth, and sediment composition. Although it is challenging to assess the potential impact of anchors for offshore wind without more information, they are generally expected to have a lesser impact compared to other structures like cables or activities like dragging a net across the continental shelf.

The most significant impact is expected during the setup and retrieval of anchors. Dropping anchors can disturb and resuspend sediment, creating plumes that may smother nearby benthic organisms, both nearby and down current. Once in place, anchors should pose minimal issues unless they are constantly moving, potentially disturbing the seabed and organisms. The risk of anchor movement due to various forces remains uncertain. Seafloor dynamics are crucial, with accidental losses due to rough seas being reported, alongside effects like rusting and flaking, discharging due to weathering, and entangling equipment. If occurring on a small scale, anchor movement could create feeding opportunities, but no studies have explored this aspect. Careful planning is necessary to avoid placing offshore anchors in sensitive seafloor habitats.

Offshore wind will involve a departure from typical anchor-related activities. For example, temporary anchors are used to secure moorings, which are not permanent structures. However, offshore wind installations represent a different scenario. These structures are not temporary. They will be installed on the seafloor in a more permanent kind of way. It is essential to understand the process and rationale behind leaving structures in place. For example, offshore oil platforms were decommissioned but not completely removed. In particular, minimizing anchor abandonment is crucial due to the risks and conflicts it poses. Sedimentation can quickly occur, potentially complicating or preventing the removal of installed structures. In some cases, leaving structures in place could be less disruptive. If abandonment cannot be avoided, anchors that bury quickly and have minimal surface expression should be considered to reduce interactions. There is interest and emerging technologies for the recovery of anchors. Using ROVs to locate anchor losses and assess its response and implications will be valuable.

Feedback on importance: Presumably, habitat disruptions related to anchor installation may be similar to those associated with cable installation. If the anchor installation is on a smaller scale and limited in duration, once placed, the seafloor may recover. This will depend on the type and size of anchors. Heavy anchors often become rapidly buried in areas of high unconsolidated sediment. Anchors could also have a significant impact if they move, causing constant disturbance and potentially creating plumes or dragging through reefs. If securely in place, no effect is expected. There are likely insights from offshore oil projects and Europe’s experiences with offshore structures, potentially backed by community surveys. These sources could provide valuable insights into potential effects of offshore wind anchors on the seafloor.

WCMAC: There are concerns about the impact of anchors from floating offshore wind developments. Dropping anchors—one or multiple—per platform may cause different types of disturbances compared to activities like pile installation. Additionally, unlike monopiles, which have a single connection point to the seabed, floating offshore wind installations require multiple connection points to the seafloor, leading to increased interactions with the benthic community. Further, if the anchoring system employs an extended array of cables or lines to the anchors, it is essential to ensure there is sufficient scope to prevent dragging. With three or four anchors, the total necessary scope increases, potentially resulting in additional seabed scouring as currents shift and chains move. The impact will vary depending on scouring conditions and bottom characteristics. Softer sediments generally experience fewer long-term issues from this type of disturbance, unless the disturbances are continuous, which is likely in offshore wind scenarios with limited recovery time. In contrast, rocky reefs, coral, or harder substrates will suffer more significant habitat damage and longer-lasting environmental consequences.

Effect of offshore wind on the ecological productivity of the seafloor. The seafloor is enriched by bottom currents, upwelling which brings nutrient-rich waters from deeper areas to the surface, and nutrients that descend from the surface and pelagic areas above. The installation of offshore wind raises concerns regarding its impact on productivity. An offshore wind platform may increase productivity if it acts as a reef structure. However, if its installation reduces alongshore winds, it may diminish local upwelling and productivity. The effect of turbines on local productivity is uncertain, but they will undoubtedly impact the area beneath them. Scale is and cumulative effects are also important factors. While a few structures in discrete areas may have minimal impact, multiple installations could result in significant cumulative effects, such as altering upwelling patterns. However, dynamic factors may mitigate this impact. In areas that are highly mixed and turbulent, the footprint of the platform may not significantly disrupt productivity.

Offshore wind installations could also alter sediment dynamics, potentially leading to burial and affecting food availability for filter feeders like deep-sea corals, sponges, and benthic invertebrates. The conditions of the seafloor are critical for species like Dungeness crab, which spend much of their lifecycle on the seafloor. Female crabs carry eggs that are exposed to seafloor conditions before being released into the water column, where they float before eventually settling. Many of their life stages are influenced by these conditions. Additionally, vibrations and electromagnetic fields from these installations may affect species, potentially causing them to avoid affected areas or move elsewhere to evade interaction. Such shifts could significantly alter ecosystem productivity.

Predicting the overall impact on ecosystem productivity is challenging. Given these complexities, further research is needed to understand the full impact of offshore wind installations on seafloor conditions and fish population productivity.

Feedback on importance: Understanding the impact of offshore wind development on ecological productivity is both challenging and essential. Numerous uncertainties exist, requiring consideration of a wide range of organisms, from plankton to whales. Often, critical lessons are learned too late. The more information available on how offshore wind affects the overall ecosystem, the better the long-term understanding of ocean development will be. However, the impact may be localized and not large enough to pose a major concern compared to other potential effects on the seafloor.

WCMAC: The impact of offshore wind on marine species productivity and behavior represents a significant data gap. Understanding how these changes influence integrated ecosystems—from the benthos to the surface—remains challenging. Isolating the effects on the benthos without considering their implications for the surface ecosystem, and vice versa, is complex.

If wind wake effects from offshore wind farms alter wind patterns, there may be an increase in offshore winds and a decrease in onshore winds. This could reduce the upwelling that mixes nutrient-rich waters with oxygen-rich waters above the benthos and diminish productivity in deeper ocean layers, adversely affecting fish and other organisms. While fish can relocate relatively quickly, slower-moving species may encounter hypoxic conditions or find their benthic habitats uninhabitable, limiting their ability to relocate before facing mortality.

Effect of offshore wind on seafloor communities. There is currently a lack of research examining the effects of offshore wind installations on seafloor communities.

The introduction of structures such as anchors, lines, and cables can disrupt existing communities, potentially displacing some species while creating new habitats for others. Depending on the size and scale of these structures, the impact could be significant. For example, Polymer Constrained Layer (PCL) cables in marine environments have been observed to foster sponge growth on exposed areas. Similarly, offshore wind installations could create attractive habitats for certain species, while adversely affecting others that rely on the natural seafloor environment. Additionally, structures in the open ocean can attract both small fish and larger predators, such as tuna, altering the local distribution and abundance of species. It is essential to assess the environment during the development phase, with a particular focus on the construction period.

Other offshore wind activities such as vessel operations will also generate significant noise. This noise should be carefully considered in relation to local marine communities and whale migration patterns. Addressing these factors during the development phase of offshore wind is crucial to mitigating potential impacts on marine ecosystems.

Feedback on importance: This effect is difficult to understand but is crucial. Offshore wind may affect distribution of living resources. Often, lessons are learned too late. The more information available on how offshore wind affects the overall ecosystem, the better the long-term understanding of ocean development will be.

WCMAC: The effects of offshore wind extend beyond transmission lines and corridors, necessitating consideration of how turbines and cabling influence benthic activity, as well as how changes in currents and wind patterns may amplify these impacts. Data indicates that wind wake effects from offshore wind development may create a wind deficit on the shore side, leading to changes in currents, upwelling, and mixing. Such alterations could affect larval drift, which is crucial for species survival like Dungeness crab. Crab megalopes that develop in deeper waters must be transported to shallower areas to survive. Maintaining larval and phytoplankton transport is vital for ocean productivity; any disruption can have significant negative consequences. Changes in currents may also impact the frequency and severity of hypoxia events, diminish nutrient transport, and affect overall productivity and seafloor conditions. If dead zones form, the repercussions for productivity and benthic ecosystems could be severe, potentially leading to mortality among animals unable to escape the affected areas.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Effect of disturbance on the seafloor

Effect of disturbance on the seafloor. Seafloor sediments serve as significant carbon stores. Disturbance can disrupt carbon dynamics, which are not fully understood. It's preferable to leave seafloor sediment undisturbed whenever possible, as the effects of resuspension, including its impact on potential dynamics and interactions, remain unclear.

Offshore wind data gaps

- Effect of offshore wind structures on the seafloor

Effect of offshore wind structures on the seafloor. Offshore wind platforms have the potential to evolve into a reef-like structures, much like offshore oil rigs that often become artificial reefs. While this transformation is not necessarily harmful, it could provide a pathway for the spread of invasive species, as observed with oil and gas platforms in the Gulf of Mexico.

Additionally, these platforms may alter light availability on the seafloor, with a more pronounced effect expected in shallower waters. Offshore wind platforms could attenuate or obstruct light, potentially causing shading and resulting in slightly cooler local waters. However, for the seafloor, light penetration is already limited due to turbidity within the water column, especially in deeper areas. As such, this issue isn't a high concern. Nonetheless, the significance of this effect depends on the size and scale of the operation; large-scale shading could impact diurnal species that rely on light for behavior and feeding.

Rather than direct effects, the primary effect of the platforms will be the displacement of other ocean uses, such as fishing and scientific surveys. New surveys will need to be developed to access the areas within the offshore wind energy lease areas and complement existing scientific surveys.

Offshore aquaculture data gaps

- Effect of nutrients, waste, and chemicals from offshore aquaculture on the seafloor
- Effect of offshore aquaculture structures on the seafloor

Effect of nutrients, waste, and chemicals from offshore aquaculture on the seafloor. Offshore aquaculture can have environmental consequences due to the introduction of food and chemicals, which can accumulate near and beneath the installations, altering the local ecosystem. The impact of these nutrients, waste, and chemicals will depend on whether they disperse throughout the water column or settle to the seafloor. As nutrients are consumed by other species, they may contribute to respiration and hypoxic events on the shelf. Additionally, the bioaccumulation of chemicals is a concern, as foraging species may ingest contaminants. Bioaccumulation is a well-documented phenomenon in the ocean.

A smothering effect is anticipated, particularly if waste accumulates and settles on the seafloor. The severity of this impact will depend on factors such as species and water depth. It could lead to anoxic conditions, degrade habitat quality, and disrupt food webs and trophic interactions. The effects of burying the seafloor or altering sediment composition are expected to be more pronounced in shallower waters.

However, offshore aquaculture is likely to occur at greater depths, where strong currents prevail for most of the year and help with dispersion. This, combined with the reduced disturbance from trawling activities, may result in less resuspension or release of carbon from seafloor sediments. However, these projections are speculative and require further research.

Kelp aquaculture, in contrast, holds potential as a form of blue carbon. With kelp populations in decline, large-scale cultivation could help absorb carbon dioxide (CO_2) and support the production of kelp-derived products. This process typically involves the use of rope lines to cultivate kelp seeds, offering a sustainable method of production.

Effect of offshore aquaculture structures on the seafloor. The effect of offshore aquaculture structures will vary depending on factors such as depth, surrounding environment, size, and quantity. Anchoring would also be required, and depending on the scale and location, this could potentially affect the seafloor habitat.

Resources

Table 26. Resources relevant to the seafloor.

NAME	ACCESS	TYPE	DESCRIPTION
JISAO Seasonal Coastal Ocean Prediction of the Ecosystem (J-SCOPE)	https://www.nanoos.org/products/j-scope/	Website	Provides experimental seasonal forecasts of upper ocean properties, including sea-surface temperature (SST), chlorophyll stock, and dissolved oxygen.
LiveOcean	https://faculty.washington.edu/pmacc/LO/LiveOcean.html	Website	Provides the output of a computer model simulating ocean biology and chemistry.
National Centers for Environmental Information: Bathymetric Data Viewer	https://www.ncei.noaa.gov/maps/bathymetry/	Data Viewer	An interactive map to search and access bathymetric data, including multibeam, singlebeam, lidar, and crowdsourced bathymetry data.
NOAA: Integrated Ocean & Coastal Mapping (IOCM)	https://iocm.noaa.gov/	Website	Provides data, information, and resources associated with IOCM.
NOAA: Prioritizing Areas for Future Seafloor Mapping, Research, and Exploration Offshore of California, Oregon, and Washington	https://repository.library.noaa.gov/view/noaa/22029	Article	Identifies ten high priority locations for future mapping, sampling and visual surveys.
NWIFC: Tribes Making Better Ocean Maps	https://nwifc.maps.arcgis.com/apps/Cascade/index.html?appid=8ee7967fbb5f43948a803438b07938b8	ArcGIS StoryMap	Provides information on the Habitat Framework Initiative.

NAME	ACCESS	TYPE	DESCRIPTION
Olympic Coast National Marine Sanctuary: Seafloor Mapping	https://olympiccoast.noaa.gov/science/habitatmapping/	Website	Provides information on OCNMS's seafloor mapping efforts.
PMEP: Data Products	https://www.pacificfishhabitat.org/data/	Website	Contains various habitat and fish data collected through West Coast-wide assessments.
PMEP: State of the knowledge: US West Coast nearshore habitat use by fish assemblages and select invertebrates	https://honu.psmfc.org/media/PMEP/Documents/PMEP_Nearshore_FishInvert_Habitat_Report.pdf	Report	Documents the current state of knowledge of US West Coast nearshore habitat use by fish assemblages and select marine invertebrates.
Prioritizing Seafloor Mapping for Washington's Pacific Coast	https://pmc.ncbi.nlm.nih.gov/articles/PMC5421661/	Published article	Develops a web-based mapping tool, the Washington State Prioritization Tool, to solicit and analyze seafloor mapping needs in Washington State.
Tribes Making Better Ocean Maps	https://nwifc.maps.arcgis.com/apps/Cascade/index.html?appid=8ee7967fbb5f43948a803438b07938b8	Website	Provides information on the Coastal and Marine Ecological Classification Standard (CMECS)

Shoreline: Rocky Shores

Key Data Gaps

General Data Gaps

- Bathymetry and elevation data of rocky shores
- Turbidity and sediment dynamics of rocky shores
- Effect of waves on rocky shores
- Effect of air and water temperature on rocky shores
- Species communities in rocky shores

Offshore Aquaculture Data Gaps

- Risk and effect of invasive species from offshore aquaculture on intertidal communities

Other Data Gaps

General Data Gaps

- Health, distribution, trend, and spatial coverage of rocky shores
- Health, distribution, and abundance of subtidal community of species

Offshore Wind Data Gaps

- Effect of offshore wind structures on rocky shores
- Effect of offshore wind on the subtidal zone of rocky shores

Offshore Aquaculture Data Gaps

- Effect of added nutrients, waste, and chemicals from offshore aquaculture on rocky shores
- Monitoring the effect of offshore aquaculture on rocky shores

Background

Washington's shoreline features diverse landscapes including cliffs, rocky shores, sandy beaches, dunes, and headlands. The northern portion, from Neah Bay to Point Grenville, has rocky shores with pocket beaches. The southern portion, from Point Grenville to Cape Disappointment, is dominated by sandy beaches, dunes, and ridges with estuaries like Grays Harbor and Willapa Bay bordered by barrier spits.

Rocky shores habitat represents rocky and mixed intertidal shorelines and encompasses various substrate types like bedrock, boulder fields, cobble, and gravel. Tide pools, boulder size, and proximity to sand can influence community diversity. Several physical drivers affect this habitat. The intertidal zone is shaped by tides and geomorphology, with tidal elevation playing a key role in determining which areas are exposed to stressors and for how long. Stressors include exposure to air, temperature changes, predation, competition with non-native species, changes in freshwater inputs, wave action, and light. Additionally, human activities such as trampling, harvest, and pollution also affect the health of rocky shores.

Rocky shores host diverse species such as macrophytes; sessile suspension-feeding invertebrates like barnacles and mussels; grazing invertebrates, including snails and chitons; predators like sea stars and crabs; fish and seabirds that use the area for foraging and nesting; and pinnipeds like harbor seals and sea lions that inhabit these habitats year-round. Zonation in rocky intertidal habitats results from organisms' tolerance to tidal exposure. Species' upper limits are set by physical extremes, while lower limits are influenced by competition and predation. In particular, although wave energy can disrupt habitats, especially during severe storms, it can also enhance productivity by providing competitive advantages for wave tolerant organisms, replenishing nutrients, and enhancing light uptake by algae. Upwelling provides nutrients, plankton, and larval recruits to the system.

Climate change is expected to stress intertidal organisms with limited vertical ranges such as through increased heat stress and predator pressure. Rising air temperatures may force organisms lower into the intertidal zone, while sea level rise enables predators to move higher. Organisms may also be affected by increasing storms, wave energy, erosion, and sediment influx from rivers. Ocean acidification may shift the intertidal community structure as well. For example, the survival rate of species that rely on shell formation may decline while others may increase like algae that thrives with increased carbon dioxide (CO_2). Additionally, sea star wasting disease, exacerbated by warm anomalies, has caused high mortality rates among keystone predators like the ochre sea star. There are concerns about future recurrences due to climate change.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to rocky shores:

General data gaps

- Bathymetry and elevation data of rocky shores
- Turbidity and sediment dynamics of rocky shores
- Effect of waves on rocky shores
- Effect of air and water temperature on rocky shores
- Species communities in rocky shores

Bathymetry and elevation data of rocky shores. Access to bathymetry data, a digital elevation model (DEM), and a comprehensive elevation model specifically tailored for coastal areas would be highly beneficial to understand rocky shorelines.

Feedback on importance: This is a key data set for various applications such as modeling and habitat mapping and is currently unavailable.

Turbidity and sediment dynamics of rocky shores. Depending on various factors, rocky shorelines can either accumulate sediments or undergo erosion. To enhance understanding of sediment dynamics in these areas, more data collection on turbidity and nearshore sediment processes are necessary. Currently, there is a lack of comprehensive data on these aspects related to rocky shorelines. For example, given their impact on turbidity and nearshore ecosystems, there is a growing interest in measuring and monitoring seasonal sediment dynamics.

Feedback on importance: There is conjecture that turbidity and sediment dynamics structure rocky shores, but there isn't enough information to evaluate this effect.

Effect of waves on rocky shores. Assessment of wave effects is a component of marine monitoring. However, while marine monitoring can provide general information about what constitutes a typical storm season, it cannot directly assess the specific effects of an individual storm event.

There is some wave data collection close to the shore. Along the shoreline, there are very localized differences in how a big swell may impact an area. There are a few offshore buoys, such as the Cape Elizabeth buoy (located 20-30 miles offshore) and NDBC - Station 46087, that collect relevant data. However, offshore buoys may not adequately cover all areas. Waves exhibit significant variability, making it challenging to assume that conditions at the Cape Elizabeth buoy mirror those closer to shore. Having a broader distribution of instruments collecting swell data which are then modeled, would be beneficial. Collecting data from areas that are more sheltered and at various angles would be preferred, but obtaining these measurements poses challenges. Setting up buoys along the coast is inherently difficult due to the harsh coastal environment.

Feedback on importance: More wave data is necessary to assess the effects of waves on rocky shores. Having this data would inform the effect of sediment dynamics and turbidity on rocky shores.

Effect of air and water temperature on rocky shores. Water temperature is the only robust dataset available for physical parameters, which is why most assessments focus primarily on temperature. Loggers are used to record water temperature, but due to limited funding, monitoring is typically done on a small scale. However, where regular monitoring is in place and loggers are submerged in water, temperature data can be effectively retrieved. These data are accessible on the Multi-Agency Rocky Intertidal Network (MARINe) website[90]. It is important to note that sites used for long-term temperature monitoring often do not reflect true intertidal conditions. For example, water temperature at the shoreline can be cooler compared to areas a few miles inland.

There are no reliable sources for air temperature, wind speed, swell, and other variables at a large scale. There is so much variation depending on where data is collected (e.g., crevice, shade, or direct sun), hindering comparisons on a regional or broader base. There is a need to determine how to, for example, collect air temperature consistently.

On a broad scale, shifts have been observed within rocky shore communities. For example, strong correlations in community change have been observed with longer-term water temperature signals. Northern communities increasingly resemble those in the south, with "southern" species moving northward. This change is accelerated during periods of warmer water. Heat wave events exhibit clear effects on community dynamics. While recovery is possible, it may not occur before the next warming period.

Feedback on importance: Better documentation of key physical parameters will help interpret trends in community data.

Species communities in rocky shores. Every inch of rocky shores is covered by living species, making these areas incredibly productive and diverse. Biologists have diligently studied rocky shores since the 1960s, making them probably one of the best studied regions in the world. The MARINe program is specifically designed to study species communities. However, it does not provide continuous coverage. Instead, it is site-based, with annual monitoring of the community composition of rocky intertidal systems along the coast. Not all species are included in these studies. For most MARINe sites, there are no plots dedicated to rockweed (*Fucus*), gooseneck barnacles, or seaweeds. Only one site, Sokol Point, features rockweed (*Pelvetiopsis*) plots, in addition to barnacles, mussels, and sea stars.

Feedback on importance: Currently, trends in certain key species communities, like seaweeds and gooseneck barnacles, are not being captured.

Offshore aquaculture data gaps

- Risk and effect of invasive species from offshore aquaculture on intertidal communities

[90] https://marine.ucsc.edu/index.html

Risk and effect of invasive species from offshore aquaculture on intertidal communities. To date, introduced species have predominantly originated from the aquaculture and shipping industries, concentrated in bays or calm water areas. For example, *Sargassum muticum*, a non-native species successfully established itself in rocky intertidal zones along the West Coast, including Washington, with varying degrees of impact. Japanese oysters (*Crassostrea gigas*) also appear to be expanding in both abundance and distribution within rocky intertidal sites in the Salish Sea.

Rocky shores are ecosystems often shaped by select species. It's conceivable that an invasive species could affect a keystone species and profoundly reshape the community structure. For instance, predators like drills that prey on California mussels could significantly alter these communities. The extent of the effect would vary depending on the species involved and its ecological role. The understanding of these potential causal effects is a data gap. While highly exposed shores appear to be less vulnerable to invasive species establishment, invasive species remain a significant concern because this may not hold true over the long term.

Feedback on importance: Invasive species and diseases are currently at the forefront of everyone's concerns because of their potential to reshape intertidal communities.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Health, distribution, trend, and spatial coverage of rocky shores
- Health, distribution, and abundance of subtidal community of species

Health, distribution, trend, and spatial coverage of rocky shores. There is generally solid coverage of these data for the outer coast. A logical initial step would be to consult the site map on the MARINe website to pinpoint currently monitored sites and identify any spatial gaps in coverage. MARINe comprises various universities, agencies, and private organizations dedicated to collecting long-term rocky intertidal monitoring data from California to Alaska. Data is centralized and managed by University of California, Santa Cruz (UCSC).

Most sampling occurs during the summer months, primarily due to the timing of low tides and safety concerns during winter. The Olympic National Park (ONP) employs pH sensors and ocean chemistry instruments which are monitored every three to four months. Physical data are collected through temperature loggers at many sites. While there are seasonal variations in the abundance of focal species, conducting surveys exclusively during the summer helps to minimize potential data variation and enables studying long-term trends. The study also encompasses monitoring sea star populations and changes in their number and size distribution. On the outer coast, a diverse array of species constitutes the key zones in the intertidal. However, due to funding constraints, ONP and the Olympic Coast National Marine Sanctuary (OCNMS) concentrate solely on acorn barnacles, mussels, and sea stars. Other seaweed and other invertebrate communities are overlooked due to these financial limitations.

MARINe also conducts complementary biodiversity surveys. The initial biodiversity surveys were conducted on the Olympic Coast at ONP sites in 2001 and have been repeated multiple times at some locations, with the most recent surveys conducted in 2022/23. MARINe also secured funding from Sea Grant until 2026 to conduct biodiversity surveys at other sites in Washington. In addition, at sites where biodiversity surveys are conducted, drone surveys are also being implemented to map habitats. These efforts will contribute to the development of a preliminary model to assess and predict the impacts of sea level rise on rocky intertidal communities. Currently, drone surveys are being carried out along the entire California coast, and similar efforts are expected to be initiated in Washington. Data from biodiversity and drone surveys generally become available within about six months.

Assessing health can be notoriously challenging and depends on the definition of "health." In the context of rocky shore habitats, which are highly dynamic, certain areas might feature species that people commonly associate with "unhealthy" conditions. However, the habitat may actually be healthy and merely in a natural state of disturbance. Certain metrics of health have been well-assessed, such as the impacts of events like the 2021 heatwave. These data have been used to evaluate the effects of events like oil spills and heat waves.

Distribution is not a data gap. Rocky shores are relatively physically stable, and their locations are well documented. There are good maps and various sources of data from state agencies and universities detailing the distribution of this habitat. Certain locations have been intensively studied since the 1960s. The ShoreZone Inventory[91] provides valuable information. Intertidal areas were surveyed from 1994 to 2000 for Washington. While older data may not be ideal for shoreline areas prone to dynamic changes over time, it remains relevant for rocky shores due to their inherent stability. The rate of change is relatively low. The MARINe network is actively monitoring intertidal community composition at several sites. While there is room for more data, the existing dataset for rocky shores is more comprehensive compared to other shoreline areas.

On trend, MARINe has been collecting long-term rocky intertidal monitoring data employing vetted protocols at 15 sites spanning the Salish Sea and the outer coast of Washington since as early as 2008. These sites, with the most recent ones established in 2014, are positioned along a stretch from Point Grenville to Point of the Arches, extending into the Strait of Juan de Fuca. To minimize variability, sites are selected in regions featuring contiguous rocky reef habitat exposed during negative low tides. Areas with boulder fields, sandy beaches, or subtidal zones are excluded. Moreover, these sites must offer

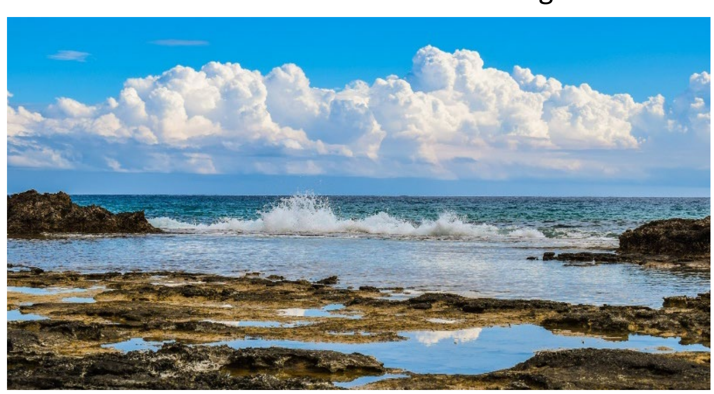


Figure 10 Coast with visible natural rocky structures and crashing waves.

[91] https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-inventory

sufficient space to accommodate monitoring plots, typically requiring at least 30 meters of contiguous rocky bench. Notably, within the broader Salish Sea region, there are significant data gaps due to the vast extent of habitat diversity and lack of capacity.

Health, distribution, and abundance of subtidal community of species. The relationship between environmental parameters and species is generally understood. Surface-visible features like kelp beds have been extensively mapped. However, there is a data gap concerning understory kelps in areas other than where diving is permissible. There's also a pressing need for data on species that inhabit and depend on these nearshore habitats, as they remain relatively understudied. The subtidal areas are a difficult area to gather data. Because sites are generally inaccessible by boat, methods such as scuba diving are necessary for data collection. Some community members in Washington monitor select sites, conducting repeated counts and health assessments of sea stars, particularly pertinent considering the sea star wasting disease. This effort led to the development of a protocol for divers. MARINe houses this data.

Offshore wind data gaps

- Effect of offshore wind structures on rocky shores
- Effect of offshore wind on the subtidal zone of rocky shores

Effect of offshore wind structures on rocky shores. Potential effects are minimized because cables are typically not routed ashore on rocky shorelines, especially through areas that experience extreme wave exposure. If cables are routed through the intertidal zone to reach an onshore facility, the installation of infrastructure could potentially have an effect. Given the diversity and density of communities on rocky shorelines, they may be more vulnerable than softer shorelines lacking such diversity. The cables themselves may cover or displace organisms and, if moved, could cause damage to surrounding habitats. Sediment accumulation might also occur, altering scouring and burial patterns. Additionally, the introduction of new permanent structures could influence localized currents. However, the affected area would likely be small. Given that this impact will likely be localized within several hundred miles of rocky coastline, it can be considered to have a relatively low footprint.

It is important to acknowledge that certain known threats like oil spills could occur through activities associated with offshore wind development and affect rocky shores. For instance, increased boat traffic required for offshore wind installations may raise the risk of maritime accidents.

BOEM conducted a pilot study in Oregon to assess the potential impact of offshore facilities on rocky intertidal communities, including the possibility that these structures could dampen swell. There was initial speculation that platforms might reduce the amount of wave energy reaching the shoreline. However, due to the high wave energy along the Oregon coast, the study found that the impact of wave energy facilities would likely be minimal. For the Salish Sea, increased vessel activity could have the opposite effect, with boat wakes potentially extending the wet periods for these communities at irregular intervals. The Grays Harbor area, consisting primarily of sandy beaches, is not directly relevant to the findings of this pilot study.

Effect of offshore wind on the subtidal zone of rocky shores. The subtidal zone is part of the marine environment associated with rocky shores. It provides a continuous habitat that extends offshore from the rocky intertidal area. There are currently no known concerns. For example, kelp is not expected to be affected by electromagnetic fields. Regardless, it would be beneficial to review existing global studies.

Offshore aquaculture data gaps

- Effect of added nutrients, waste, and chemicals from offshore aquaculture on rocky shores
- Monitoring the effect of offshore aquaculture on rocky shores

Effect of added nutrients, waste, and chemicals from offshore aquaculture on rocky shores. There is a potential for an effect; however, assuming this operation will occur far offshore, effects are likely to be limited.

There has been research into potential impacts from outflows into the intertidal zone. The impacts largely depend on the type of nutrients, waste, or chemicals being introduced, which can benefit some species while negatively affect others. If a significant amount is deposited, there will be an effect to the food web. For example, seaweed thrives in environments with specific nutrient concentrations. While there's a definite potential to affect intertidal communities, this aspect hasn't been specifically examined on the scale of the MARINe network. Existing literature may provide insights into thresholds and potential impacts.

Monitoring the effect of offshore aquaculture on rocky shores. Currently, there are no monitoring sites specifically linked to offshore aquaculture facilities, and collecting measurements on rocky shorelines presents certain limitations. While existing systems may detect significant changes in the community, they often cannot explain the underlying causes of these changes. When changes are identified, there is a tendency to attribute causality to the most visible factors at the time. Determining the cause from the available data is challenging, and it is unclear how this could be effectively achieved. Pairing onshore monitoring sites with offshore aquaculture areas could provide valuable insights into these dynamics.

Resources

Table 27. Resources relevant to rocky shores.

NAME	ACCESS	TYPE	DESCRIPTION
DNR: Nearshore Habitat Inventory	https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-inventory	Website	Contains data and information for the Washington State ShoreZone Inventory along with other intertidal habitat data.

NAME	ACCESS	TYPE	DESCRIPTION
MARINe Multi-Agency Rocky Intertidal Network	https://marine.ucsc.edu/index.html	Website	Provides data, methods, research products, and an interactive map reflecting research conducted at over 200 rocky intertidal monitoring sites.

Shoreline:Sandy beaches

Key Data Gaps

General Data Gaps

- Distribution, health, and trend of sandy shorelines
- Benthic habitat data, including grain size
- Distribution and importance of large woody debris
- Basis for trends and patterns of sandy shorelines
- Inventory of shoreline armoring

Offshore Wind Data Gaps

- Effect of offshore wind on the shape of sandy shorelines

Other Data Gaps

General Data Gaps

- Cobble habitat data

Offshore Wind Data Gaps

- Effect of offshore wind facilities on sandy shorelines
- Effect of offshore wind on sedimentation and erosion and the effect on sandy shorelines

Offshore Aquaculture Data Gaps

- Efect of offshore aquaculture on deposition and the subsequent effect on sandy shorelines
- Effect of offshore aquaculture on sedimentation and erosion and the effect on sandy shorelines
- Effect of offshore aquaculture on the shape of sandy shorelines
- Effect of offshore aquaculture on marine debris and the subsequent effect on sandy shorelines

Background

Sandy intertidal beach habitats constitute half of Washington's outer coastline. The beaches in southern Washington are relatively flat, with fine sand, large tidal ranges, and broad surf zones. These habitats are shaped by physical factors such as sediment deposition, wave energy, beach slope, upwelling, and climate fluctuations. Wave energy is influenced by the proximity to features like headlands and bays, storm-driven winds, and offshore structures like islands, reefs, or sea stacks. Upwelling brings nutrients to enrich beach ecosystems and weather events affect sandy habitat conditions. Additionally, waves, currents, detached kelps, and other macrophytes bring in phytoplankton, particulate organic matter, and detritus. These various dynamics play a key role in the ecology and function of sandy beach habitats.

Sandy habitats along Washington's coastline host various species. There are diverse primary producers, invertebrate macrofauna, crustacean scavengers, and meio- and microfauna. The community composition is influenced by beach structure. Dissipative beaches, with their gentler slopes, support more microhabitats and niches compared to intermediate and reflective beaches, which have steeper slopes, coarser sand, and fewer surface zones. Subtidal waters adjacent to sandy beaches are home to numerous fish species, including surf smelt and flatfish. Birds and terrestrial mammals also forage on sandy beaches, enhancing the area's ecological richness. Sand dunes along Washington’s outer coast beaches support both native and introduced vegetation and provide habitat for shorebirds such as sanderlings and snowy plovers. Additionally, dunes offer shoreline protection from wave erosion and may accumulate logs from nearby forested areas.

Human activities such as clamming, recreation, shoreline development, and sediment alterations affect Washington's sandy beaches. For instance, dams and dredging reduced sediment supply from the Columbia River, affecting beaches south of Point Grenville and leading to habitat loss and erosion north of the river mouth. Sand and gravel, which are widely mined for construction and land reclamation, are also extracted globally. In Washington, in-water mining is mostly limited to rivers for navigation and flood control purposes, with minimal sand mining on the Washington side of the Columbia River for construction and other uses. Few operations focus exclusively on sand extraction for sale. Additionally, Washington State Parks occasionally removes accumulated sand at access points along ocean beaches within the Seashore Conservation Area. This sand is made available to cranberry growers for use in their bogs, provided it is deemed reasonable and non-destructive. However, growers typically use only small amounts of sand and often prefer alternative sources.

Climate change also poses significant threats to sandy beaches. Erosion, intensified storms, and rising sea levels may lead to habitat loss, beach coarsening, and steepening, resulting in coastline retreat. Storm surges and high waves will exacerbate these effects, with potential consequences for coastal ecosystems and communities.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to sandy beaches:

General data gaps

- Distribution, health, and trend of sandy shorelines
- Benthic habitat data, including grain size
- Distribution and importance of large woody debris
- Basis for trends and patterns of sandy shorelines
- Inventory of shoreline armoring

Distribution, health, and trend of sandy shorelines. From a distribution standpoint, there is limited understanding of sandy shorelines. Part of the coast's shoreline is fairly well characterized. Specifically, the southern portion has been monitored since the 1990s through a partnership involving the Washington State Department of Ecology (Ecology), Oregon State University (OSU), and the United States (US) Geological Survey (USGS). This collaborative effort has provided extensive insights including sand thickness, inherent substrate composition, mobile sediments, and the historical development of beaches over the past few millennia. Significant research has also been conducted up to Point Grenville, particularly on the subsurface sediment layers, beaches, and coastal estuaries formed by the Columbia River sediments.

Data on the northern coast of Washington is relatively limited, offering only a basic overview of shoreline conditions and nearshore beaches. North of the Quinault Reservation, the region features a mix of sandy, cobble, and rocky intertidal zones, along with bluff-backed upper beaches. The shoreline morphology is complex and varied, making it difficult to categorize clearly. Many areas lack sufficient data to accurately map shoreline changes, and there is a significant absence of temporal data, inventories, and monitoring assessments on these beaches, including information on sediment types, erosion cycles, and beach alterations.

Research efforts in the northern area have been sparse. Available resources include geology maps from the 1960s and 1970s, along with a few limited reports. Specific areas have been studied, such as Kalaloch, and at La Push, where the US Army Corps of Engineers (USACE) has conducted jetty maintenance dredging. NOAA has also performed offshore bathymetry surveys, and a small portion was included in the USGS national assessment[92]. Additionally, a bathymetry profile of the nearshore seafloor was conducted about 2 kilometers offshore of the Quinault Reservation. More recently, an erosion assessment provided a basic understanding of shoreline change in the area.

Makah Bay has also been studied due to its unique characteristics as a confined bay with abundant sediment and rocky shoreline. As part of this study, Ozette was examined for ongoing erosion, focusing on assessing the accuracy of erosion measurements. Despite a detailed historical shoreline change assessment, there is still a sense that the complexity of this shoreline is not fully understood. Additionally, Sea Grant has been monitoring several profiles

[92] https://pubs.usgs.gov/publication/ofr20121007

along the remote northwest coast, spaced roughly 20-25 miles apart, for the past few years. While there are signs of beach change at specific points, these changes appear to be isolated.

Several efforts have been made to study the coastline as a whole. Since 2004, the National Park Service has implemented a standardized protocol to monitor six fine sandy beaches along the Olympic Coast, from Shi Shi Beach to Kalaloch. This monitoring effort collects both biological and physical data, including infaunal invertebrate community structure, sand sediment size, and beach slope. Three shore transects are conducted annually, at the same time each year, ensuring consistency across the monitoring efforts. Biological data evolves over time, driven by reproduction and seasonal changes. For example, during the spring, isopods are abundant, but by late summer, mortality reduces the numbers of the initial recruits. Additionally, ocean dynamics vary with the seasons, with winter waves causing the movement of sediments offshore and onshore. During this time, approximately 6-8 feet of sediment can be displaced.

Another resource is the ShoreZone Inventory[93] , which compiled data from 1994 to 2000. While the extent of coast mapped is unclear, data for the Olympic Coast is available, including intertidal habitats captured through aerial photography. The dataset aims to categorize shoreline types, but as landscapes and shorelines evolve, its accuracy may decline over time. Maintaining an updated database that reflects the dynamic complexity of shoreline habitats would be highly beneficial.

Several reports and studies provide valuable data on coastal conditions. One such report[94] details the geomorphology of the Olympic Coast, offering high-resolution mapping of coastal landforms. Another[95] provides a global-scale analysis of sandy beaches and shoreline change rates, utilizing satellite imagery. However, the utility and reliability of satellite data for accurately mapping shorelines and its potential to replace field campaigns remain uncertain. A recent study[96] assessed the accuracy of satellite-derived shoreline positions by comparing them to field observations along the Columbia River Littoral Cell. The study found strong agreement between the two methods, suggesting that satellite remote-sensing techniques could enhance coastal monitoring, particularly in data-poor areas.

Despite these efforts, there are still significant data gaps. Recent water depth surveys are limited, and many existing datasets rely on outdated methods, such as using strings and weights to measure depth. There is also a need for more nearshore data, as some areas remain unmapped due to logistical challenges. There is growing interest in expanding lidar coverage of the shoreline and entire coastal area, especially during low tides. However, obstacles like poor water clarity due to algae or turbulence make data collection difficult. Fortunately, advancements in technology, such as autonomous surface vessels, offer new opportunities to collect data in hard-to-reach areas.

93 https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-inventory

94 https://irma.nps.gov/DataStore/DownloadFile/660243

95 https://www.researchgate.net/publication/324805485_The_State_of_the_World's_Beaches

96 https://www.cambridge.org/core/journals/cambridge-prisms-coastal-futures/article/monitoring-interdecadal-coastal-change-along-dissipative-beaches-via-satellite-imagery-at-regional-scale/14D0C6DFCD9235CF1A385EF8C4D814B2

When it comes to health, the state of knowledge depends on what constitutes a "healthy" sandy shoreline. For instance, there are many questions on how to manage erosion at specific areas along the southwestern coast of Washington. Studying erosion hotspots is crucial, especially for land use management and planning for the evolving coastline. Key considerations include the direction of sediment movement—whether it's northward, southward, offshore, or inshore. There is also a need to better comprehend the effects of El Niño, La Niña, and the Pacific Decadal Oscillation (PDO), including the effect of wave heights increasing over time, particularly with more frequent and intense storms.

In terms of trends, the shoreline is generally stable and requires significant force to experience notable changes. The shoreline is already subject to severe storms, particularly during El Niño years, which can stir up large amounts of sand and cause erosion. However, conditions north of Quinault are less certain, as this area may experience more rapid changes.

Feedback on importance: There are various applications for this data. Questions about the shoreline's past and future trajectory are among the most common over the past decade.

> **WCMAC:** The health, distribution, and trends of sandy beaches are crucial for recreational activities. Sandy beaches provide essential space for walking and access, while areas affected by coastal erosion can pose safety risks. Additionally, the dynamics of sand and sediment impact activities such as surfing, kayaking, and recreational fishing.
>
> Coastal geomorphologists offer valuable insights into the state of sandy beaches. However, to establish a comprehensive baseline for the entire coast, a detailed overview and dataset are needed. Current data on beach conditions is limited, with much of it relying on anecdotal evidence. For instance, research on erosion patterns is particularly sparse along the remote Washington coast, especially when compared to more populated areas like Westport, where more data may be available.

Benthic habitat data, including grain size. This is a significant data gap. Sandy shorelines provide crucial habitat for various species, including razor clams and shorebirds like plovers. Benthic habitat data is essential for understanding the habitat requirements of species such as forage fish and for designing nature-based features that reflect natural conditions. Effective planning, however, is challenged by the absence of detailed measurements for substrate bathymetry, spatial characterization, and temporal changes. At present, there is no reliable inventory for grain size, bathymetry, or benthic habitat mapping along the coast.

Mapping efforts for benthic habitat are currently insufficient. Comprehensive data for habitat mapping is needed across the entire coastline. Existing bathymetry data is relatively coarse, offering a general understanding of depth but lacking the level of detail required for precise habitat classification and mapping of various substrate types such as soft sediment, silt, rock, gravel, and outcrops.

There is also a significant gap in comprehensive data on seafloor substrates and grain sizes for much of the coastline. In some areas, changes in grain size have been hypothesized to drive ecosystem shifts, potentially contributing to the decline of the forage fish fishery at Rialto Beach. Grain size data is available near the mouth of the Columbia River and in Grays Harbor, where sediment sampling has occurred. However, data is scarce between these two points and further north of Grays Harbor. Further north, the substrate shifts to a mix of gravel, sand patches, relic streambeds, rocky coastlines, and non-active relic materials with little new sediment supply. South of Grays Harbor, the sandy shoreface receives sediment from the Columbia River, and there is a broad understanding of sediment movement in this region. The SandSnap[97] program, led by USACE, is working to address some of these data gaps by facilitating the collection of grain size data from sandy beaches along the Washington coast. This initiative provides valuable observations to improve the understanding of the coastline's sediment dynamics.

Relevant to this data gap, the species that make up a healthy beach are well monitored. For example, trend data exist for key species like razor clams, which hold both recreational and commercial significance. However, generally, studying trends in sandy beach communities remains challenging. Organisms that inhabit the sand are sparse, and disturbances can displace species, making it difficult for them to re-establish. There is limited monitoring of specific populations in these areas. The National Park Service conducts some of this monitoring.

Feedback on importance: There is a need for data on substrate characterization, depth, and surface roughness. High-resolution bathymetry can also offer insights into texture.

> **WCMAC:** Sea Grant has conducted extensive research on benthic habitats, though this may not extend to the outer coast. They are examining various sizes of rocks and observing the movement of cobbles. There is also ongoing research on the effects of wave energy on different grain sizes, focusing on how these interactions dissipate energy and mitigate coastal erosion.

Distribution and importance of large woody debris. Currently, there is a lack of data on the distribution and abundance of large woody debris. Theories and anecdotal evidence indicate that woody debris was once more abundant and played a vital role in ecosystem dynamics. However, with the removal of mature trees, large wood reaching shorelines became scarce, leading to a decline in the number of woody debris observed on beaches. While logging activities may have temporarily increased woody debris input, this likely occurred in short bursts. The decrease in woody material is also attributed to the interception of large floods by dams.


Figure 11 A driftwood on a beach

Data on the presence and role of woody debris is particularly crucial for both the northern and southern coasts. In certain erosion-prone areas, logs can emerge from dunes and impact sediment deposition patterns by altering sediment flow and forming new depositional

[97] https://sandsnap-erdcchl.hub.arcgis.com/

features. Information on historical patterns, spatial distribution, variability, and the protective role of wood in shoreline stability and sediment accretion are needed. Presently, apart from aerial photography, there are no methods available to comprehensively map woody debris.

Feedback on importance: There is a lack of information regarding the role of large woody debris on the coast. This information could be useful to understand basic trends and patterns within sandy beaches.

> **WCMAC:** While unaware of the information available on this data gap, the vital role large woody debris plays in coastal ecosystems is recognized. The wood matrix provides essential habitat, facilitates nutrient dispersal, and acts as a crucial structural element that helps resist erosion and serves as a buffer against sea level rise.

Basis for trends and patterns of sandy shorelines. There is a limited understanding of sandy shoreline dynamics. Coastal changes are influenced by a range of factors, including sediment supply, wave energy, and wave direction. While there is a general understanding of these cause-and-effect relationships, certain instances, such as the erosion at La Push, remain poorly understood. Additionally, the observed patterns of accretion and erosion along the southwest coast are not fully understood and require comprehensive baseline data for greater clarity.

Even when patterns and trends are understood, it may not always suffice for accurate predictions. Currently, there are limitations in understanding how waves interact with the seafloor and the changes in wave direction as they approach the shore. This information is necessary to determine sediment transport rates. A more comprehensive understanding is needed which requires baseline data, such as bathymetric information.

In the event of offshore wind installations causing unexpected shoreline behavior, there's a lack of tools to analyze such occurrences. This gap in knowledge is particularly notable given that the southwest coast is more extensively studied than the northwest. There's a pressing need for data collection along the northwest coast.

Feedback on importance: There is an interest in understanding the cause and effect of shoreline dynamics, the mechanics of coastal processes, and the reasons behind observed phenomena.

> **WCMAC:** There is much that remains unknown regarding the underlying trends and patterns of sandy beaches. For instance, the effects of a jetty in a location like Westport, with its large estuary, may differ significantly from those of jetties installed in other coastal areas. Each environment along the coast is unique, and further research is needed to understand these specific contexts.

Inventory of shoreline armoring. There isn't a great inventory of shoreline armoring along the coast. Multiple shoreline protection projects, including nourishment and interventions, have been implemented without systematic tracking. However, there is an Emergency Management Division project that mapped the coastline from Pacific County to the Jefferson County in the Strait. This initiative assessed shoreline change and identified areas with shoreline armoring based on photographs taken between 2006 and 2018. It is uncertain whether the armor attribute data is accessible to the public via online shoreline maps.

Feedback on importance: There is not much attention being paid to inventorying shoreline armoring. While it may not be helpful with spatial planning, it is a general data gap that is worth tracking.

WCMAC: An overall inventory of existing coastal armoring is essential. While it is unclear if there is a comprehensive resource documenting this, it is evident that significant armoring occurs, especially during severe winter storms. Current research is just beginning to reveal the impacts of coastal armoring on erosion and beach ecosystems. This information could help identify potential reasons for the need for armoring, as well as issues related to low-lying areas and critical infrastructure.

Offshore wind data gaps

- Effect of offshore wind on the shape of sandy shorelines

Effect of offshore wind on the shape of sandy shorelines. Sediment redistribution is a critical factor in the formation and modification of shorelines. As sediment is transported and deposited along the coastal zone, it modifies the shoreline's configuration. This alteration in shape influences the orientation of the shoreline and affects sediment transport dynamics. For example, when the shoreline assumes a more acute angle relative to incoming waves or currents, the interaction between wave forces and sediment intensifies and facilitates enhanced sediment movement and redistribution along the shoreline.

If offshore wind development leads to changes in vessel navigation, it could significantly alter sediment transportation and distribution, potentially affecting the shoreline. For instance, vessels associated with offshore wind projects may require deeper channels due to their larger draft. This could necessitate extensive dredging and modifications to port infrastructure and navigation channels. Jetties would also need to be constructed to support the increased depth, prevent sediment accumulation, and ensure safe navigation. These jetties may need to be extended seaward to minimize frequent dredging, though such extensions could cause shoreline scouring. On the southwest coast, the influence of jetties on shoreline dynamics is somewhat understood. For example, the shoreline at Ocean Shores illustrates how jetty construction can affect coastal morphology. The challenge lies in minimizing further disruption to sediment supply, especially to beaches south of Westport and along the Willapa shoreline.

Aside from offshore wind, the baseline is gradually shifting through continuous, “small” impacts. One such impact is from the Columbia River deepening project, which involves dredging at the river's mouth. This dredging can significantly affect sediment transport and supply to nearby beaches. Conceptually, sand moves northward during large southerly waves, and during the summer, with increased northerly waves, sand is transported southward. The deepening of the channel disrupts these natural sediment distribution patterns, potentially causing sedimentation issues between Grays Harbor and Grayland. Additionally, the deepened channel at the Columbia River will reduce the amount of sand that flows south to Oregon and likely contribute to long-term erosion. Although USACE has designated a dredge material site to mitigate some of these effects, it may not be enough to offset the loss of sand, especially in areas like Grays Harbor. Deepening an estuary to create accommodation space also creates a sand trip, resulting in a net loss of sediment from nearshore zones.

The shape of the shoreline may be influenced by offshore wind cables, depending on their placement. If a large cable is positioned on the surface, it could redirect wave energy and currents, potentially affecting the shoreline. However, if the cable is buried subsurface, its impact on sandy shorelines would likely be minimal. Sandy shorelines are primarily shaped by the way wave energy erodes the coastline, which is driven by both alongshore and cross-shore currents—water movement that occurs parallel and perpendicular to the shoreline. These currents fluctuate seasonally due to factors such as winds, undercurrents, and overcurrents. The physical processes of these currents and wave energy influence the shape and maintain the beach morphology. Introducing a structure that alters these processes could therefore change the shape of the beach.

Feedback on importance: It is crucial to emphasize that one of the most significant influences on the shoreline stems from human activities, particularly the construction and promotion of navigation infrastructure such as docks, jetties, and shoreline facilities. While the role of these structures in shoreline processes and coastal activities is well understood, the potential impact of offshore wind activities on the shape of the shoreline is less clear. Addressing this data gap is essential for a comprehensive understanding of coastal dynamics.

WCMAC: The potential effect of offshore wind development on beach morphology and shoreline dynamics represents a significant data gap that requires further investigation. Any form of industrial development along the coast warrants study, even if the effects are not directly causal, as they could be indirect. The influence of large-scale offshore wind projects on localized wind patterns along the shoreline remains uncertain, particularly regarding the potential for even minor changes in wind strength to affect shoreline retreat. Having definitive evidence indicating whether or not there are effects would be invaluable.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Cobble habitat data

Cobble habitat data. The shoreline features a diverse array of habitats, including rocky cliffs, expansive boulder fields, cobble, gravel, and sandy areas. These habitats are distributed unevenly along the coast, with the northern regions being rockier and the southern areas primarily sandy. Notably, cobble habitat covers approximately 30-35% of the coast, including a substantial portion of park shorelines. This habitat consists of boulders and smaller rocks that shift with wave energy, creating a dynamic environment. In between, there is sand and gravel. It is an incredibly diverse habitat. However, monitoring cobble habitat is challenging due to the labor-intensive sampling process, which typically involves using crowbars and shovels to observe what lies beneath the surface. While there have been attempts to sample cobble habitat, these efforts have been inconsistent, time-consuming, often yielded variable results, and involved working with poor data signals. Improving data collection in these areas remains a challenge. Techniques such as environmental DNA (eDNA) sampling could provide valuable insights into cobble habitats. The [ShoreZone](https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-inventory)[98] data, collected in 2001, may also offer relevant information, including cobble classifications. While the data is over two decades old, it should still be informative as those cobble zones are expected to be fairly persistent.

Offshore wind data gaps

- Effect of offshore wind facilities on sandy shorelines
- Effect of offshore wind on sedimentation and erosion and the effect on sandy shorelines

Effect of offshore wind facilities on sandy shorelines. Where offshore cables are proposed will require extensive study due to significant data gaps. Areas have not been mapped and current information on what is underlying the beach, including sediment type and underlying rocks, is limited and fragmented. The effect will depend on how cables are installed, whether through trenching or drilling. Horizontal directional drilling is likely to be employed, which would bury the cables underneath the seabed. Additionally, while construction impacts may be temporary, there could also be environmental consequences, such as the release of drilling fluids. These impacts may take time to resolve. Oregon has made significant progress in addressing these challenges through its Offshore Cable Committee, which has developed strategies to install cables with minimal negative environmental impacts.

The primary challenge is the installation of infrastructure in these dynamic environments. Along the southern Washington coast, the two estuaries and the outer regions with sandy beaches experience constant sediment movement due to wave energy. Introducing fixed infrastructure into such dynamic environments may affect coastal shapes by causing scour, erosion, and changes to how wave energy is delivered to the shoreline. The erosion and scour may cause these structures to become exposed or move. For example, anchors placed in mobile substrates can shift over time. The Olympic Coast National Marine Sanctuary (OCNMS) contains telecommunication cables that were originally buried but have become exposed as sediment moves due to wave action, causing them to shift. At Elwha, buried cables have been exposed due to erosion, which is unsightly, hazardous, and concerning but remains a localized effect and does not significantly impact shoreline morphology. In the case of offshore wind, cables may be trenched or moved to the surface. This cable movement could potentially impact marine activities, including fishing and ship anchoring. The effect of cables will also depend on how deep the cables will be installed beneath the beach surface. In the Kalaloch area, a US Navy cable has remained buried and has not been exposed, but as cables enter the intertidal zone, they may be impacted by wave action. It's challenging to have infrastructure in such areas without providing protection, and protecting it often comes with its own set of consequences.

[98] https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-inventory

Bringing in these cables will require additional infrastructure, which will cause disturbances, particularly at the high-energy shorelines of the Pacific coast. To ensure the cable remains buried and does not become exposed, it is crucial to assess the vertical changes of the beach face over time. Understanding decadal-scale changes to the shoreface is necessary to ensure the cable remains safely buried.

The cables themselves are unlikely to have an impact, nor will the electromagnetic fields (EMF) they generate. Similarly, any structure placed on top of a sandy beach would not have a significant effect unless it acts as a barrier that prevents sand movement. Any disruption to the natural movement of sand can cause an impact. For instance, sediment from the Columbia River is transported northward by wind and currents, like a conveyor belt. Interfering with this "conveyor belt" could disrupt the movement of sand. An example of such interference would be the construction of a breakwater. However, offshore activities are not likely to significantly affect sand supply or movement unless they alter wave energy reaching the shore.

There have been some proposals that include modeling to assess potential changes in the incident wind on the shore zone and nearshore areas. While some initial observations may exist, there is no comprehensive data specifically addressing this issue. The most significant impact may come from new shoreline development to support vessel activity.

The effects will also depend on the density of offshore wind installations; a high concentration of turbines could have a more significant impact than widely spaced turbines. At a certain threshold, dense offshore wind infrastructure may alter the broader oceanographic processes and affect the intertidal zone. For instance, if offshore wind affects upwelling, there may be affects to the biology of the intertidal zone. Offshore wind development could also potentially influence the amount and type of plankton washed ashore, which are vital food sources for organisms living on sandy beaches and shorelines. Additionally, changes in sand grain size (e.g., fine sand, coarse sand, pebbles) could also have a notable effect, as many beach organisms rely on specific grain sizes for habitat.

There is considerable marine traffic off the Olympic coast servicing major ports and vessels from Canada, Alaska, and California. The OCNMS is a voluntary area to be avoided for marine activities. For offshore wind, efforts would likely focus on directing these projects to deeper waters, farther away from the Sanctuary. If offshore wind development increases activities within OCNMS, there could be significant impacts on, for example, bottom disturbance. This is an issue for which Congress granted the OCNMS authority to manage. The sanctuary would play a key role in addressing and mitigating these potential environmental impacts. Additionally, it is difficult to envision offshore wind infrastructure passing through a Washington State Parks (Parks) property, as 75% of the outer coast park shoreline is congressionally designated wilderness. Under the Wilderness Act, activities like offshore wind development are prohibited, and obtaining a permit for such infrastructure would be a significant challenge. Even in areas outside the designated wilderness, permitting offshore infrastructure would be a complex process for PARKS, likely requiring Congress to alter the boundary to accommodate such developments.

The overall value of these potential effects is difficult to assess. Some may see the changes as beneficial, while others may view them as harmful. While research on similar effects has been done in other parts of the world, it is limited for areas like Washington and possibly Oregon. Understanding these impacts would require extensive modeling and specialized studies by oceanographers. However, for sandy beaches and shorelines, the likely concerns would focus more on the impact of offshore wind development on commercial fishermen, rather than on the beaches themselves.

Effect of offshore wind on sedimentation and erosion and the effect on sandy shorelines. The concerns of offshore wind on sedimentation and erosion and the subsequent effect on the shoreline center around scour and sediment transport dynamics. Sedimentation can be beneficial or, if excessive, problematic. Changes in sand supply or movement can lead to the smothering of plants and animals at sandy beaches. For instance, excessive sediment settling can bury eelgrass, which requires ample light and may struggle if it becomes buried beneath sediment layers. As for erosion, increased storm frequency and intensity results in erosion around and behind hard structures. This can result with habitat loss which can have detrimental effects on coastal ecosystems. Currently, for Washington state, erosion poses a more pressing challenge than sedimentation.

Sedimentation and erosion on the shoreline will depend on factors such as size, scale, and distance of offshore wind from the shoreline. It's plausible that the location of offshore wind installations could influence erosion and sediment dynamics on the seafloor. While it's likely that any effects would be localized, this remains speculative. If offshore wind is capable of absorbing wind or wave energy to alter the wave climate along the coast, their impact could be significant. However, it's uncertain whether this will be the case. Currently, there is limited understanding of the extent of interference required to induce such changes.

Hard structures, such as cables on the surface, also have the capacity to redirect wave and current energy, potentially leading to local erosion. The extent of movement depends on the type of sediment. The biggest effect is expected from poorly executed cabling or dredging activities which can increase sedimentation within channels and erosion in surrounding areas. This can result in a combination effect where sand accumulates in deeper holes, unable to redistribute from north to south because it must pass a deeper channel. These anticipated effects would primarily stem from the facilities required to support offshore wind facilities.

Offshore aquaculture data gaps

- Effect of offshore aquaculture on deposition and the subsequent effect on sandy shorelines
- Effect of offshore aquaculture on sedimentation and erosion and the effect on sandy shorelines
- Effect of offshore aquaculture on the shape of sandy shorelines
- Effect of offshore aquaculture on marine debris and the subsequent effect on sandy shorelines

Effect of offshore aquaculture on deposition and the subsequent effect on sandy shorelines. The primary concern for sandy beaches is the fine sand, which is transported by onshore wave processes and deposited in shallower waters. As waves approach the shore, they create orbital motion that generates an onshore flow, gradually moving coarser sand closer to the shore. To influence changes to the beach, activities must occur within the depth of closure, which is the maximum depth at which significant sand exchange happens between the continental shelf and the shoreface on an annual scale. However, aquaculture facilities cannot operate in shallower waters due to the breaking of waves; for example, a 1-meter wave would break in 4 meters of water. On a decadal scale, coastal changes can be observed up to depths of about 25 meters, which is roughly 2-3 miles offshore. Different sediment types dominate at various depths. Fine sands, which form beaches, typically remain closer to shore, while silts become more prominent at depths of around 40 meters. At 60 meters, silts and mud dominate. The mid-shelf area, characterized by deposits of silt and mud, is primarily influenced by the Columbia River plume. Activities affecting sedimentation at the mid-shelf are likely too far offshore to impact beach sediments directly. For example, a large net pen that dissipates wave energy could create a deposition zone beneath it, but it would likely be too far offshore to influence the shoreline.

Depending on the distance from shore and the scale of the operation, the direct impacts of offshore aquaculture are likely to be relatively minor. While wave damping is a consideration, it is unlikely to have a significant effect. Rather, the main concerns are the direct impacts associated with navigation for offshore aquaculture operation, such as the development of new facilities, navigation channels, and the expansion, raising, and maintenance of jetties.

Aside from the physical impact on sandy shorelines, offshore aquaculture may also affect the species residing in these areas. Salmon aquaculture practices result in the deposition of substantial amounts of waste material, including excess feed, nutrients, fecal matter, and antibiotics. Although the dynamic nature of the ocean may mitigate these effects in offshore facilities, waste deposition could still influence the composition and abundance of plankton, potentially impacting beach-dwelling organisms. The seabed should be monitored to observe any changes over time. Studies conducted in other regions may offer valuable insights into the potential effects of offshore aquaculture on the marine environment.

Effect of offshore aquaculture on sedimentation and erosion and the effect on sandy shorelines. There is uncertainty regarding whether offshore aquaculture will directly influence erosion and thereby, affect sandy shorelines. Although local effects may occur, they are anticipated to be minimal. There are no comprehensive data that would be informative on this matter, but existing modeling work could contribute to a better understanding of potential impacts. For instance, live oceanographic models like LiveOcean[99] could provide general information of particle settling from aquaculture pens.

Effect of offshore aquaculture on the shape of sandy shorelines. It's unlikely that offshore aquaculture would have a direct significant effect on the shape of sandy shorelines. It is unlikely to be at a big enough to scale and too offshore to have an effect. Rather, there may be effects

[99] https://faculty.washington.edu/pmacc/LO/LiveOcean.html

through navigation activities associated with offshore aquaculture, such as the development of new facilities; navigation channels; and the expansion, raising, and maintenance of jetties. Additionally, if offshore aquaculture could alter wave energy distribution, it could lead to wave focusing and change the energy distribution along the shoreline.

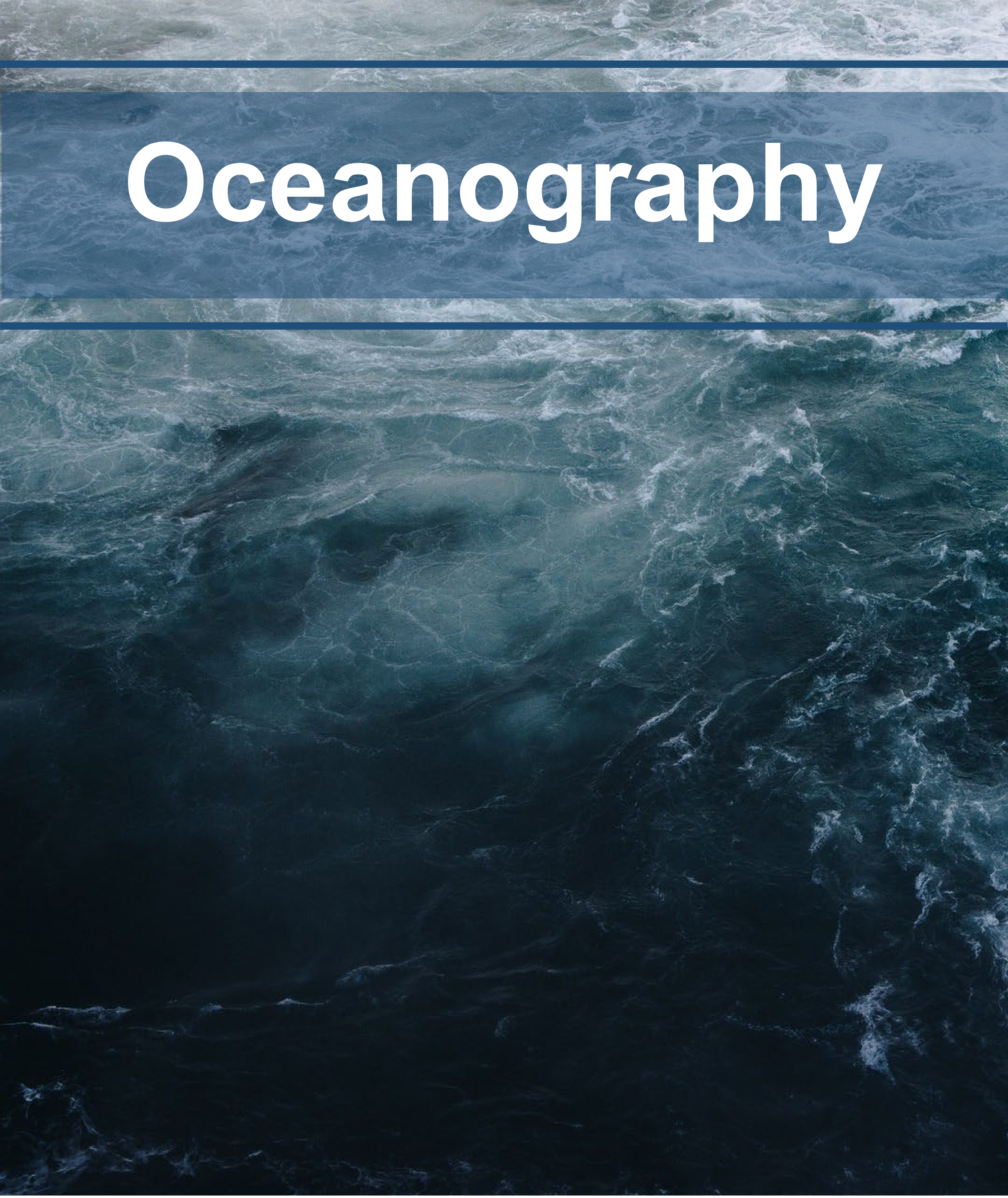
Effect of offshore aquaculture on marine debris and the subsequent effect on sandy shorelines. Marine debris can lead to various consequences, including creating hazards for habitats, transporting toxins, causing aesthetic issues, and influencing shoreline dynamics, such as geomorphology. There is a need to forecast the likely fate of debris generated by offshore aquaculture. Understanding where debris may end up if it breaks apart is crucial for engaging with communities effectively.

Resources

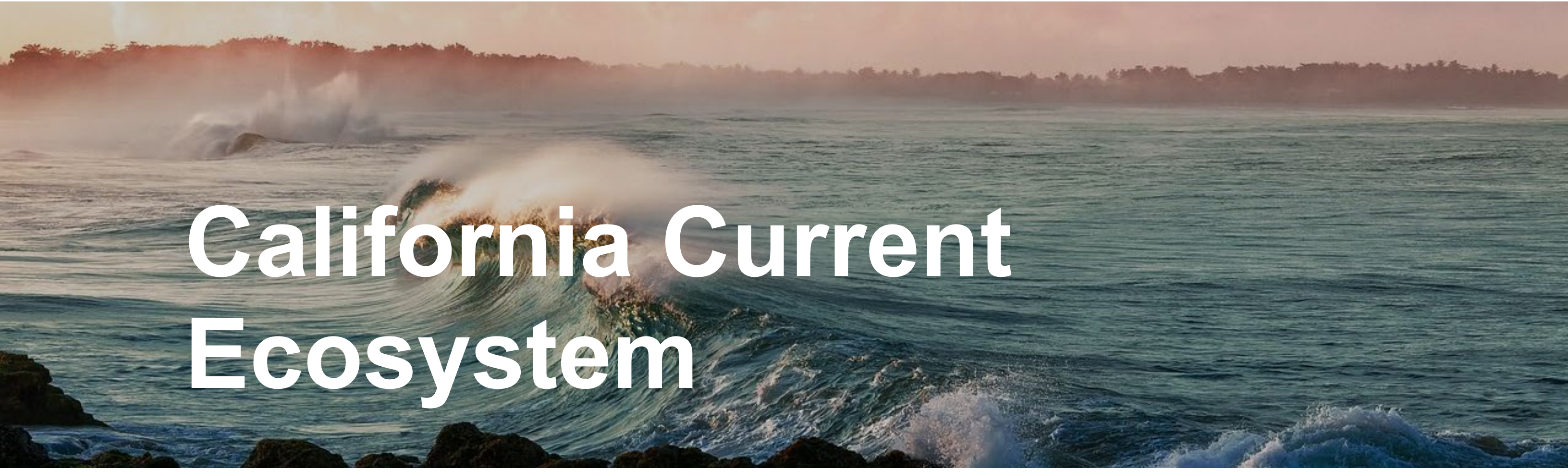
Table 28. Resources relevant to the sandy shorelines.

NAME	ACCESS	TYPE	DESCRIPTION
DNR: Nearshore Habitat Inventory	https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-inventory	Website	Contains data and information for the Washington State ShoreZone Inventory along with other intertidal habitat data.
LiveOcean	https://faculty.washington.edu/pmacc/LO/LiveOcean.html	Website	Provides the output of a computer model simulating ocean biology and chemistry.
Monitoring interdecadal coastal change along dissipative beaches via satellite imagery at regional scale	https://www.cambridge.org/core/journals/cambridge-prisms-coastal-futures/article/monitoring-interdecadal-coastal-change-along-dissipative-beaches-via-satellite-imagery-at-regional-scale/14D0C6DFCD9235CF1A385EF8C4D814B2	Published article	Examines the accuracy of satellite-derived shoreline time series of the Columbia River Littoral Cell by validating them against *in situ* beach elevation profiles.
National Park Service: Geomorphology of Coastal Olympic National Park	https://irma.nps.gov/DataStore/DownloadFile/660243	Report	Provides data and information collected from surveys on the surficial geology of coastal Olympic National Park from 2012 to 2016.

NAME	ACCESS	TYPE	DESCRIPTION
SandSnap	https://sandsnap-erdcchl.hub.arcgis.com/	Data portal	A collaborative initiative aimed at involving citizen scientists in building a comprehensive database of beach sand grain size while also fostering education about coastal processes for the next generation.
The State of the World's Beaches	https://www.researchgate.net/publication/324805485_The_State_of_the_World's_Beaches	Published article	Presents a global-scale assessment of the occurrence of sandy beaches and the rates of shoreline change.
USGS: National assessment of shoreline change: historical shoreline change along the Pacific Northwest coast	https://pubs.usgs.gov/publication/ofr20121007	Report	Analyzes historical shorelines changes along Pacific Northwest coasts of Oregon and Washington.



Oceanography



California Current Ecosystem

Key Data Gaps

General Data Gaps

- Effect of climate change on the California Current Ecosystem (CCE)
- Dynamics and relationships within the CCE, including species distribution, abundance, and trophic interactions
- Effect of the CCE on human activities and vice versa
- Integration of the CCE data
- Subsurface data in the CCE

Offshore Wind Data Gaps

- Effect of offshore wind on circulation and productivity in the CCE

Other Data Gaps

General Data Gaps

- Temporal and spatial gaps of the CCE
- Benthic habitats and substrate mapping of the CCE
- Freshwater interface of the CCE
- Monitoring of nearshore temperatures and subsurface of the CCE

Offshore Wind Data Gaps

- Data integration of offshore wind effects on the CCE
- The interaction between offshore wind and climate change, and its effect on CCE
- Effect of offshore wind on species distribution and abundance in the CCE
- Effect of offshore wind on trophic interactions within the CCE
- Mapping of benthic habitats and substrates in the CCE for offshore wind

Offshore Wind and Offshore Aquaculture Data Gaps

- Social effects of offshore uses in the CCE
- Temporal and spatial gaps of the CCE relevant to offshore uses

Background

The Pacific Northwest, including Washington's Pacific coast, is predominantly influenced by large-scale ocean processes characterized by seasonal patterns and a highly dynamic ocean environment. A key oceanographic feature in this region is the California Current System (CCS), which exhibits strong interannual, seasonal, and daily variability. The CCS encompasses several currents, including the southward-flowing California Current running offshore year-round from the shelf break, and the northward-flowing California Undercurrent along the continental slope. Additionally, the CCS includes the northward-flowing Davidson Current in winter and the southward-flowing California Coastal Jet Current in summer. Each current varies in properties such as temperature, nutrients, oxygen, and salinity, depending on its source waters from the Pacific Subarctic, North Pacific Central, and Southern water masses.

The CCS is critical to supporting the California Current Ecosystem (CCE), a biological system that thrives in the nutrient-rich waters brought about by the CCS. The MSP Study Area encompasses some of the most productive regions of the CCE, supporting abundant fish and shellfish resources.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to the CCE:

General data gaps

- Effect of climate change on the CCE
- Dynamics and relationships within the CCE, including species distribution, abundance, and trophic interactions
- Effect of CCE on human activities and vice versa
- Integration of CCE data
- Subsurface data

Effects of climate change on the CCE. This issue is of utmost importance, especially given the current era of fundamental changes driven by climate change. The ability to forecast the timing, extent, and effects of climate change on coastal ecosystems are limited. While studies are actively being conducted, there remains a substantial gap in understanding how climate change will affect the CCE.

Climate change introduces dynamic shifts rather than static or predictable patterns, leading to unexpected and unfamiliar variations. It is expected to cause significant disruptions. Historically, there was an understanding of large-scale phenomena such as the Pacific Decadal Oscillation (PDO), El Niño, and La Niña. With climate change, the variability of these phenomena and the pace of that variation may diverge from recognized patterns, potentially resulting in more frequent storms, prolonged heat waves, and droughts. For instance, both the PDO and the North Pacific Gyre Oscillation (NPGO) are major climate signals that play a crucial role in shaping oceanographic conditions. Recent research has shown significant changes in

PDO over the past decade. It is unknown whether its signal will intensify or how a warmer PDO might affect the region. Furthermore, the NPGO has also shifted in its correlation with the PDO. These alterations in basin-scale indices complicate their use as reliable predictors or descriptors of current and future ecosystem conditions.

To better understand the effects of climate change on the CCE, it is also crucial to study variability in short-term phenomena like heat waves and atmospheric rivers. While atmospheric rivers are not new, they may become more intense and frequent due to climate change, posing challenges to predictive capabilities.

Detecting climate change requires a long-term dataset spanning approximately 20-30 years, collected consistently at the same locations and times, regardless of the data type (e.g., temperature, oxygen, species). Without long-term data, determining the direction and effects of change becomes challenging. It is crucial to maintain existing long-term datasets off Washington and promptly establish new locations for time series sampling, which may take about 10-15 years to become informative.

More extensive data is also required to comprehensively assess the long-term and short-term impacts of climate change on this ecosystem. This includes investigating changes in ocean temperatures, acidification, hypoxia, and their effects on species distributions, abundance, and overall ecosystem function. For long-term trends, while there is a general understanding, predicting their manifestation under different scenarios remains uncertain. For example, warming is anticipated and fluctuations in upwelling are expected in certain areas; however, their interaction with natural variability remains unclear. Additionally, understanding how species will respond to these changes, particularly in terms of temperature shifts, presents significant challenges. Temperature plays a pivotal role among environmental variables, influencing species survival and chemical reactions. When temperatures rise excessively, species may not survive, and there is an increased risk of deoxygenation. Phenomena like marine heat waves may also contribute to the gradual rise in temperature and cause greater variability.

Feedback on importance: No specific feedback provided.

> **WCMAC:** There is significant interest in addressing this data gap. Currently, there are no definitive predictions regarding how climate change will affect the CCE. Discussions and interactions indicate a growing imperative to take various actions in response to climate change, including the potential industrialization of the ocean.

Dynamics and relationships within the CCE, including species distribution, abundance, and trophic interactions. The CCE is widely recognized as one of the most thoroughly assessed systems globally, yet additional studies are crucial. Despite theoretical models outlining the relationship between the environment and marine species, there is a notable absence of empirical data to validate these models. While models can simulate potential relationships, uncertainties remain about their real-world application. For instance, while surveys can be performed to study the effects of ocean acidification on small species, predicting how these effects will propagate through the food web is challenging due to inherent random variability that is difficult to model. There is also a substantial lack of information concerning the mechanisms of fish species, such as regime shifts between sardines and anchovies, or the interactions between population size and habitat dynamics.

Distribution and abundance: Many species, particularly those of lesser commercial importance, lack adequate data on their distribution and abundance. This information gap impedes effective management and conservation efforts, highlighting the need for improved monitoring. For instance, shifts in forage fish populations have been evident, such as changes in both northern and southern sardine stocks. While annual coast-wide surveys collect data on forage fish, this infrequent sampling may not adequately capture critical fluctuations. The need to adjust surveying efforts is also supported by the need to capture environmental and seasonal changes. Over the past 7-8 years, substantial heatwaves have increasingly impacted the Oregon and Washington coasts, typically occurring from late summer to early fall (September to early November). These warm intrusions are believed to have contributed to phenomena such as more frequent harmful algal blooms (HABs). In recent years, there has also been a trend towards earlier springs and longer summers, likely exerting additional effects on the ecosystem. Adequately capturing these changes may necessitate adjusting the timing and duration of survey cruises and other monitoring efforts.

The factors driving population fluctuations in many species are also not well understood. For example, sardines possess thiaminase, an enzyme that breaks down thiamine which is an important nutrient. When salmon consume significant quantities of sardines, this enzyme can deplete thiamine levels in salmon and affect their reproductive success and subsequent generations. The extent of harm caused by this interaction remains uncertain and requires further investigation.

Trophic interactions: Trophic interactions encompass data on predator-prey relationships, competition, and the broader impacts within ecosystems, such as the effects of removing top predators. Researchers are currently exploring these interactions and investigating potential mismatches between predators and prey. There are ongoing questions about how changes in predator abundance might affect prey availability and whether prey species will adjust their distribution in response. The 2014 "Blob" marine heatwave, which altered conditions in the CCE, resulted in a notable increase in jellyfish populations. The impact of these increased jellyfish on trophic interactions remains uncertain. It is not yet clear whether jellyfish compete with other species, serve as a significant food source, or influence ecosystem dynamics by consuming important prey. As another example, while it is possible to predict phytoplankton blooms, forecasting which specific types will bloom remains challenging. The identity of the dominant phytoplankton species influences subsequent ecological interactions, including predator-prey dynamics and potential toxicity effects. To address these complexities, efforts are underway to model interactions between zooplankton, phytoplankton, and various fish species. Accurate modeling and interpretation of results require collaboration with fisheries experts to ensure comprehensive and reliable insights.

Species interactions within the CCE can also vary significantly, with each group displaying distinct preferences and sensitivities. For example, oysters and burrowing shrimp are highly sensitive to the quality of benthic habitats and bottom oxygen levels. In contrast, salmon populations are influenced by the presence of predators like seals and sea lions. Crabs are particularly responsive to changes in bottom oxygen conditions, whereas razor clams are vulnerable to harmful algal blooms.

Feedback on importance: There is a specific interest in collecting temporal and abundance data of forage fish which serve as a primary food source for many other fish species and are valued resources.

WCMAC: Understanding these dynamics, relationships, trophic interactions, and species distribution is essential for grasping both the current system and its finer points. Significant efforts are underway to understand species distribution and abundance. For instance, coastal pelagic species under the Pacific Fishery Management Council (PFMC) are studied through extensive trawl transects and acoustic surveys. However, a deeper understanding of species distribution will be helpful. For example, while sardines have historically fluctuated in population, their current locations remain uncertain. It is unclear whether they move offshore or migrate southward. Continued research could enhance confidence in assessments of species distribution and abundance.

Currently, knowledge about the dynamics and relationships within the CCE is comparatively limited. Although there is a general understanding, specific details are lacking, indicating substantial room for further inquiry. The trophic interactions within the CCE are particularly intriguing. Recent events, such as a significant herring spawn in Puget Sound that had not occurred in several years, underscore the need for better understanding of these relationships—from herring and salmon to the apex predators such as seals and orcas that feed on salmon. Addressing these interactions is vital for filling data gaps related to species dynamics and distribution.

Additionally, it is critical to understand the existing relationships and dynamics before layering in, for example, the effects of climate change to enhance scientific knowledge. Researchers have recently begun to conduct this level of inquiry and are approaching a baseline understanding of the ecosystem. Factors such as ocean acidification and climate change can be integrated into this baseline to assess their potential impacts on the ecosystem.

Effect of the CCE on human activities and vice versa. While there have been analyses of historical ocean uses, predicting future changes in their impacts over the next few decades remains challenging. In particular, there are data gaps regarding the effects of the CCE on various ocean users, including commercial and recreational users, shipping, maritime industries, and coastal Tribes. There is a critical need for both qualitative and quantitative data on social systems to address these gaps effectively. Additionally, there is limited information on the cumulative impacts of human activities on the California Current, encompassing fishing, pollution, shipping, and coastal development. Understanding these effects is essential for managing human activities and ensuring the sustainable use of the ecosystem.

Feedback on importance: No specific feedback provided.

WCMAC: Coastal communities have evolved around and depend on ocean resources for economic activities and employment. The collapse of fisheries would have serious repercussions. In California, the salmon season was closed for 2024. Understanding these challenges is crucial, particularly for species that are vital to these communities.

Integration of the CCE data. There is a substantial gap in the integration of data from various sources relevant to the California Current. Numerous agencies and organizations study and manage this ecosystem independently, each gathering its own data. Improved integration and sharing of these diverse datasets could significantly enhance the understanding of the California Current system.

There are generally four systems in place:

1. Data independently collected by an entity.
2. Data consolidated from various sources into unified platforms by Regional Ocean Observing Systems (OOS).
3. Data integrated across regional OOS efforts by the National OOS system, overseen by the National Science Foundation.
4. Data managed by NOAA, distinguishing between local and non-local sources.

NOAA’s Environmental Research Division's Data Access Program (ERDDAP) serves as NOAA's data server and management system, supporting a wide range of datasets and offering a centralized platform for data discovery. Regional OOS utilize ERDDAP as a backend for data storage and access. A significant amount of data hosted on ERDDAP is also stored on OOS data servers, and there are ongoing efforts to coordinate and streamline these data resources. However, the ERDDAP user interface has limitations, including access controls that restrict data availability. There is ongoing discussion about whether data generators should submit their data to a larger system. Additionally, the process for making data available on ERDDAP needs to be clearly defined, and the development of a user-friendly data uploader and system automation should be explored. It is also important to identify effective strategies for encouraging data submission. However, while uploading data to ERDDAP is free, the platform’s maintenance costs must be taken into account.

Additionally, with data collection, while data gaps exist, the larger issue lies in organizing and making this data readily accessible. It is crucial for interested or affected parties to acknowledge the scale of this problem, which is often underestimated. Gathering necessary data and processing it effectively are daunting tasks. For instance, the Ocean Observatory Initiative gathers mooring data and deploys ocean gliders across the shelf, which yield substantial insights. However, accessing this data is challenging. This involves a complex data gathering operation with shortcomings in data cleaning, presentation, archiving, and backend management—a common issue in scientific data gap operations. As a citizen or policymaker, accessing visualizable or understandable data poses a substantial challenge. There are insufficient resources to address these issues.

There is a prevailing mindset among researchers that a new portal must be created with every initiative. This approach may not always be optimal. Rather, there is a critical need to prioritize establishing efficient data pipelines. For example, there should be a focus on how to streamline the process of transforming fisheries data into a usable format within a reasonable timeframe.

Achieving common data formatting and enhancing accessibility, such as utilizing platforms like ERDDAP, is essential. Additionally, there is a need to explore synergies among existing data portals to maximize their collective utility.

Similar to the need for data integration, there is a parallel need for model integration. Currently, there are several independent modeling initiatives, but operational models that interested or affected parties can depend on are lacking. Ecosystem status reports often rely on modeling efforts from universities, but these initiatives are typically not supported by sustained funding. Consequently, if a model malfunctions, there is uncertainty whether sufficient time and resources will be available for repairs. There is currently no mandate for universities to maintain these models over the long term.

Feedback on importance: No specific feedback provided.

> **WCMAC:** Discussions regarding data integration have taken place with the Pacific Fishery Management Council (PFMC) and the Marine Fisheries Commission. The challenge arises when different states and agencies use varying data systems. It is essential to standardize data collection methods to facilitate collaboration and enable agencies to leverage each other's work. However, it is also crucial to ensure that the efficiency and quality of the data are not compromised during this integration process. It is possible that one state may be employing a more effective method than another.

Subsurface data in the CCE. Satellites are effective at capturing surface data, providing reliable information on surface temperatures and chlorophyll levels. However, satellite data collection can be challenging due to cloud cover that obscures images and creates significant data gaps. For phenomena like the Blob, which extended up to 140 meters deep, subsurface data becomes crucial for assessing potential impacts on species. Increasing the frequency and extent of subsurface ocean measurements, both spatially and temporally, is essential for a comprehensive understanding of these impacts.

Other data assets include mooring stations maintained by the National Science Foundation at Grays Harbor and Newport, OR; and one maintained by NANOOS near Neah Bay. Additionally, the National Marine Sanctuary deploys several buoys during the summer. Despite these resources, creating a comprehensive map of the Washington continental shelf remains challenging with the current data. While models can be developed and tested using data from these locations, understanding broader shelf conditions is difficult. The California Cooperative Oceanic Fisheries Investigations (CalCOFI) offers quarterly subsurface data, but there are intermittent gaps between surveys and in survey locations. However, these gaps are somewhat mitigated by ocean modeling products, which effectively provide information on variables such as oxygen and temperature.

Although efforts to collect more data are underway, there is still a need for sustained measurements of subsurface variables, including temperature, salinity, pH, and nutrients such as nitrate, to better understand the CCE. In particular, additional measurements of bottom oxygen and pH levels are critical, both spatially and temporally. Oxygen, along with temperature, are vital subsurface variables that serve as key indicators for various aspects of the ecosystem. Their importance makes them standard measurements. Existing datasets on bottom temperature are also inadequate, and there is a need for more comprehensive long-term data.

Feedback on importance: No specific feedback provided.

Offshore wind data gaps

- Effect of offshore wind on circulation and productivity in the CCE

Effect of offshore wind on circulation and productivity in the CCE. A modeling study is recommended to assess the impact of wind farms on upwelling patterns, as well as how these changes may affect circulation and productivity within the CCE. Additionally, it is important to assess these impacts in conjunction with climate change factors.

Feedback on importance: No specific feedback provided.

> **WCMAC:** The relationship between the CCE circulation, productivity, and the potential offshore wind infrastructure likely reflects a substantial data gap. Currently, coastwide cumulative effects of numerous offshore wind energy projects have not been modeled, leaving the impacts of removing 3, 10, 30, or 50 gigawatts of wind energy from the system unclear.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Temporal and spatial gaps of the CCE
- Benthic habitats and substrate mapping of the CCE
- Freshwater interface of the CCE
- Monitoring of nearshore temperatures and subsurface area of the CCE

Temporal and spatial gaps of the CCE. Many studies have been constrained by limited spatial or temporal scales, leading to fragmented data that makes it difficult to identify trends or make broad-scale predictions. To address these limitations, there is a critical need for long-term, large-scale monitoring efforts. Spatially, there is a significant bias for nearshore data due to its lower cost and greater accessibility. On temporal scale, typically, sampling is robust during spring and summer but declines during fall and winter, especially due to challenging weather conditions. This seasonal discrepancy represents the largest data gap in fisheries independent surveys, and likely in fisheries surveys overall. This trend may shift with climate change. There is also a need for data on short-term variability, including daily time scales, which are influenced by unpredictable local and regional weather patterns.

Benthic habitats and substrate mapping of the CCE. There is a gap in the detailed mapping of benthic habitats and substrates within the CCE. Benthic ecosystems play crucial roles as habitats, food sources, and breeding grounds for various species. Current knowledge about the composition, distribution, and temporal changes of these habitats is often insufficient. This includes inadequate data on different substrate types (such as sand, mud, and rock) that influence the species composition in an area, as well as the three-dimensional structure of these habitats, which provide shelter and breeding sites for diverse organisms. This data gap will address concerns related to activities like setting anchors (e.g., near deep-sea corals).

Freshwater interface of the CCE. The extent of observation at the freshwater interface of the CCE remains uncertain. While some data is collected, this interface is often insufficiently represented in ocean models, particularly regarding the effects of stream flow from dams. There is a clear need for more comprehensive modeling to understand it.

Monitoring of nearshore temperatures and subsurface area of the CCE. Currently, there are numerous sampling stations, and temperature is better understood compared to many other factors. Monitoring of nearshore temperatures and subsurface area will help understand the effects of climate change.

Offshore wind data gaps

- Data integration of offshore wind effects on the CCE
- The interaction between offshore wind and climate change, and its effect on the CCE
- Effect of offshore wind on species distribution and abundance in the CCE
- Effect of offshore wind on trophic interactions within the CCE
- Benthic habitats and substrate mapping for offshore wind

Data integration of offshore wind effects on the CCE. Integrating data from various sources could provide a more comprehensive understanding of the potential impacts of offshore wind projects, thereby improving the decision-making process related to their development.

The interaction between offshore wind and climate change, and its effect on the CCE. While some research is underway on offshore wind effects, understanding their interactions with climate change is limited. Offshore wind installations can alter both the flow and wind fields, necessitating a thorough examination of downstream effects. For instance, changes in upwelling and nutrient distribution may propagate through the ecosystem, affecting various ecological processes and interactions. There are also questions about potential species migrations into offshore wind areas and the exclusion of fishing grounds due to climate shifts.

Additionally, understanding the effects of climate change on the CCE is essential for predicting long-term changes during the lifespan of a wind project, which can extend over decades. This information is critical for conducting robust environmental impact assessments and ensuring the sustainability of these projects.

Effect of offshore wind on species distribution and abundance in the CCE. Whether an offshore wind facility will aggregate or disperse species depends on its configuration and the species involved. Given that these installations can potentially disrupt habitats and migration routes, comprehensive data on marine species are crucial for strategically siting these projects. Incomplete data on species distribution and abundance can introduce uncertainty into the environmental impact assessments of offshore wind projects.

It is hard to envision floating offshore wind platforms not offering habitat for benthic-oriented species like groundfish. Coupled with local fishing restrictions, abundance may increase. However, this increase could stem from attraction, enhanced productivity, or both. Research is required to understand these dynamics. Typically, assessments only record presence or absence and variables like growth rates are inferred. Merely counting the number of animals near a wind farm will not address this data gap. There may be a situation where species are attracted, but there is a decrease in productivity. Aggregation can also create the appearance of increased species presence, but it may simply reflect higher densities rather than actual abundance. This distinction is crucial for accurate surveys. It is crucial to directly measure population size, growth rate, and reproduction rate. Additionally, if offshore wind results in the loss of survey locations, this could falsely indicate higher species densities at remaining sites. Such biases can skew survey results, potentially leading to inaccurate assessments of species distributions and abundance.

Data from oil rigs could offer insights into whether the effects from offshore wind are limited to surface levels or extend deeper into the ocean. However, research on the effects of oil rigs has focused on bottom-dwelling species, with less attention given to forage fish, pelagic species, and surface-dwelling species.

Effect of offshore wind on trophic interactions within the CCE. Understanding the trophic interactions in the CCE can help predict the cascading effects of any disruptions caused by offshore wind projects, including changes in habitat or direct impacts on specific species.

Mapping of benthic habitats and substrates in the CCE for offshore wind. Comprehensive knowledge of the composition and distribution of benthic habitats and substrates in the CCE is essential for offshore wind projects. The construction and operation of these projects can physically disturb the seafloor, potentially altering or diminishing habitats. Detailed habitat maps are crucial for strategically siting offshore wind installations to mitigate impacts on sensitive or critical benthic habitats. Furthermore, alterations in sediment distribution resulting from offshore wind farm operations, such as changes in water currents, may also affect benthic habitats, necessitating thorough understanding and monitoring.

Offshore wind and offshore aquaculture data gaps

- Social effects of offshore uses in the CCE
- Temporal and spatial gaps of the CCE relevant to offshore uses

Note: A slight departure from the format of other topics, there were data gaps that applied to both offshore wind and offshore aquaculture. Because some feedback pertained to both activities, these data gaps were consolidated.

Social effects of offshore uses in the CCE. Research is crucial to understand the cascading and indirect responses to introducing new physical habitats where species are highly abundant, as well as the reactions of fishing communities. For instance, if fishing is restricted near an offshore wind or aquaculture farm, fish mortality rates could decrease and potentially lead to increased abundance and reproduction. This may result in spillover effects beyond farm boundaries into areas currently used by fishing activities, possibly increasing overall exploitation rates.

Farms have the potential to concentrate fishing activities, but whether this will compensate, overcompensate, or under-compensate fishers for lost fishing grounds remains uncertain. This notion of unfishable areas potentially serving as de facto marine protections could initially hold true but may not persist over time, creating a situation that could mislead or distract from other issues. The answers to these questions will depend on the assumptions made by fisheries management.

With this in mind, there is a need to collect qualitative and quantitative data on social systems. There are data gaps regarding who benefits and who faces challenges among commercial, recreational, shipping, maritime, and coastal Tribal communities.

Offshore wind: Understanding the cumulative impacts of human activities, including offshore wind projects, is crucial for effective ecosystem management. While each activity may have minor individual impacts, their cumulative effects could result in significant changes to the ecosystem. Offshore wind projects, in particular, will significantly affect shipping routes. The Navy has designated some areas as unmanageable. Concerns also extend to offshore fisheries and surveys. Automated sampling assets, such as glider surveys, could mitigate some survey challenges. Moving forward, it will be essential to identify mitigation areas and develop a comprehensive plan to address these concerns.

Offshore aquaculture: There are concerns that offshore aquaculture projects could limit or exclude other human uses of the ocean. While there has been great work on examining historical aquaculture activities and their impacts, it is essential to better understand how these projects may affect other ocean activities. One significant knowledge gap is how climate change-driven species redistribution might interact with offshore aquaculture, which could have further implications for ocean use and management.

Temporal and spatial gaps of the CCE relevant to offshore uses.

Offshore wind: There are gaps in long-term, wide-scale data that contribute to uncertainties in predicting the long-term effects of offshore wind projects. For instance, if certain species inhabit the project area seasonally, short-term studies may not capture this information.

Offshore aquaculture: Subsurface temperature and oxygen levels are crucial for understanding the environmental conditions that influence aquaculture activities. Oxygen levels are vital for supporting fish farming, as fish require adequate oxygen to thrive. Similarly, temperature plays a key role in plant-based aquaculture, such as kelp farming. Data gaps in both the timing and location of these variables create uncertainty in the potential success and sustainability of offshore aquaculture operations.

Resources

Table 29. Resources relevant to the California Current Ecosystem.

NAME	ACCESS	TYPE	DESCRIPTION
California Current Integrated Ecosystem Assessment Indicators	https://www.integratedecosystemassessment.noaa.gov/regions/california-current/california-current-iea-indicators	Website	Provides current and historical indicator data relevant to evaluating the status of the California Current Ecosystem

Climate Variability

Key Data Gaps

General Data Gaps

- State of climate
- Trend of climate variability
- Physical processes that affect climate
- Species response to climate variability
- Climate change
- Monitoring of biogeochemical properties

Other Data Gaps

General Data Gaps

- Vulnerability of infrastructure to climate variability

Offshore Wind Data Gaps

- Effect of offshore wind on long-term variability
- Effect of offshore wind on short-term variability
- Effect of offshore wind on climate variability and the effect on various habitats and species
- Effect of offshore wind on climate variability and the effect on species movement
- Effect of offshore wind on climate variability and the effect on coastal circulations

Offshore Aquaculture Data Gaps

- Effect of offshore aquaculture on long-term and short-term variability
- Effect of offshore aquaculture on climate variability and the effect on various habitats and species

Background

Washington's Pacific coast experiences a temperate climate with seasonal rainfall peaking from October to March and drier, warmer conditions during the summer. The seasonal rainfall and snowfall influence river flows, coastal turbidity, sediment input, temperature, and salinity gradients along the coast and estuaries. Winter storms are also pivotal in shaping the physical environment.

Global climatic processes, like El Niño-Southern Oscillation (ENSO), impact ocean productivity by altering sea surface temperatures, sea surface height anomalies, turbidity, and sediment transport. ENSO can change the global atmospheric circulation which can then influence temperature and precipitation globally.[100] There are three states to ENSO: El Niño, La Niña, and neutral.[101] Observable responses to El Niño, the warm phase of ENSO, include warm upper-ocean temperatures, winds favorable to downwelling, reduced primary productivity, elevated water levels, and the appearance of southern marine species. The El Niño phase also induces storms and large wave heights, leading to erosion hotspots in the Pacific Northwest. The cold phase, referred to as La Niña, reverses these effects. The neutral phase is neither El Niño nor La Niña.[102]

The Pacific Decadal Oscillation (PDO) is a recurring climatic event that affects sea surface temperature and sea level in the northeast Pacific, influencing marine fisheries abundances. Positive PDO phases bring warm temperatures, positive sea level pressure, and higher sea levels. These phases correlate with reduced salmon production in Washington, Oregon, and California. Negative PDO phases see increased salmon production.

ENSO and PDO operate on different time scales. ENSO events typically last 6-18 months, whereas PDO phases span 20-30 years. Differentiating between long-term climate change trends and shorter-term climate cycles poses challenges. It remains uncertain how climate change will affect ENSO and PDO. Scientists anticipate that climate change will lead to heightened intensity and frequency of storms, increased wave heights, and alterations in wave direction.

Climate phenomena like ENSO and PDO also affect various habitats. Sandy intertidal beaches are influenced by sediment deposition, wave energy, beach slope, upwelling, and climate variability, creating variable conditions for the residing organisms. Within the pelagic habitat, shifts in zooplankton species composition can be correlated with regional climate and seasonal patterns. Cold water species typically dominate the zooplankton community during the summer season, while the warm water species usually dominate during winter. Climate forces such as El Niño events and PDO can alter these seasonal patterns. For kelp forests, strong storm events and nutrient-poor waters during El Niño can decrease kelp coverage, while cold, nutrient-rich La Niña events provide optimal growth conditions. Disturbance from storm-driven waves also

[100] https://www.climate.gov/news-features/blogs/enso/what-el-ni%C3%B1o%E2%80%93southern-oscillation-enso-nutshell
[101] *Id.*
[102] *Id*.

promote the recruitment of bull kelp and macroalgae. Additionally, suppressed cold water upwelling, increased water temperatures, and reduced light penetration from sediment runoff can adversely affect these ecosystems. For coastal estuaries, tidal mixing is a key driver. Other physical drivers for estuaries include sediment dynamics, river plumes, large-scale climate patterns, and weather.

The Blob, a North Pacific mode or marine heat wave, is another large-scale process. From 2013 to 2015, the Blob significantly warmed sea surface temperatures off the west coast, including the MSP Study Area. During this period, scientists observed a decline in copepod populations off the Oregon coast, thousands of seabird deaths, and the starvation of many sea lions in California, all potentially linked to the Blob. The Blob is believed to have resulted from a high-pressure atmospheric ridge. With ongoing ocean heat absorption and climate shifts, anomalous events like the Blob may increase in frequency.

The Pacific Northwest (PNW) also experiences severe waves, especially during winter storms. Storm intensity and wave height have increased since the late 20th century, with fewer weak to medium-strength storms. Winter storms create deep-water significant wave heights greater than 10 meters and have generated wave heights up to 15 meters. The most intense storms can generate winds comparable to hurricane speeds. PNW storm and wave energy shape ocean and coastal conditions, affecting erosion, accretion, sediment transport, surf zone energy, and flooding. While the entire coast is affected, the southwestern Washington coast faces increased erosion risks during major storm events, exacerbated by intensified storm frequency and strength.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to climate variability:

General data gaps

- State of climate
- Trend of climate variability
- Physical processes that affect climate
- Species response to climate variability
- Climate change
- Monitoring of biogeochemical properties

State of climate. While there are always data gaps, there is a very good knowledge of the present state of climate. The west coast is one of the better sampled systems in the world. Researchers have a strong grasp of climate patterns and their variability, supported by reliable observing systems, resources, and reporting, including the California Current Ecosystem Assessment report. This report covers system states, variability, and impacts to communities. It encompasses oceanography from large to regional scales, specific species impacts across trophic levels, and social sciences.

Different networks specialize in various measurements, each serving distinct monitoring goals:

Table 30. Description of network and monitoring assets

NETWORKS/MONITORING ASSETS	DESCRIPTION
Cooperative Observer Network (COOP)	Relying on volunteer-operated weather stations, COOP focuses on temperature and precipitation. However, there are insufficient land-based weather stations and, with many of the weather stations having been in families for generations, there is less interest in the younger generation to continue this volunteer work. While alternative data collection methods, such as satellite and gridded temperature maps, are being explored, actual measurements remain sparse. Although estimates can be derived from nearby stations to fill in data gaps, there is still significant underfunding in infrastructure for climate measurement in Washington. A comprehensive suite of measurements is needed, including temperature, salinity, precipitation, humidity, cloudiness/solar radiation, wind, soil moisture, acidification, and evapotranspiration. With the exception of temperature and precipitation, more accurate data can be collected on all these factors through higher-frequency or higher-spatial-resolution monitoring. Also, despite some awareness of wind patterns, there is insufficient data on mean wind speed and severe storms.
National Centers for Environmental Prediction (NCEP)	Focusing on broader weather patterns, NCEP is a continuous weather model used to fill observational gaps since the late 1940s. It contributes to atmospheric re-analyses and is a useful source to review variations and trends.
National Data Buoy Center (NDBC)	NDBC provides oceanic observations and forecasts through buoys and atmospheric equipment, measuring parameters like salinity, conductivity, temperature, and depth (CTDs). There are different types of buoys—land-based versus water-based—and are deployed by various agencies for a range of purposes. They collect information at varying frequencies. Challenges include occasional missing data due to structural or technical issues. Ex: The Cape Elizabeth Buoy has recorded data since 1987, with synthetic datasets reaching back to the 1940s. These datasets offer insights into how much the mean wind speed and the strongest winds of the year have varied over time, trends, and how they fluctuated with the ENSO cycle.

Other data gaps for this area primarily lie in understanding the effects of climate on various trophic levels and species, and event-scale processes like marine heat waves. There is also an interest in understanding the effect of the El Niño-La Niña transition on the state, including snowpack and subsequent winter conditions.

Feedback on importance: While there is a solid understanding of the state of climate, this is critically important information that can be better studied.

> **WCMAC:** This feedback applies to the following four data gaps: state of climate, trend of climate variability, physical processes that affect climate, and climate change.
>
> There is a wealth of data available regarding the state, trends, and physical processes related to climate variability and climate change. NOAA has an integrated ecosystem assessment team that collects data and produces an annual report synthesizing this information. This report provides an update on the status of the California Current Ecosystem (CCE), including data on climate change monitoring along the West Coast and its impacts on various fisheries. Each year, the report details the current state of the climate, trends observed over the past year, the physical processes influencing climate, and forecast models for the upcoming year. Notably, Appendix E focuses specifically on climate change and offshore wind and provides resources. NOAA is monitoring everything possible.

Trend of climate variability. There is a solid understanding of climate variability trends, particularly through historical observations of the CCE, which offer valuable insights at a global scale. With data extending back to the mid-20th century, there is ample information to grasp trends and the nature of variability. In particular, the baseline of observations for the surface is relatively strong, with satellite data available for the past few decades. However, there is a shorter baseline for the subsurface pelagic habitat which makes it more challenging to detect changes in the context of climate change and complicates the attribution of changes to climate change versus climate variability. A solid baseline is essential for identifying and quantifying variability.

While the trends of climate variability are understood, the reasons behind these trends remain unclear. For example, consistent with observations over the past 50 years, climate models show greater warming over land than ocean. However, the observed warming patterns diverge from model projections. This discrepancy can have various implications. For example, if sea level rise diverges from climate model predictions, this can affect hydroelectric power production and reservoir management. There are ongoing research efforts to determine whether observed trends reflect genuine responses or stem from natural variability that is responding to Carbon dioxide (CO_2) levels. Most believe that the observations are the true force response and not natural variability.

Additionally, how trends vary over a certain period of time is an open question. With significant fluctuations in extremes such as temperature and precipitation, there has been no confirmation of whether these changes are seasonal, monthly, or the result of abnormal months. It is unknown how to measure changes in monthly or seasonal temperature or precipitation variability. Spatial variability also complicates defining and assessing changes.

Forecasting both short- and long-term climate variations is also a significant challenge. There is uncertainty about when the climate regime will shift. Trend analyses must account for long-term variations, which are part of the natural system, as well as multiyear changes in atmospheric patterns, winds, and other factors. While various indices are available to characterize these systems, they often fail to capture the full complexity of climate variability. For instance, while the Pacific Decadal Oscillation (PDO) is a valuable index for understanding climate patterns, it represents conditions across the entire North Pacific. Its broad-scale nature means that, although it can sometimes align with conditions at specific locations, it is not always an accurate predictor. To address this, reanalysis products are available that can generate time series for specific areas, such as monthly wind speeds, allowing for a more localized assessment of past variability.

Other data gaps exist, particularly regarding the impacts of climate variability on ecosystems and human systems. However, a sufficiently long time series is available to offer some insights into wind conditions, providing valuable information for developers.

For specific feedback on understanding trends in short- and long-term climate variability, see below:

> **Short-term variability** (3 months to a year, e.g. ENSO)**:** High-resolution modeling is essential to better understand short-term variability, such as wind statistics during El Niño years. Statistical estimation of yearly wind changes can be achieved by analyzing historical offshore winds from weather forecast products and comparing El Niño and La Niña years. NCEP's reanalysis products also offer estimates of the atmospheric state for recent years and the European Centre for Medium-Range Weather Forecasts[103] can predict wind changes during ENSO cycles across seasons.
>
> **Long-term variability** (multi-year trends, 30 years and longer)**:** Before addressing questions such as how climate change will affect mean wind circulations, it is crucial to first understand why the observed trends differ from the models' projected patterns.

Feedback on importance: This data gap is well understood, but it remains critically important to address. Identifying and assessing temporary changes is challenging, as statistics are more reliable for means than for variations. A longer period of data collection is needed to identify statistically robust trends. However, not everything can be predicted, as there are significant limitations in understanding such a complex system. For example, the state of the PDO in five years remains uncertain.

> **WCMAC:** This feedback applies to the following four data gaps: state of climate, trend of climate variability physical processes that affect climate, and climate change.
>
> There is a wealth of data available regarding the state, trends, and physical processes related to climate variability and climate change. NOAA has an integrated ecosystem assessment team that collects data and produces an annual report synthesizing this information. This report provides an update on the status of the CCE, including physical

[103] https://www.ecmwf.int/en/forecasts

> data on climate change monitoring along the West Coast and its impacts on various fisheries. Each year, the report details the current state of the climate, trends observed over the past year, the physical processes influencing climate, and forecast models for the upcoming year. Notably, Appendix E focuses specifically on climate change and offshore wind and provides resources. NOAA is monitoring everything possible.

Physical processes that affect climate. This data gap requires a deep understanding of the current state and trends of climate variability. In some areas, this understanding is well-established. For instance, short-term variability plays a key role in modulating the frequency and nature of winter storms and summer winds along the Pacific Northwest coast—factors that are crucial for the coastal ecosystem. Extensive research has also been conducted on phenomena like El Niño and La Niña, and we have methods for anticipating how short-term variations affect events. However, certain physical processes remain poorly understood and are currently only hypothesized. For example, over western Washington, the prevailing low-level flow includes a component from the west, and the atmospheric boundary layer is in quasi-equilibrium with the ocean. As a result, warmer-than-normal ocean temperatures along the Pacific coast are correlated with higher air temperatures and dewpoints over western Washington. There is also limited understanding of climate change and long-term variation. While event frequency may remain relatively stable, there is concern that their intensity could increase over time.

Various models, including physical, oceanographic, climate, and ecological models, are available to understand the physical processes and their significance. However, the quality of these models depends on their assumptions, the data integrated into them, and the monitoring status of systems. Data gaps exist within these models, such as the significant uncertainty with how climate models represent cloud response to increased carbon dioxide (CO_2) levels.

Feedback on importance: No specific feedback provided.

> **WCMAC:** This feedback applies to the following four data gaps: state of climate, trend of climate variability physical processes that affect climate, and climate change.
>
> There is a wealth of data available regarding the state, trends, and physical processes related to climate variability and climate change. NOAA has an integrated ecosystem assessment team that collects data and produces an annual report synthesizing this information. This report provides an update on the status of the CCE, including physical data on climate change monitoring along the West Coast and its impacts on various fisheries. Each year, the report details the current state of the climate, trends observed over the past year, the physical processes influencing climate, and forecast models for the upcoming year. Notably, Appendix E focuses specifically on climate change and offshore wind and provides resources. NOAA is monitoring everything possible.

Species response to climate variability. It is understood that climate is changing, and this will cause disruptions in species interaction and their ecological niches. For example, as summer and winter temperatures rise and snowpack decreases, species movement is expected to shift. There are also reports on changes to species movement due to ENSO cycles. Species response to climate variability is well understood for phytoplankton and certain species such as well-monitored, commercially valuable species. Hence, for the most part, data is limited and there is poor predictability on how species will respond to change. There aren't enough observations of different species across different trophic levels to monitor their response to variability. Theories can be proposed, but the effect of climate variability cannot be understood until observations are made. In addition to studying the response of specific species, there is also a need to understand the response to climate variability across a species' life history.

Currently, extensive efforts are underway within the scientific community to assess the climate vulnerability of various species. NOAA's 2023 publication, "Vulnerability to climate change of managed stocks in the California Current large marine ecosystem,"[104] assesses the vulnerability of species using data on their life history, characteristics, and predictions of climate change impacts. The National Marine Sanctuaries is also undertaking Climate Vulnerability Assessments, which includes the Olympic Coast National Marine Sanctuary Climate Vulnerability Assessment[105] workshop. This work can guide monitoring needs and studies.

Feedback on importance: Species response to climate variability is the least understood data gap.

> **WCMAC:** There is an urgent need for more studies on species responses to climate variability which requires a detailed, species-by-species approach. Evaluating these responses on a stock-by-stock basis is crucial. For example, significant information exists regarding salmon, including the development of "stoplight tables" that categorize their status as red, yellow, or green based on the physical effects of climate from the previous year. These tables assess the number of returning juveniles and provide forecasts based on marine environmental conditions in the prior year.
>
> The response of specific species to climate variability is studied through stock assessments. However, fewer than 25% of groundfish stocks are included in these assessments, with priority given to species that are targeted in fisheries and have significant economic value. As a result, more than 75% of groundfish species remain understudied. Data on species' responses are also gathered from protected groups, including marine mammals, sea turtles, and other species listed under the Endangered Species Act (ESA).

Climate change. Climate change is anticipated to amplify existing trends in climate variability. While data for the Washington coast is reasonably robust, researchers are still in the early stages of quantifying change. The available time series are not sufficiently long, and data gaps persist, making it challenging to distinguish between shifts caused by climate change versus natural variability. For instance, there is ongoing research examining how climate change affects ENSO in Pacific Northwest waters, but there is no consensus on its effects, such as whether the increased frequency of La Niña is a temporary anomaly or linked to long-term climate change. There have been numerous La Niña events, possibly due to changes in the

[104] https://repository.library.noaa.gov/view/noaa/50502
[105] https://www.noaa.gov/information-technology/climate-vulnerability-assessment-for-olympic-coast-national-marine-sanctuary-id473

climate system, but climate models have struggled to accurately capture this phenomenon. Species that have thrived during La Niña may face challenges if there is a shift towards more frequent El Niño events in the future.

Regional climate models have been extensively developed to refine projections from global models by focusing on specific areas and parameters. While significant effort has been devoted to analyzing these projections, uncertainties remain due to the limitations of the models, making precise predictions challenging. For example, extensive research has examined how climate change impacts upwelling and downwelling along coastlines and their effects on marine ecosystems. Upwelling is generally more pronounced during warmer seasons, and ecosystems have adapted to this seasonal pattern. In contrast, the effects of climate change on coastal winds and windstorms are less well understood, with varying projections across different models. Although some studies have explored trends through the early 21st century, predictions for the mid-21st century remain uncertain. It is speculated that, while systematic changes in storm frequency may not occur, warmer ocean temperatures could increase the intensity of extreme storms.

Feedback on importance: While there is a clear understanding of the current situation, further work on applying model results to local issues remains a research priority.

> **WCMAC:** This feedback applies to the following four data gaps: state of climate, trend of climate variability physical processes that affect climate, and climate change.
>
> There is a wealth of data available regarding the state, trends, and physical processes related to climate variability and climate change. NOAA has an integrated ecosystem assessment team that collects data and produces an annual report synthesizing this information. This report provides an update on the status of the CCE, including physical data on climate change monitoring along the West Coast and its impacts on various fisheries. Each year, the report details the current state of the climate, trends observed over the past year, the physical processes influencing climate, and forecast models for the upcoming year. Notably, Appendix E focuses specifically on climate change and offshore wind and provides resources. NOAA is monitoring everything possible.

Monitoring of biogeochemical properties. More surveys of chemical properties are needed to enhance the evaluation of ocean models.

Feedback on importance: The monitoring of biogeochemical properties will be important to assess the effect of offshore wind development.

> **WCMAC:** There is some monitoring of biogeochemical properties related to ocean acidification (OA) and harmful algal blooms (HABs), including elements such as aragonite. This information is included in the ecosystem reports. While the full extent of available monitoring is not entirely clear, relevant data is available.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Vulnerability of infrastructure to climate variability

Vulnerability of infrastructure to climate variability. Existing infrastructure systems are expected to be robust against known threats, thanks to ongoing collaboration with civil engineers. This partnership focuses on improving coastal zone protections against tsunamis and major earthquakes. However, certain infrastructure, such as roads along the coast, may lack active analysis or comprehensive evaluations of their vulnerabilities.

As sea levels rise, infrastructure issues relating to climate variability are expected to become more critical. Furthermore, increased temperatures during the summer could lead to more frequent flooding, potentially worsened by storms during El Niño years due to elevated ocean baselines. Warmer winters may also result in more severe flooding and intensified rainfall. In addition to flooding issues, warmer winters may result in reduced water storage in reservoirs, leading to lower water levels in summer. This diminished water availability will impact both water supply and power generation. Adapting to these changes will require addressing the effects of warming in both winter and summer.

There is strong infrastructure for ocean observing, which offers valuable information on various aspects such as harmful algal blooms (HABs) and climate conditions. The NANOOS website provides access to a range of data sets and a comprehensive catalog of oceanographic knowledge.

Offshore wind data gaps

- Effect of offshore wind on long-term variability
- Effect of offshore wind on short-term variability
- Effect of offshore wind on climate variability and the effect on various habitats and species
- Effect of offshore wind on climate variability and the effect on species movement
- Effect of offshore wind on climate variability and the effect on coastal circulations

Effect of offshore wind on long-term variability. While there has been limited research on the impacts of offshore wind on climate variability, existing knowledge suggests that these developments are unlikely to cause major changes. While a highly dense wind farm could reduce wind speeds, such extensive development is unlikely. Additionally, if the farms are located far from the coast, the winds are expected to recover. Hence, the energy extracted from wind fields by offshore wind is unlikely to have a significant impact. However, there may be local responses in wind and ocean conditions. For example, offshore wind projects could affect upwelling patterns, altering water column structure and potentially impacting productivity at lower trophic levels. A recent study[106] modeled offshore wind development off the coast of California, using atmospheric and oceanographic models to examine its effects on the water column. While the spatial footprint was small, the changes in upwelling dynamics were enough to imply potential impact on biological processes.

The effect of offshore wind over a long-time scale such as 20 to 50 years is a data gap. Studies in the North Sea have suggested significant effects of large wind farms on ocean properties and ecosystems, though caution is necessary when applying these findings to the Pacific Northwest shelf waters. While it is unclear if there is definitive work for the Washington region that will provide insight, there are resources available to pursue this data gap. With data available from 1987, there are at least thirty years of records, encompassing several ENSO events.

Rather than a direct effect on climate variability, there is greater concern on how offshore wind structures and activities might add to the effect of climate change and variability on the ecosystem. Placing structures in featureless areas can create habitat and attract species and may also cause disruptions. There are efforts in Seattle that are exploring how these developments may impact movements for large marine mammals or seabirds.

Effect of offshore wind on short-term variability. Short-term variability spans from months to a couple of years, such as the ENSO cycle. Very little research has explored how offshore wind will impact climate variability. However, it is not expected to directly affect climate variability.

Short-term variability can be viewed in two ways: seasonal transitions and short-term climate fluctuations over the next 10-15 years. There is a significant data gap in understanding both. For seasonal transitions, particularly on land, it is clear that climate change is lengthening the growing season, which in turn affects industries dependent on these transitions, such as agriculture. The potential interaction between offshore wind development and these seasonal shifts, both year-to-year and in the context of a changing climate, remains uncertain.

Rather, than climate variability, offshore wind may have more significant impacts on ecosystems. Changes in mean wind patterns could notably affect the ecosystem, as variations in upwelling may alter ocean properties like temperature, oxygen concentration, and pH, potentially favoring certain species over others.

Effect of offshore wind on climate variability and the effect on various habitats and species. Offshore wind development is not expected to influence climate variability. However, offshore wind projects and climate variability could both directly affect species and habitats. Though the extent of the effects from offshore wind is not yet fully understood, it will likely depend on siting procedures. Presently, efforts in California are underway to address these considerations. Future reports could offer valuable guidance for optimal wind development siting.

The effects of offshore wind and climate variability on specific habitats are described below:

Kelp forests: Atmospheric dynamics offshore are closely linked to coastal conditions. Kelp forests, which are sensitive to freshwater input, may be impacted by changes in river dynamics

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[106] https://www.nature.com/articles/s43247-023-00780-y.pdf

and flooding due to climate change. For example, warmer atmospheric conditions and increased moisture content from climate change are expected to intensify precipitation and flooding events. Atmospheric rivers will also become more intense, delivering occasional large pulses of freshwater that could have both positive and negative impacts on ecosystems. However, offshore activities are not expected to directly impact this dynamic. Offshore wind developments are unlikely to significantly alter wind patterns beyond their immediate vicinity.

Pelagic: Climate variability has been shown to affect pelagic habitats in various ways. Increased upwelling and higher nutrient levels in upwelled waters are expected to enhance overall productivity, while declining oxygen concentrations present challenges for certain species, as already observed along the coast.

Regardless of the effect of offshore activities on climate variability, climate change will warm the environment and drive a shift toward a pelagic community more suited to warmer waters.

Sandy beaches: Sea level rise and reduced sediment input are expected to be the primary contributors to beach erosion, rather than offshore wind activities. Coastal areas are already feeling the effects of rising sea levels. For example, Washaway Beach is experiencing significant loss of beach area due to increased sea levels, reduced sediment flow, and the impact of Columbia River dams. The extent of beach erosion may vary across different regions. In some cases, dredging from offshore wind activities could help replenish beaches that have been heavily impacted.

Seafloor: In the southern part of the CCE and occasionally in the PNW, offshore wind activities and climate variability may lead to impacts near the seafloor. Increased productivity in these regions could result in higher rates of decomposition, lowering oxygen levels and causing fluctuations in pH. These changes in ocean chemistry could have significant consequences for shell-forming organisms. Furthermore, the increased ship traffic associated with offshore wind development raises the risk of spills, which may pose additional environmental risks

Rocky Shores: Offshore wind is unlikely to directly affect climate variability to detrimentally affect rocky shores.

Effect of offshore wind on climate variability and the effect on species movement. Although research on the impact of offshore wind on climate variability is limited, it is not expected to have a direct effect on climate patterns and thereby, effect species movement. Instead, the depending on the location of offshore wind development, species habitats and migratory pathways may be affected. The CCE Assessment will offer valuable insights by detailing the core and preferred habitats of various species, helping to understand these potential impacts.

Effect of offshore wind on climate variability and the effect on coastal circulations. There are deep currents with countercurrents that may evolve with climate change. Investigating these changes and assessing how offshore wind activities might affect coastal circulations is of interest.

Offshore aquaculture data gaps

- Effect of offshore aquaculture on long-term and short-term variability
- Effect of offshore aquaculture on climate variability and effect on various habitats and species

Effect of offshore aquaculture on long-term and short-term variability. Offshore aquaculture activities are unlikely to directly influence climate variability or significantly alter climate forcing or oceanographic conditions. However, their effects should be considered over different time scales. Short-term changes in ocean properties may differ from long-term trends, and the specific impact in any given area is not fully understood. More critically, understanding how cumulative impacts from offshore aquaculture may differ from long-term changes is essential. Monitoring these changes is feasible with current technology.

Effect of offshore aquaculture on climate variability and effect on various habitats and species. Offshore aquaculture is not expected to directly influence climate variability or significantly alter climate forcing or oceanographic conditions, especially in the absence of large-scale, extensive facilities. Climate variability is anticipated to have a more substantial impact on the shelf ecosystem as a whole compared to offshore aquaculture. However, offshore aquaculture could still have meaningful implications for how ecosystems respond to climate change.

Offshore aquaculture activities may exacerbate the local impacts of climate change. Climate change is expected to increase nutrient concentrations in coastal zones of the offshore region in the future. As ocean stratification intensifies, vertical exchange near the surface will decrease, causing nutrients from deeper waters below the mixed layer to remain more concentrated than in the past. Consequently, upwelled waters may have lower oxygen levels and higher concentrations of macronutrients such as nitrates and phosphates. If an aquaculture facility adds nutrients to the water in conjunction with the climate-driven increase in nutrients, it could worsen local eutrophication. The extent of the nutrient footprint from an aquaculture facility will vary depending on the species being farmed, particularly with finfish aquaculture. It is crucial to consider and limit this footprint. Additionally, long-term changes in ocean chemistry—such as shifts in nutrient dynamics and the base of the food chain—could have lasting consequences for the marine ecosystem, including potential effects on disease outbreaks. However, not all impacts will be negative, as aquaculture facilities may also serve as habitat.

Resources

Table 31. Resources relevant to climate variability.

NAME	ACCESS	TYPE	DESCRIPTION
California Current Integrated Ecosystem Assessment (CCIEA)	https://www.integratedecosystemassessment.noaa.gov/regions/california-current	Website	Contains news, highlights, reports, and project information relevant to the CCIEA.
Climate Vulnerability Assessment for Olympic Coast National Marine Sanctuary	https://www.noaa.gov/information-technology/climate-vulnerability-assessment-for-olympic-coast-national-marine-sanctuary-id473	Website	Provides information on an upcoming report that will summarize the outcomes of the Olympic Coast National Marine Sanctuary Climate Vulnerability Assessment workshop.
European Centre for Medium-Range Weather Forecasts	https://www.ecmwf.int/en/forecasts	Website	Provides global forecasts, climate reanalyses, and specific datasets.
Northwest Association of Networked Ocean Observing Systems (NANOOS)	https://www.nanoos.org	Website	Website for NANOOS, the Regional Association of the national Integrated Ocean Observing System (IOOS) in the Pacific Northwest.
Ocean Observatories Initiative's (OOI) Research Arrays	https://ooinet.oceanobservatories.org	Data portal	Provides data and information on the various research arrays used by OOI.
Projected cross-shore changes in upwelling induced by offshore wind farm development along the California coast	https://www.nature.com/articles/s43247-023-00780-y	Published article	Examines changes to upwelling using atmospheric and ocean circulation numerical models with a hypothetical turbine buildout scenario across three areas of interest.

NAME	ACCESS	TYPE	DESCRIPTION
Vulnerability to climate change of managed stocks in the California Current large marine ecosystem	https://www.frontiersin.org/articles/10.3389/fmars.2023.1103767/full	Published article	Assesses the vulnerability of 64 federally managed species in the California Current Large Marine Ecosystem to climate change.

Currents, Eddies, and Plumes

Key Data Gaps

General Data Gaps

- Processes that influence currents, eddies, or plumes
- Distribution and trend of currents, eddies, and plumes
- Monitoring of currents, eddies, and plumes

Offshore Aquaculture Data Gaps

- Effect of chemicals and waste from offshore aquaculture on currents, eddies, or plumes
- Effect of currents, eddies, and plumes on disease transmission from offshore aquaculture
- Effect of offshore aquaculture on detritus plumes

Other Data Gaps

General Data Gaps

- Data on eddies
- Data on extreme currents

Offshore Wind Data Gaps

- Effect of offshore wind on water flow
- Effect of offshore wind on detritus plumes
- Effect of offshore wind on the dynamics of base ocean properties

Offshore Aquaculture Data Gaps

- Effect of offshore aquaculture on water flow
- The role of currents, eddies, and plumes in the dynamics between offshore aquaculture and climate variability
- Effect of offshore aquaculture on detritus plumes

Background

The currents, tides, eddies, plumes, upwelling, and other physical features along Washington's Pacific coast profoundly influence habitat, fisheries, and other crucial services in these highly productive waters.

Currents are broad patterns of ocean flow driven by wind, variations in water density, and tidal forces.[107] The Pacific Northwest, including Washington's coast, is shaped by the California Current System (CCS), which consists of the strong, southward-flowing California Current offshore year-round and the northward-flowing California Undercurrent along the continental slope. It also features the northward Davidson Current in winter and the southward California Coastal Jet Current in summer. These currents vary in properties such as temperature, nutrients, oxygen, and salinity, which are influenced by the Pacific Subarctic, North Pacific Central, and Southern water masses.

Seasonal circulation patterns in the Pacific Northwest bring water properties from currents and strongly influence productivity, transportation routes for species, and ecological features. Upwelling, driven by currents and wind direction, pushes surface water offshore and replaces it with nutrient-rich water from below, primarily during spring and summer. This process enhances productivity in the photic zone, supporting phytoplankton and the marine food web. During the fall, there is a transition to downwelling which persists throughout winter. Further discussions and data gaps relating to upwelling is discussed in “Wind Driven Upwelling.”

Other factors influence ocean and coastal productivity along the Washington coast. Currents can generate circular movements of water known as eddies.[108] The Juan de Fuca Eddy is formed by outflow from the Salish Sea, characterized by high nutrient content, increased productivity and retention, and enhanced higher trophic-level biomass. Additionally, the Columbia River Plume also significantly influences productivity along Washington's Pacific coast. River plumes introduce fresh water, sediment, nutrients, carbon, and organic matter to the ocean. It affects water circulation, retention, and plankton and larval fish transportation. The Columbia River Plume’s orientation can vary; however, it is typically northward in winter during downwelling and southwestward in summer. This can differ during weak upwelling periods. While the plume generally provides fewer nutrients in summer, research suggests that it may sustain local ecosystems by supplying nutrients during periods of weak to no upwelling or during late spring transitions.

Another significant factor contributing to the higher productivity of the Washington coast compared to the rest of the Pacific Northwest, are coastally trapped waves. These waves are influenced by shelf slope, wind, and angular momentum; accelerate local longshore currents; and can extend as far south as central California.

[107] https://oceanservice.noaa.gov/facts/current.html
[108] https://oceanservice.noaa.gov/facts/eddy.html

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to currents, eddies, and plumes:

General data gaps

- Processes that influence currents, eddies, or plumes
- Distribution and trend of currents, eddies, and plumes
- Monitoring of currents, eddies, and plumes

Processes that influence currents, eddies, or plumes. The basic physics and causes of currents, eddies, and plumes are understood.

Currents: Currents are shaped by several factors, including tides, coastally trapped waves, Ekman Transport, and wind:

- Tides are categorized into two main types: the surface tide (barotropic tide), caused by changes in sea surface height, and the internal tide, which generates nonlinear internal waves within the water column.
- Coastally trapped waves are low-frequency waves that propagate along the coast and can be influenced by upwelling processes.
- Ekman Transport involves the cross-shelf movement of surface water, which can trigger upwelling. This process plays a key role in the distribution of nutrients and oxygen, while also impacting ocean acidification (OA) and pH levels.
- Wind is the primary driver of coastal currents, shaping the movement of surface waters along the coast.

Additionally, remote forcing—external processes influencing local conditions—can further affect wave dynamics, modifying how waves behave in coastal regions.

Eddies and plumes are a subset of currents.

Eddies: Eddies are circular features in ocean currents. They can trap anomalous water properties within their core. Typically occurring from May to October, eddies are known to be sources of higher nutrients, increased salinity, and can sometimes function as bioreactors, potentially generating harmful algal blooms (HABs).

The primary eddy off the Washington coast is the Juan de Fuca Eddy. This eddy is driven by wind and forms during the upwelling season. It is influenced by the water exiting the Strait of Juan de Fuca, as well as by the position of the Juan de Fuca Canyon and flows southward along the shelf. On the shelf, there are no persistent eddies because the water flow is predominantly unidirectional—either rapidly moving southward during upwelling or northward during downwelling. While there might be embedded circulations within these flows, the overall movement is consistent from north to south. As a result, changes occurring off Washington's coast are soon experienced in British Columbia or Oregon. The transport time scales vary depending on the year and depth, but typically, water moves at about 20 km/day. There are also recirculation zones, such as those south of La Push, which can play a crucial role in nutrient and larval retention.

Eddies are easier to trace, and their signatures can be observed using remote sensing techniques. Research is ongoing to analyze these features across different years. There is also some understanding of how eddies relate to species habitats and communities. For instance, some eddies enhance productivity, and certain species depend on them for nutrients, targeting and following them. Despite existing knowledge, there is still much to learn, particularly regarding how climate change may impact the mesoscale features of eddies.

Plumes: Plumes are typically confined to the shallow layer of the ocean, usually within the top 5-10 meters. The Columbia River Plume is the most significant plume in the region, and research has provided a solid understanding of its behavior and seasonal variations. Analysis of existing data offers valuable insights into its dynamics. During upwelling periods, this plume moves southward into Oregon, while during downwelling, it flows northward into Washington. Typically, this plume does not extend far offshore, usually reaching only tens of kilometers from the coast. It is distinguished by its nutrient-rich content and stratification, and its presence can be detected through salinity changes on the Washington shelf, as observed by instruments like the Cha'ba buoy. Minor river plumes also exist but are less prominent.

Anticipating the effects of specific climate-scale forces on these plumes is crucial. Freshwater from the Columbia River or sediment from the Quinault River can influence coastal properties. Although river discharge is well-monitored through an extensive network of gauges, predicting rainfall and sediment movement remains challenging. Measurement sites, such as the Quileute Tribe's mooring site, provide valuable data on temperature, salinity, and potentially sediment levels.

There is also insufficient data on how ocean waves influence currents, eddies, and plumes. These processes exhibit significant spatial and temporal variability offshore and are highly sensitive to wind conditions, which often drive their dynamics. Temperature also influences vertical circulations in the water column and affect oceanic processes. Maintaining a buoy in the ocean presents challenges, and with sensors placed approximately every 100 kilometers, the data obtained primarily offers insights into long-term trends rather than seasonal or daily variations. A study conducted in California compared data from sparsely placed buoys with model predictions, revealing significant discrepancies between the two.

A process study is also needed to understand the dynamics of these processes at a specific location. Key considerations include the accuracy of the existing list of processes, whether any processes are missing or inadequately represented by current models, the ability of the model to predict these processes, and the verification of the model's accuracy. For instance, although there is some ability to predict internal tides, this capability has not been thoroughly validated. Evidence indicates that models may struggle to accurately simulate internal tides, primarily due to a lack of data for proper verification. Models are generally more effective at predicting large-scale wind-driven currents. The accuracy of these models also depends on the boundary conditions, which are crucial for providing the correct signals. Global ocean models are also available; however, they often lack the resolution needed for detailed processes. Integrating high-resolution regional models into lower-resolution global models is necessary for accurate predictions.

Feedback on importance: The processes are well-established. There is an understanding of the key mechanisms at work. However, there is a need for further exploration of higher-order phenomena such as internal tides, nonlinear internal waves, coastally trapped waves, and flows influenced by topography near the shelf break. Additionally, accurate predictions remain challenging due to the significance of smaller scale forcing mechanisms that are difficult to monitor. Models are better suited to simulate the statistical characteristics of these events, albeit with limitations, rather than resolving individual features accurately.

> **WCMAC:** Seasonal wind patterns primarily drive currents, but tides and localized storm events also influence them. The introduction of large machines harvesting atmospheric energy could alter these currents. Modeling their potential impacts is essential, especially given the absence of local examples due to a lack of installations. Insights from the North Sea and other global developments can provide valuable lessons.
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> Fluctuating currents can have different impacts. For example, toxic algal blooms are often linked to warm water bodies and calmer currents in back eddies, such as those in the "blob." Concerns are mounting about potential man-made changes to current dynamics through ocean structures, particularly amid the effects of climate change. Understanding these changes, their causes, and whether new stressors may alter these dynamics is crucial.

Distribution and trend of currents, eddies, and plumes.

Distribution: There is limited understanding of the distribution of currents, eddies, and plumes in this region, particularly at the entrance to the Strait of Juan de Fuca and in the surrounding canyon areas. Observations in the Juan de Fuca Canyon are sparse, and current measurements are lacking. A recent cruise to the area revealed the complex nature of the canyons and the significant mixing occurring on the shelf, which influences water properties to the south, especially during upwelling events. Additional data are also needed on the mid-Washington shelf, south of the Olympic Coast National Marine Sanctuary, and in the Quinault Canyon, where information is currently absent. Canyons play a crucial role in shaping internal tides and mean currents and are essential for understanding the exchange between the deep ocean and the continental shelf, including the influence of river input, wind, and deep-ocean interactions.

Trend: There is no clear understanding of trends related to currents, eddies, and plumes. However, observed rainfall patterns show a trend of drier summers, wetter winters, and a decrease in snowpack, all of which could potentially impact plumes. Natural variability in these systems is considerable.

A warming trend is also beginning to emerge in Puget Sound, with potential insights from the Cha'ba buoy. With climate change, there is a growing emphasis on monitoring temperature and carbon dioxide (CO_2) levels. Some unverified trends are also emerging for the shelf, including potential declines in oxygen levels and signs of ocean acidification. While these trends have not been confirmed, a decrease in oxygen is likely, as warmer water naturally holds less oxygen than colder water. Additionally, warmer waters tend to increase metabolism rates in marine organisms, leading to higher oxygen consumption, which could further intensify the effects of warming on oxygen levels.

Historical data would be invaluable for understanding these changes over time. Efforts to compile comprehensive measurement datasets are ongoing, though long-term time series remain rare and challenging to obtain. Notably, a group has been conducting long-term measurements at Tatoosh Island, offering valuable data on pH and temperature trends, and NANOOS has recently been working to establish a long-term time series with the Cha'ba buoy.

Below is specific feedback on the distribution and trend for currents, eddies, and plumes:

> **Currents:** Currents can be influenced by tidal forces. While surface tides can be predicted with reasonable accuracy, internal tides are more challenging to forecast and may differ from model predictions. Additionally, the northern part of the coast is more complex compared to the southwest, where existing theories on coastal circulation are more applicable. To better understand the nuances of these systems, more detailed measurements are needed. Remote sensing tools, such as satellite products, offer some insight but have limitations in resolution and in capturing the temporal variability of processes driving current patterns. Seasonal variations affect data collection, with winter conditions posing challenges and leading to increased data gaps.
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> **Eddies:** Eddies can manifest in different regimes, with those near coastlines being bathymetrically controlled and influenced by the geography of the coastline. In the offshore area, eddies exhibit more random behavior. Although there is a statistical understanding and some field characterization of these eddies, research is still in its early stages. Remote sensing techniques have made it easier to trace and identify them. However, measuring eddies remains challenging due to the large spatial and temporal scales involved. Additionally, long-term monitoring is difficult, particularly during the northwest winter when data collection is especially challenging.
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> **Plumes:** There is a solid theoretical understanding of how plumes behave in simplified coastal environments. However, this understanding becomes more complex in intricate coastlines. Plumes exhibit transient features across a wide range of scales, making it essential to use modeling in conjunction with specific observations to fully grasp their behavior. Recent projects have focused on smaller plumes along the Northwest coast, primarily investigating how ocean waves impact their evolution and movement along the coastline. Circulation dynamics remain an active area of research.

Significant progress has been made in studying coastal circulation, but there is considerable variability in these processes depending on the location. The NANOOS system provides a current snapshot of the region’s conditions and is actively compiling all available measurements to offer a more comprehensive view of the data collection points across the area. However, measurements remain sparse, particularly along the northern Washington coast, where there is only one subsurface measurement point located more than two miles offshore. The Cha'ba buoy offers valuable subsurface profiling measurements of currents, temperature, and salinity. Other buoys are available for wave predictions.

Models can be used to either predict future conditions through forecast models or estimate past conditions using reanalysis or state estimate models. Validating these models will be essential to ensure their accuracy, given the limited number of measurements available across the vast ocean. However, given the limited data, it is essential to first understand the underlying physical processes, such as fluid dynamics theory, before using numerical models, like computer simulations, to explore ocean processes. Scientific papers are available to provide valuable insights into coastal physical processes.

Feedback on importance: There is currently a lack of information regarding trends in various oceanographic phenomena, which is crucial for assessing impacts on the ocean. For example, these features are key to transport processes and have been shown to influence the distribution of Harmful Algal Blooms (HABs). While some understanding of seasonal variability exists, long-term trends remain poorly understood. There is significant uncertainty regarding how the California Current Ecosystem (CCE) will respond to global warming—whether it will strengthen, weaken, or experience changes in seasonality remains unclear. Long-term studies are lacking, and there is insufficient data to comprehensively assess historical changes. While data from the summer of 2010 is available, there is a notable absence of winter data and long-term investigations. Additionally, validating numerical models would be highly beneficial.

WCMAC: The ocean features distinct currents with unique dynamics, and it is not a uniform body of water. Fish navigate this dynamic landscape, responding to constantly changing conditions. Much remains unknown about the intricate currents that sustain ocean health and productivity. Identifying definitive trends in ocean conditions is challenging. For example, there appears to be an increase in hypoxia, which may indicate changes in currents, but other stressors complicate the picture. Events like El Niño and La Niña episodically alter currents and marine life behavior.

One of the principal current systems, the California Current Large Marine Ecosystem (CCLME) stretches from Southeast Alaska to Mexico and is influenced by storms, weather, and seasonal dynamics. Within the CCLME, tidal plume currents vary in distribution and patterns. Understanding how stressors could alter this system is crucial, particularly before introducing new impacts. Evaluating potential effects requires considering the CCLME as an interconnected whole rather than in isolated segments. For instance, cumulative impacts from large-scale industrial structures could be significant. The Davidson Current, which flows opposite to the CCLME, also plays a vital role in this system. Upwelling brings nutrient-rich waters shoreward and surface currents like the Davidson aid in mixing these waters. The interactions among these systems are complex and not fully understood. Areas like the Columbia River, Grays Harbor, and Willapa Bay show rich oxygen levels, while locations further north, like Quileute, face lower oxygen levels and episodic hypoxia, suggesting less dynamic mixing. Disturbances, such as wind deficits, can affect these systems by reducing mixing and exacerbating hypoxia. There is a need for deeper exploration of these complex interactions.

Monitoring of currents, eddies, and plumes. Direct observations and short-term ocean model results provide valuable information on ocean currents and the transport of materials.

a. Direct observations

Direct observations are severely limited:

- The Cha'ba buoy off La Push offers data on currents and water properties, boasting the most complete velocity record from 2010 onwards. Velocity records are typically seasonal, covering periods from April/May to October, with occasional full-year records.
- The Ocean Observatories Initiative (OOI) operates 2 or 3 shallow profiling moorings, including at least one on the slope and another on the shelf. These moorings are funded through the National Science Foundation (NSF)and have been active for approximately 10 years. Operations in this region are challenging during the winter due to harsh environmental conditions. Recently, a mooring broke free amidst measured 25-foot waves. Specifically, the Washington Inshore Surface Mooring[109], offer real-time data collection.
- There is a NOAA mooring, the Cape Elizabeth buoy[110], which provides data on sea surface observations including temperature and salinity.
- There are ten mooring sites within the Olympic Coast National Marine Sanctuary, spanning from inshore (20m) to offshore depths (42m, sometimes 60m). These moorings typically operate seasonally from April to October. However, velocity data is rarely collected, with a current meter deployed once or twice in the past decade.

These moorings provide data at sporadic intervals rather than continuously in real-time. This creates a significant data gap for real-time information. Only the Cha'ba buoy and OOI moorings provide velocity information that are publicly available. Direct velocity measurements are crucial for understanding currents, eddies, and plumes, as velocity directly influences how water moves.

There are other monitoring assets:

Glider: Since 2011, a glider funded through NANOOS/IOOS has been operational. It conducts transects rather than continuous operations.

Landers: A lander is an underwater device equipped with tools and sampling devices and can collect data such as sea water samples and images. [111] The Quileute Tribe's landers have current meters that profile the water column at depths of 40m and 60m off La Push and provide real-time velocity data. Year-long records are collected with each deployment, and the landers are redeployed every spring. The collected data is accessible through NANOOS. This effort represents one of the longest continuous time series, spanning through winter, and has revealed the intensity of velocities during storms, reaching speeds of up to 4 knots at these depths. Prior to this initiative, there was limited understanding of the water's speed during storms.

[109] https://oceanobservatories.org/site/ce06issm/
[110] https://www.ndbc.noaa.gov/station_page.php?station=46041
[111] https://schmidtocean.org/technology/elevators-landers/

High-frequency (HF) radar: The Mapping Coastal Ocean Currents project[112] uses HF radar along the west coast to provide real-time monitoring, offering valuable insights into ocean dynamics. HF Radar operates from shore sites, emitting radar signals to detect surface currents. It exclusively captures surface currents and is constrained by limited horizontal resolution. It provides data points every 1 or 2 kilometers. Despite these limitations, it effectively gathers surface current information across a broad area of the continental shelf. Currently operational in Oregon, its coverage is expanding northward to Washington, reaching up to Willapa Bay.

b. Short-term Ocean Modeling

A wealth of information is available for short-term forecasting, and assuming the models are reasonably reliable, they prove to be valuable resources. Several models, including LiveOcean[113] and HYCOM[114] (which LiveOcean uses for boundary conditions), are available for this purpose. LiveOcean is currently undergoing enhancements, though the latest version has yet to be released to the public. At present, the model struggles to accurately depict reversals in deep currents. For instance, during the summer, deep water on the shelf flows north while surface water moves south—a phenomenon LiveOcean does not capture effectively. Other models, like Nucleus for European Modeling of the Ocean[115] (NEMO), lack local resolution but assimilate data from various sources. While NEMO operates at lower resolutions in both time and space compared to LiveOcean, it can capture some current reversals.

There are also that use satellite data, specifically satellite altimetry, to derive sea surface height and infer currents. However, satellite altimetry has its limitations, particularly in nearshore regions. Efforts are underway to enhance this capability. For example, NASA's SWOT (Surface Water and Ocean Topography) leverages satellite altimetry to estimate geostrophic currents—currents influenced by the Earth's rotation and pressure gradients caused by sea surface slopes. SWOT is expected to improve the understanding of coastal areas.

Models offer comprehensive 3D spatial and temporal coverage but are limited by vertical, horizontal, and temporal resolution, preventing them from fully replicating real-world conditions. For example, models struggle with simulating internal tides due to their formation in local and remote regions such as Hawaii, California, and Alaska. Current models lack boundary condition inputs necessary to capture these remote internal tides, limiting their ability to accurately represent their influence. This limitation is significant as internal tides play a crucial role in shaping currents on the continental shelf.

Moreover, models also often fail to capture complex features, such as nonlinear internal waves and intense storm events. These waves can generate strong currents, with vertical currents of 5 to 10 meters and horizontal currents reaching speeds of up to a meter per second—far higher than the average current speed of 0.3 meters per second. While moorings can capture these

[112] http://bragg.ceoas.oregonstate.edu/
[113] https://faculty.washington.edu/pmacc/LO/LiveOcean.html
[114] https://www.hycom.org/
[115] https://www.nemo-ocean.eu/

phenomena, models often are unable to because they require sampling at a high enough frequency for accurate representation.

Additionally, models often don't reflect the ecological importance of currents, such as their role in mixing nutrients and oxygen or concentrating food sources. For example, LiveOcean lacks the resolution to accurately simulate these dynamics. Many models also rely on hydrostatic assumptions, treating water as incompressible, which simplifies calculations but does not reflect the more complex, nonhydrostatic conditions that better represent the chaotic ocean environment.

The ocean is inherently turbulent, with currents constantly evolving and no two waves behaving the same. As a result, models are imperfect and often struggle to capture this complexity fully. Ongoing projects are dedicated to improving model accuracy, but observations remain limited, with few providing real-time data.

Feedback on importance: This data gap requires more observations. This is a high priority. There is extremely limited monitoring on the Washington shelf, which covers a vast area. Both spatial and temporal data are needed to gain a better understanding. Additionally, profiling moorings have been offline for over a year and a half, resulting in a significant gap in observations. Overall, the data available for this region is very sparse.

> **WCMAC:** Baseline information and data collection on West Coast current dynamics must be expanded. Comprehensive surveys are essential for assessing ocean productivity and identifying potential disruptions to survey protocols. It is also necessary to intensify monitoring efforts for specific aspects and incorporate additional considerations into the monitoring framework, such as changes in nutrient concentrations, aquatic species in the water column, and oxygen levels. Additionally, enhancing measures of ocean health and productivity—such as evaluating larval populations, early life cycles, and various aquatic species—is critical.
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> Robust monitoring is particularly vital to detect and mitigate ecological damage if ocean structures are installed regionally without a thorough understanding of potential cumulative impacts. Projects should not proceed without preemptive modeling of impacts. Nevertheless, if development occurs, establishing baseline information and monitoring is critical to track changes in atmospheric conditions, wind deficits, wake effects, and alterations in stratification and currents. These factors can influence upwelling patterns and the mixing of nutrient-rich and oxygenated waters, potentially leading to hypoxia events. Viewing monitoring as a mitigation strategy is misguided; it is essential for understanding impacts from the outset. Relying solely on monitoring, modeling, and measurement as mitigation tools will not effectively prevent detrimental ecosystem and socioeconomic consequences.

Offshore aquaculture data gaps

- Effect of chemicals and waste from offshore aquaculture on currents, eddies, or plumes
- Effect of currents, eddies, and plumes on disease transmission from offshore aquaculture
- Effect of offshore aquaculture on detritus plumes

Effect of chemicals and waste from offshore aquaculture on currents, eddies, or plumes. Offshore aquaculture is unlikely to affect the physics of currents, eddies, and plumes; however, there are concerns about its potential ecological impacts. While the scale of offshore aquaculture may not be sufficient to cause significant changes, added nutrients may cause localized effects on the shelf. Inputs of carbon and nutrients can influence ecosystem pH and carbon exchange with the atmosphere. Changes in water alkalinity, such as calcium carbonate levels, can shift carbon fluxes between the atmosphere and ocean. Alterations in sunlight absorption in shallow layers can lead to surface warming and stratification. Additionally, in areas with concentrated aquaculture activity and limited water circulation, excess nutrients from operations can lower oxygen levels, impacting local fisheries. Salmon aquaculture in fjords poses challenges due to prolonged residence times and slow flushing rates caused by weak currents. Monitoring oxygen levels, especially at the seabed, is difficult as measuring tools can become buried over time. The effect of chemicals and waste also varies depending on the species being raised and the operational practices involved. Shellfish farming is unlikely to have a significant impact, whereas farming fish with specific diets could pose uncertainties. How pollutants or tracers disperse in these scenarios is not fully understood.

Feedback on importance: This data gap is likely more applicable to finfish aquaculture and less so to kelp aquaculture.

> **WCMAC:** Aquaculture operations may not directly alter currents, eddies, or plumes; however, the impact may depend on the type of aquaculture and the species being cultivated. For example, a large kelp aquaculture operation near an estuary or covering a significant area could influence local currents and vice versa. Additionally, while one could argue that individual operations won't cause changes, currents, eddies, and plumes can transport potential stressors introduced by aquaculture across varying distances, thereby expanding their footprint.

Effect of currents, eddies, and plumes on disease transmission from offshore aquaculture. Disease outbreaks at aquaculture facilities can occur suddenly, with bursts of pathogen potentially causing different impacts than steady sources. While there is limited expertise on disease transmission, Harmful Algal Blooms (HABs) serve as a reference. These blooms typically arise in topographic features where phytoplankton thrive. A mechanism is needed to transport these blooms to areas where they impact human populations. Small changes in current patterns could have an impact on this transport, but accurately predicting these changes is challenging. In aquaculture, diseases like sea lice are typically contained within fjords, where circulation is limited. On the other hand, contaminated salmon in shelf environments have a much higher dispersal potential, capable of reaching California within a week, illustrating the greater spread that can occur in open shelf waters.

Feedback on importance: This data gap is likely more applicable to finfish aquaculture and less so to kelp aquaculture.

> **WCMAC:** The effect on disease transmission largely depends on the mechanisms of transport and dispersion. The footprint of these impacts could extend well beyond the immediate facility area. There are concerns, particularly regarding the introduction of non-native species. Diseases carried by non-native species may significantly differ from those affecting native species, potentially devastating populations that lack immunity. Furthermore, the ability of various species to withstand newly introduced diseases varies, and the spread and effects of parasites specific to certain animals remain uncertain.

Effect of offshore aquaculture on detritus plumes. Increasing nutrient loading may affect detritus plumes, but this is difficult to ascertain. The extent of mixing and how offshore aquaculture will influence detritus settling at the site is unknown. Infrastructure development may stir sediment or alter river flows affecting plumes. The effect will depend on the volume of detritus involved, with effects potentially extending beyond local areas and spreading downstream or regionally. Nutrient loads generated by these facilities, which may fluctuate between consistent low levels and occasional surges, will need to be carefully evaluated.

Upwelled water, rich in nutrients, may also contribute to detritus and cause localized hypoxia. In this region, nutrients in upwelled water may be in particulate form rather than dissolved. Vertical and horizontal mixing can introduce oxygenated water, which helps offset the localized oxygen depletion caused by bacteria that consume oxygen and produce CO_2. However, if bacterial oxygen consumption exceeds the supply of oxygenated water, hypoxia may occur. Storms can complicate this process by reversing currents, shifting hypoxic zones, and placing added stress on local organisms.

Feedback on importance: There is an interest in how detritus plumes will be affected. Whether large pulses or gradual releases, offshore aquaculture may have varying effects. A steady, small stream may not have a significant impact. However, a large pulse that could potentially harm nearby species could be problematic.

> **WCMAC:** Chemicals introduced into the water system can be transported significant distances by currents. For example, the 1989 Nestucca Oil Barge Spill near Grays Harbor released heavy oil that was carried by winds, tides, and currents to the northern tip of Vancouver Island. With oil reaching Vancouver Island through subsurface pathways, this incident demonstrates that toxic plumes, regardless of their source, can travel extensive distances.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Data on eddies
- Data on extreme currents

Data on eddies. Eddies represent weaker and less predictable components of ocean currents, exhibiting greater randomness than models typically forecast. Some eddies, such as the Juan de Fuca Eddy, are influenced by the surrounding topography and contain trapped bodies of water. These eddies appear regularly and can significantly affect their environment. While the formation is relatively understood, specific mechanisms remain unclear and are an area of ongoing research. Current models can provide general statistics, such as the average size of eddies in specific regions, though additional validation is needed. Some eddies can be detected in satellite imagery, allowing for partial verification. Near the coast, eddies tend to be smaller and are less detectable by satellite imagery. In contrast, river plumes are more easily visible from satellites.

A new satellite, Surface Water and Ocean Topography (SWOT), collects data on sea surface height across lakes, rivers, and oceans. The satellite captures a snapshot of the Earth every 20 to 21 days. However, distinguishing between internal waves, currents, and eddies from this data remains a challenge. NANOOS is interested in acquiring a high frequency (HF) radar system, which can provide surface current data up to 100 miles offshore. Such radars are already installed off California and Oregon. There are plans to develop additional sites along the Washington coast, pending land availability and permits. This radar technology will be valuable for assessing the impacts of wind and aquaculture on ocean currents.

Eddies often concentrate materials, leading to heightened biological activity and making them important hotspots for trophic interactions. Research on the Juan de Fuca Eddy has focused on HABs and domoic acid, revealing higher concentrations of phytoplankton associated with certain HABs. This data can aid in predicting HAB events. At the Cha'ba site, a new prototype automated HAB processing system is being tested. This system utilizes an Environmental Sample Processor for chemical and genetic analysis, designed to identify HABs, and may be deployed in additional locations.

Data on extreme currents. There are few measurements available for extreme current conditions, and the limited data that does exist is often flagged as anomalous due to its deviation from expected norms. While average conditions are well understood, engineers require information on extremes, which is more challenging to obtain. The ocean environment contains significant energy and variability that must be accounted for.

Offshore wind data gaps

- Effect of offshore wind on water flow
- Effect of offshore wind on detritus plumes
- Effect of offshore wind on the dynamics of base ocean properties

Effect of offshore wind on water flow. It is possible for offshore wind to influence water flow, but the extent of this effect is currently a topic of active research.

Offshore wind installations may not necessarily obstruct currents enough to produce significant effects. The effects will depend on the density, shape, and size of the structures. The critical factors are the air effect, which refers to the amount of wind energy extracted by the rotors, and the wake effect, which influences ocean mixing. The influence from cables is negligible.

The primary concerns are the platforms and the energy extracted by the turbines. Low-pressure zones behind the structures could generate downstream eddies, enhancing lateral and vertical mixing. If offshore wind facilities were spaced every 10 feet across the shelf, they could influence currents, but the extent of the effect would depend on various factors. While there may be measurable effects, the shelf is expansive and currents can be robust, making scale a critical consideration.

If the water flow in an area is highly responsive, such that changes in residence time can lead to significant impacts on environmental or ecological conditions, even minor engineering changes could have a substantial effect. However, these effects are unlikely to be significant for the coast in its entirety. In areas like the Juan de Fuca canyon with stronger currents, restricting flow could alter the magnitude and direction of water flow. However, numerous offshore wind structures would be necessary to affect water transport.

The structure’s region of influence may be limited. Around the structure, flow patterns may accelerate or decelerate, but the overall net flow may remain unaffected. Water will inherently establish a pressure gradient to mitigate the effect, resulting in a self-correcting situation. A starting point would involve creating a model simulation where drag can be adjusted. There is a theory that the Bay of Fundy experiences large tides due to the bay's shape and length. Though this theory remains untested, installing enough turbines could potentially introduce sufficient drag to alter a bay's resonance properties.

Effect of offshore wind on detritus plumes. Offshore wind is unlikely to significantly impact detritus plumes. However, if it alters the mixing dynamics of the upper ocean, it could affect the settling rate and suspension of detritus, potentially deviating from natural conditions. For instance, the speed of currents can influence the rate of sediment accumulation. Offshore wind could influence the timescale of mixing and water movement around a wind farm, which requires further investigation. The scope of this effect should be assessed in relation to the settling of detritus.

It is uncertain whether the installation of offshore wind structures will directly influence sediment movement in this environment, and, in turn, affect detritus plumes. The shelf is generally wide and flat with few natural features, though occasional rocky spots provide habitat for additional life. Sediment movement in these areas is driven by low pressure and the strength of currents, which can reach up to 1 meter per second on the shelf. Landers placed at 37 meters were buried due to sediment transport, indicating significant movement in the area. Additionally, structures like anchors often create oases for species by offering surfaces for organisms to attach to. Further research is needed to understand the potential impacts of offshore wind structures on sediment dynamics and detritus plumes in this region.

Effect of offshore wind to the dynamics of base ocean properties. Eelgrass helps mitigate stress on the seafloor from ocean currents by forming a dense array of vegetation, providing a refuge for larvae to settle. Similarly, the presence of an offshore wind array could have a range of effects. Modeling is required for a more thorough understanding.

One of the most significant potential impacts is that a sufficiently large wind farm could reduce wind stress. A decrease in wind stress could dampen internal waves, leading to reduced vertical mixing and, in turn, weakening surface currents and waves. Offshore wind may also cause water to diverge, leading to localized upwelling within the array.

Changes in mixing patterns can influence the local dynamics of the water column, affecting its density stratification—the layering of water at different depths. These alterations in stratification may, in turn, shift the distribution of water properties, such as temperature, nutrients, salinity, and light availability at various depths. How offshore wind structures will impact local mixing is unknown. It is important to consider whether these structures might divert flow entirely around the wind farm, and how such flow alterations could influence water column density and, by extension, water properties.

While small offshore wind farms are likely to have minimal effects, larger farms could have more noticeable impacts. However, even large wind farms are unlikely to cause significant disruptions, as a substantial number of obstacles are required to block wind and water flows. A few hundred wind turbines are unlikely to have a noticeable impact, at least along the entire Washington coast. Additionally, the cables connecting the turbines will likely be bundled together, settle into the sediment, and run out to various nodes, posing minimal problems.

The primary concern with offshore wind installations is not the extraction of wind energy at climatological levels, but rather how these structures might disrupt oceanographic behavior. While ecological consequences may not be significant, understanding these potential disruptions remains crucial.

Offshore aquaculture data gaps

- Effect of offshore aquaculture on water flow
- The role of currents, eddies, and plumes in the dynamics between offshore aquaculture and climate variability
- Effect of offshore aquaculture on detritus plumes

Effect of offshore aquaculture on water flow. Offshore aquaculture structures may not sufficiently obstruct currents to significantly affect water flow. However, there is potential for an effect. The scale and density of these structures are crucial factors. For example, with kelp farming, dense patches of kelp can create drag, diverting water around rather than through them, potentially altering flow patterns even over a 1 km x 1 km area. The effect will also depend on the location of the offshore aquaculture site. Certain locations, such as the Quinault Canyon, have topographies that channel and direct flow in specific directions. Altering the structure of the seafloor in these areas could potentially disrupt these flow patterns. As modifications in one area can influence the entire current, such changes may also impact net transport to the coast. Canyons, being sensitive conduits, could be particularly vulnerable to offshore activities. However, more research is needed to fully understand whether these locations are indeed sensitive to such changes.

The role of currents, eddies, and plumes in the dynamics between offshore aquaculture and climate variability. The current understanding of the relation between offshore aquaculture activities and climate variability remains incomplete. There are numerous unknowns, including significant uncertainty regarding future environmental conditions. Various factors, such as changes in ocean temperature and circulation at a regional scale due to climate change, could potentially alter the landscape. Shifts in wind patterns may also increase exposure to heat waves and sea level rise represents a notable concern, particularly for coastal regions.

Changes in water quality, wind patterns, temperature, and precipitation could all potentially impact aquaculture operations. Understanding how aquaculture operations will respond to these changes is crucial. For instance, if kelp impedes water flow and reduces flushing, it could exacerbate warming during heat waves. Heat can become trapped in water surrounded by kelp, potentially intensifying temperature increases. Additionally, the color and composition of the kelp could influence its ability to absorb heat, further affecting local conditions.

These connections can be studied through existing research and resources. Studying phenomena like the El Niño-Southern Oscillation (ENSO) cycles may provide insights into how aquatic systems respond under different climatic conditions. This approach serves as a valuable method for testing models that simulate various environmental scenarios. The University of Washington has datasets researchers can use to explore how mesoscale features interact with larger-scale phenomena such as the ENSO. There is also research[116] focusing on transport pathways originating from hot spots of HAB formation. Seasonal variations were identified in these pathways, with prevailing wind-driven currents responsible for transporting materials from northern and southern sources to the Washington coast. *Id*. Additionally, a 2003 study[117] constructed an updated synthesis of large-scale current patterns and water properties of the PNW coastal zone and their variability. Productivity was observed to be higher off the coast of Washington despite upwelling-favorable wind stress being stronger off the coast of Oregon than Washington. Possible reasons include wider, gently sloping shelves promoting upwelling of nutrient-rich deeper waters, submarine canyons boosting upwelling, and the influence of micronutrients like iron from the Columbia River plume.

[116] https://agupubs.onlinelibrary.wiley.com/doi/10.1002/2013JC009622

[117] https://www.researchgate.net/publication/225446295_Oceanography_of_the_US_Pacific_Northwest_Coastal_Ocean_and_estuaries_with_application_to_coastal_ecology

Effect of offshore aquaculture on detritus plumes. To evaluate the effect of offshore aquaculture on detritus plumes, it is essential to analyze the nutrient loads generated by nearby facilities, which may vary and potentially surge. Predicting the effects of nutrient loading is complex, especially since upwelling events already introduce substantial amounts of nutrient-rich water.

Activities like construction can also disrupt sediment and alter water flows, potentially affecting how these detritus plumes behave. If detritus, or particulate carbon, settle in water bodies, it can lead to localized hypoxia. Hypoxia can arise when oxygen depletion exceeds the influx of oxygen-rich water, a process influenced by both vertical and horizontal mixing. Storms can complicate this by reversing currents, redistributing hypoxic zones and potentially stressing aquatic life in those areas. Beyond causing hypoxia, these plumes can also facilitate the transmission of diseases by carrying detritus throughout the water column.

Resources

Table 32. Resources relevant to currents, eddies, and plumes.

NAME	ACCESS	TYPE	DESCRIPTION
Hindcasts of potential harmful algal bloom transport pathways on the Pacific Northwest coast	https://agupubs.onlinelibrary.wiley.com/doi/10.1002/2013JC009622	Published article	Investigates transport pathways from known HAB formation hot spots to the coast.
HYbrid Coordinate Ocean Model (HYCOM)	https://www.hycom.org/	Website	Provides information and data collected through the ocean model HYCOM.
LiveOcean	https://faculty.washington.edu/pmacc/LO/LiveOcean.html	Website	Provides the output of a computer model simulating ocean biology and chemistry.
Mapping Oregon Coastal Ocean Currents	http://bragg.ceoas.oregonstate.edu/	Website	Provides maps of ocean surface currents, measured with a radio transmitter and receiver.
NASA: Surface Water and Ocean Topography (SWOT)	https://swot.jpl.nasa.gov/	Website	Provides data, information, and resources associated with NASA's global survey of the Earth's surface water.

NAME	ACCESS	TYPE	DESCRIPTION
National Data Buoy Center: Station 46041 – Cape Elizabeth – 45NM NW of Aberdeen, WA	https://www.ndbc.noaa.gov/station_page.php?station=46041	Website	Contains data and information on the Cape Elizabeth buoy.
Nucleus for European Modelling of the Ocean (NEMO)	https://www.nemo-ocean.eu/	Website	Provides access to NEMO, a modelling framework used for research activities and forecasting services in ocean and climate sciences.
Oceanography of the United States (US) Pacific Northwest Coastal Ocean and estuaries with application to coastal ecology	https://www.researchgate.net/publication/225446295_Oceanography_of_the_US_Pacific_Northwest_Coastal_Ocean_and_estuaries_with_application_to_coastal_ecology	Published article	Constructs an updated synthesis of large-scale current patterns and water properties of the Pacific Northwest coastal zone and their variability.
OOI: Washington Inshore Surface Mooring	https://oceanobservatories.org/site/ce06issm/	Website	Provides information on the Coastal Endurance Washington Inshore Surface Mooring, designed to examine coastal-scale phenomena.

Harmful Algal Bloom

Key Data Gaps

General Data Gaps

- Offshore monitoring of Harmful Algal Blooms (HABs)
- Factors that influence toxin production of HABs

Offshore Wind Data Gaps

- Effect of offshore wind on upwelling and the effect on HABs
- Effect of offshore wind on HAB distribution
- Enhancing HAB monitoring through offshore wind

Offshore Aquaculture Data Gaps

- Monitoring the effect of offshore aquaculture on HABs

Other Data Gaps

General Data Gaps

- Temporal and spatial trends of HABs
- Relationship of HABs with environmental parameters
- Effect of HABs on other species
- New and emerging HABs
- Termination of HABs
- Monitoring of environmental parameters for HABs

Offshore Wind Data Gaps

- Effect of offshore wind structure on HABs
- Effect of offshore wind on presence and abundance of HAB species
- Effect of electromagnetic fields from offshore wind on HABs
- Effect of light and shade from offshore wind structures on HABs

Offshore Aquaculture Data Gaps

- Effect of offshore aquaculture on presence and abundance of HAB species
- Effect of nutrients, waste, and chemicals from offshore aquaculture on HABs
- Effect of offshore aquaculture structure on HABs

Background

Phytoplankton in nutrient-rich environments can proliferate, with some types producing toxins harmful to marine life and humans. *Pseudo-nitzschia spp.* produces domoic acid causing amnesic shellfish poisoning. *Alexandrium cantenella* produces neurotoxin saxitoxin causing paralytic shellfish poisoning, and *Dinophysis spp.* produce okadaic acid causing diarrhetic shellfish poisoning. Consumption of shellfish contaminated with these toxins can lead to severe illness and fatalities in humans. Harmful algal blooms (HABs) arise when toxin-producing phytoplankton reach critical concentrations.

HABs along the coast are driven by natural factors such as nutrient-rich conditions in the Juan de Fuca Eddy, enhancing productivity. Variable winds and upwelling/downwelling dynamics drive the movement of these blooms toward shore, contaminating shellfish harvesting areas. The northern part of the Study Area typically experiences the highest toxin levels during the summer and fall. Southern Washington beaches are also impacted, with potential sources of toxic phytoplankton including the Juan de Fuca Eddy and Heceta Bank (Oregon). While the Columbia River Plume may act as a barrier to HABs on southern beaches in summer and fall, it can also serve as a conduit in winter and spring, leading to periodic shellfish closures. Suspected increases in HAB frequency across the Study Area may be linked to reduced Columbia River Plume outflow, caused by dams and climate change. In 2015, a significant West Coast HAB, possibly the largest on record, extended from central California to Alaska, influenced by the Pacific Ocean's warm "Blob."

Fish and shellfish can accumulate these toxins by filtering contaminated water, posing risks to human health if consumed. Exposure to humans and animals can happen through ingestion of contaminated fish and shellfish, inhalation, or skin contact with contaminated water. The Food and Drug Administration (FDA) establishes safety thresholds for toxins in shellfish to protect consumers from harmful levels of contamination. When toxin levels in shellfish exceed safety limits, shellfish harvesting is restricted, and state beaches close to shellfish harvest. Marine waters also close to recreational and commercial crab fishing to protect public health.

The Olympic Region Harmful Algal Blooms Partnership (ORHAB) and coastal Tribes monitor phytoplankton and toxin levels in water and shellfish tissue. Coordinated by the Olympic National Resources Center, the partnership includes the Washington State Department of Health (DOH), WA Department of Fish and Wildlife (WDFW), and the Quinault Indian Nation, among others. Quileute Tribe, funded separately, submits samples to DOH, and results are published by WDFW.

In relation to climate change, there has been an observed increase in the frequency and geographic spread of HABs over the past three decades, leading to a rise in human illnesses linked to algae-related toxins. The "Blob" phenomenon in 2015 necessitated shellfish fishery closures across the West Coast, causing significant socio-economic impacts including delays in the opening of commercial and recreational crab fishing seasons. These HABs associated with the Blob may serve as a precursor of future climate change impacts. Predicted increases in air and sea surface temperatures due to climate change could result in earlier onset and longer duration of HABs. In particular, DOH is concerned that HABs and occurrences of *V. parahaemolyticus* may intensify in frequency, duration, and severity due to increasing water temperatures. Elevated temperatures could lead to the emergence of more potent toxins and pathogens, potentially causing substantial economic losses to the industry.

In addition to increasing temperatures, HABs may also be influenced by other factors such as wind-driven upwelling, and nutrients from land runoff. Changes in snowmelt and freshwater inputs may shift runoff into coastal estuaries. The Juan de Fuca Eddy acts as a source of toxic cells and blooms, transported to Washington's coast by currents, winds, and upwelling trends. Climate change impacts on factors, including wind, can potentially alter bloom frequency and transport from the eddy to coastal waters. Additionally, phytoplankton growth depends on temperature, light, and nutrient availability, impacting HAB frequency and duration. Different HAB species respond variably to climate shifts; dinoflagellates, able to swim and access deeper nutrients, are expected to benefit from these changes compared to other phytoplankton species.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to harmful algal blooms:

General data gaps

- Offshore monitoring of HABs
- Factors that influence toxin production of HABs

Offshore monitoring of HABs. Since 2018, there has been an increase in offshore data collection efforts. Much of this data is still in its early stages, including the Environmental Sample Processor (ESP) mooring. ESP mooring is the sole operational offshore platform used for data collection. This mooring is located off La Push within the Olympic Coast National Marine Sanctuary (OCNMS) and the Quileute Indian Tribe's Usual and Accustomed (U&A) fishing areas. This mooring has been delivering real-time data on *Pseudo-nitzschia* and domoic acid levels since 2016. Aquatic drones are also employed for offshore data collection. Some offshore activities are conducted by ORHAB and its partners. ORHAB does phytoplankton monitoring. It conducts water sampling to detect toxin-producing plankton, providing early warning of HABs risks and guiding the frequency of shellfish sampling. DOH collaborates with the University of Washington (UW) and NOAA through ORHAB initiatives. Additionally, ORHAB uses an ESP equipped with DNA-based technology to detect harmful algae in water samples. UW has also launched initiatives to deploy autonomous vehicles in the Juan de Fuca eddy, aiming to enhance early warning capabilities. These deployments have provided valuable insights.

Other data collection efforts are either still in development (e.g., autonomous vehicles), limited to research cruises, or opportunistic by leveraging other initiatives (e.g., Imaging FlowCytobot (IFCBs) or volunteers on fisheries surveys). IFCBs are robotic microscopes installed on NOAA fishery vessels, monitoring phytoplankton community structures during routine fishery surveys. These devices survey the entire phytoplankton community, both harmful and non-harmful species, to understand the occurrence of harmful species and the environmental factors influencing their blooms. Since these cruises or surveys occur only at specific times of the year, they provide spatial snapshots but may not always capture the optimal conditions for observing HABs. Recently, there has also been progress in leveraging IFCB data from fisheries surveys to fill offshore data gaps.

Along the coast, shellfish tissue and phytoplankton data are obtained through collaboration with WDFW and Tribes. There are good efforts on sampling beaches and harvesting areas which are part of a routine program. Beach sampling occurs biweekly during the summer and weekly starting in November, reflecting changes in seasonal patterns. Data collected from these samples include cell counts of harmful species, presence or absence of phytoplankton, as well as temperature, salinity, and chlorophyll levels. Razor clams and mussels are also regularly collected to test for biotoxins, with samples needed every two weeks. Compared to other coastal regions, coverage on the Olympic Peninsula is less comprehensive. There are significant spaces between sampling sites where testing is not conducted. Consequently, areas without sampling are closed year-round as a precautionary measure.

Despite these advancements, regular and consistent data collection remains a challenge. Efforts are needed to fill data gaps in the upwelling zone, as well as nearshore and offshore areas. This includes the critical task of mapping algal bloom cyst beds, as current efforts to identify cysts and potential bed locations along the Washington coast are insufficient. Comprehensive mapping is also essential to understand how HABs respond to offshore versus nearshore conditions and their seasonal variations. Enhancing these mapping initiatives would provide valuable insights. Additionally, consistent offshore data for advanced HAB warnings is lacking. Exploring the potential to deploy equipment on offshore infrastructure could offer valuable opportunities for improved monitoring.

Feedback on importance: Increased monitoring is essential. There are significant data gaps. Comprehensive data collection is imperative to address these gaps, enhance early warning systems for HABs, safeguard human health, and establish baseline data for various activities.

Factors that influence toxin production of HABs. Various factors such as wind, stratification, temperature, and nutrient availability can influence toxin production in HABs. For instance, strong winds can transport a bloom into a bay, potentially causing toxicity in that area. Freshwater inputs can either inhibit or promote the growth of specific species. Additionally, competitive interactions play a role in domoic acid production, enabling certain phytoplankton to outcompete others. Factors like nutrient limitation, light availability, and seasonal variations are also known to influence toxin production. While there is a foundational understanding of these factors, ongoing research continues to explore the nuances and variations involved in toxin production by HABs.

Previous research, both in field and laboratory settings, has provided insight into the conditions that promote bloom formation and toxin production. This involves a complex interplay of multiple parameters. For growth, *Pseudo-nitzschia* requires specific nutrients, particularly nitrogen, for domoic acid production. Additionally, temperature fluctuations and marine heatwaves can impact their geographic range and growth rates. Numerous studies have examined the relative importance of these factors in different regions, offering a nuanced understanding. However, predicting these dynamics remains challenging. For example, ocean acidification (OA) has been shown to enhance toxin production in certain species, but its effects can vary depending on the species' growth stage and nutrient availability. More research is needed to fully understand these interactions. There is still significant opportunity to improve the understanding of the key factors influencing *Pseudo-nitzschia* dynamics off the coast of Washington.

Feedback on importance: HAB events necessitate the optimal combination of temperature, light, nutrients, stratification, and oxygen. Each bloom varies, and there remains considerable unknowns. It is crucial to identify the key drivers relevant to the Washington region, including competition with other species.

Offshore wind data gaps

- Effect of offshore wind on upwelling and the effect on HABs
- Effect of offshore wind on HAB distribution
- Enhancing HAB monitoring through offshore wind

Effect of offshore wind on upwelling and the effect on HABs. How offshore wind will affect upwelling, and consequently, how HABs will react and manifest along the coast is unknown. However, the relationship between HABs and upwelling is understood. Upwelling supplies the nutrients that fuel these blooms. Hence, any alteration in upwelling patterns could potentially influence HAB events, although the magnitude of this impact would depend on the scale of the offshore wind infrastructure. Initially, one might hypothesize that offshore wind could reduce the occurrence of HABs. However, *Pseudo-nitzschia*, for example, demonstrates a robust ability to assimilate nutrients, particularly nitrogen, at a higher rate compared to other phytoplankton species. Whether they can outcompete others remains uncertain. There are numerous uncertainties surrounding this topic.

Feedback on importance: Upwelling, as a driver of blooms, warrants evaluation. It brings nutrient-rich water to the shore, potentially triggering HAB events if HAB species are present. Changes in upwelling patterns could introduce more uncertainties regarding HAB events.

Effect of offshore wind on HAB distribution. The potential impact of offshore wind on the distribution of HABs remains uncertain. Changes in upwelling patterns downwind of offshore wind areas could theoretically influence HAB distribution. If there is reduced upwelling, the distribution of species could be altered, though any effect is anticipated to be minor. Offshore waters are inherently challenging due to hazardous conditions and frequent storms. Additionally, there are numerous other mechanisms that bring nutrients to surface waters, such as internal waves that oscillate below the water surface and inputs from the Strait and the Columbia River plume. The outcomes may depend on how offshore wind affects the residence time of water on the shelf. Many mechanisms are involved in this complex scenario.

Effects from specific activities related to offshore wind will also need to be considered. For instance, as long as the sediment remains moist, cysts can survive the transfer through dredging and sediment placement. With vessel activities, ballast water is treated in various ways; however, there are instances where cysts have been transported via ballast water. The efficacy of treatments in eliminating cysts is uncertain, as cysts are generally resistant to most treatments.

Feedback on importance: Distribution of HABs may shift with offshore changes.

Enhancing HAB monitoring through offshore wind. Monitoring is conducted through ORHAB, which includes an early warning component for HAB monitoring. Data is collected at established sites and the program has a robust monitoring framework. There is always a desire to expand monitoring efforts, but funding constraints consistently present a limiting factor. This monitoring effort is complemented by data collected by DOH, WDFW, UW, and coastal Tribes.

Offshore wind monitoring is crucial. Data gaps exist due to limited offshore monitoring, making it challenging to detect HABs amidst other environmental changes. The longevity of ORHAB data since 1999 underscores its value, and while there may be consideration of relocating monitoring sites, maintaining continuity avoids losing this historical data's significance. Offshore wind development presents an opportunity to establish an offshore monitoring network by installing automated environmental sample devices on these offshore wind structures. Whether these installations can enhance the HAB monitoring network or if these structures or companies be willing to deploy scientific equipment on them is unclear.

Feedback on importance: There is very limited offshore information and therefore, a significant unknown.

Offshore aquaculture data gaps

- Monitoring the effect of offshore aquaculture on HABs

Monitoring the effect of offshore aquaculture on HABs. Enhanced monitoring is necessary due to numerous uncertainties associated with offshore conditions, particularly concerning additional nutrient inputs.

Feedback on importance: Monitoring will be crucial if offshore aquaculture is pursued.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Temporal and spatial trend of HABs
- Relationship of HABs with environmental parameters
- Effect of HABs on other species
- New and emerging HABs
- Termination of HABs
- Monitoring of environmental parameters for HABs

Temporal and spatial trend of HABs. For the most part, information is available on temporal and spatial trends, but much remains unknown due to ongoing and constant changes.

Phytoplankton monitoring in the Pacific Northwest is conducted by ORHAB along the coast and coastal bays, SoundToxins in Puget Sound, and DOH, which operates the largest biotoxin program in the United States. Washington State tests shellfish more extensively than any other state, a practice established since the 1950s, providing a robust understanding of biotoxin hotspots. Trend data is available which encompasses the location, timing (from the onset of blooms triggering the first closure to the end of the season), and frequency within specific locations. Some counties may have blooms earlier in the year and an area may experience multiple closures throughout the year.

There is a critical need to expand data collection to include more sites and there is a significant data gap regarding the factors that cause a HABs event to move into a new area, vary in duration, increase in severity, change in type, or introduce new toxins. These factors include temperature, wind patterns, light availability, water column stratification, nitrogen levels, metal concentrations, oxygen levels, salinity variations, and dynamics within the phytoplankton community, including competition among species.

Temporal trends: There is likely a solid understanding of temporal trends with no significant data gaps at present. Studies have examined the historical records, current status, and trends of various HAB species across the United States, including the Washington coast. There is a noted worsening trend for *Pseudo-nitzschia* in the United States (US), with the West Coast playing a significant role in driving this trend. Since the early 1990s, there has been consistent *Pseudo-nitzschia* HAB activity in this region. Data from shellfish toxicity monitoring, spanning back to the early 1990s and provided by DOH, offers a comprehensive time series. When examining HABs (defined by specific criteria such as causing harm or exceeding regulatory thresholds), trends vary among different types of blooms. Some show worsening trends, while others remain stable or are emerging.

When examining temporal trends, there are two scales: seasonal and interannual. Seasonally, there is a good understanding. HABs of *Pseudo-nitzschia* are observed during the upwelling season, with significant events often observed in the fall and spring. On an interannual scale, there appears to be a correlation with warm anomalies, although these interactions are intricate and not fully elucidated. Overall, there is a comprehensive understanding of the oceanographic processes that drive seasonal patterns and some interannual variations.

While there is a solid historical understanding of HAB events, these occurrences vary annually in terms of their location and severity. There is no fixed pattern. Particularly in the last decade, significant changes have been observed in the distribution and toxicity levels of blooms. There is also an increasing occurrence of multiple toxic blooms happening simultaneously in the same location. There are indications of a potential worsening trend, and it has been confirmed that the HAB season has expanded.

Sediment analysis serves as a valuable indicator for predicting future bloom events. When environmental conditions cease to support blooms, HABs may leave behind cyst beds in sediment, which act as initiation sites for subsequent blooms. By studying sediment, researchers sometimes find correlations that help predict future HAB occurrences.

There is also interest in being able to predict the onset of HABs in shellfish. Researchers are beginning to grasp the timing and seasonal variability of these events, exploring potential correlations with larger climate cycles or indices like ENSO. HABs typically bloom during the spring and fall, exhibiting interannual variability in their intensity and duration.

Spatial trends: Spatially, there is a developing understanding of where HAB hotspots are located, although some uncertainties remain. Known hotspot areas include the Juan de Fuca eddy and Hecate Bank. HABs originating from Hecate Bank in Oregon can impact beaches in southern Washington. Additionally new hotspots where blooms originate are being discovered. For the past 15 to 20 years, it was believed that blooms originated in the Juan de Fuca eddy during the fall. However, Trinidad Head, California, was recently identified as a source of blooms occurring in October and November, which are transported up the Oregon coastline into Washington. The question remains whether this pattern will persist over time. Occurrences outside the expected norm provide valuable opportunities for studying HABs and advancing understanding in this field.

Relationship of HABs with environmental parameters. Current understanding of environmental parameters crucial for assessing the risk of HABs includes factors such as temperature, stratification, light, wind events, onshore and offshore winds, nutrients, and climate cycles. While researchers have established a foundational understanding of these factors, there are others that are not understood and only have a basic foundation. For example, analyses of specific types of nitrogen and initiation sites are needed. Occasionally, unexpected events occur where observed conditions do not align with predicted outcomes. This could be attributed to additional nutrients introduced into the water, fluctuations in temperature, or other environmental stresses affecting algal behavior. Efforts are ongoing to deepen this foundational understanding, with a focus on identifying new environmental parameters that influence HABs. This ongoing research aims to refine risk assessments.

There is also an interest in better understanding environmental drivers that specifically influence the blooms and production of domoic acid such as the effect of nutrient limitation, temperature, and light stress on domoic acid production. Based on prior research in the field and laboratory settings, there is a general understanding of the parameters that influence toxin production in *Pseudo-nitzschia*. It is known that *Pseudo-nitzschia* requires nitrogen for domoic acid production. However, the dynamics remain complex and difficult to predict. For instance, OA has been shown to increase toxin production in some species, while having no effect or a different impact on others, depending on growth stage and nutrient availability.

Effect of HABs on other species. The effects of toxins on humans are understood, such as how toxic HABs impact access to fisheries. For other species, identification of species affected by HABs can be facilitated through ORHAB data.

Bioaccumulation of toxins can severely affect species like marine mammals; for instance, in 2009, HABs led to stranding and mortality events among seabirds. In 2015, a coast-wide domoic acid event caused mass marine mammal strandings. Understanding the implications of exposure and the movement of toxins through the food web is crucial. Additionally, while the toxin responsible for mortality can be identified in some species, the exact causes of death in areas like Willapa Bay remain unclear, as the multiple stressors are difficult to isolate. Current capacity is limited to assessing specific toxins that affect human health, and there is no routine monitoring of shellfish tissues for other toxins.

Recent evidence also indicates that environmentally destructive harmful algal blooms (HABs) are occurring with greater frequency, putting additional stress on species such as shellfish, which face multiple stressors, including harmful algae, food availability, and temperature fluctuations. Detection of toxins in marine mammals and other parts of the marine food web, including benthic infauna, prompts questions about their effect on health and fitness.

Experts provided feedback on the effect of HABs on the following animals:

Sponges: Effect is uncertain. They may filter HAB species from seawater, thereby reducing their numbers, or they could be negatively affected by other species.

Dungeness crabs: Dungeness crabs can be affected by consuming shellfish containing HAB toxins, such as domoic acid. Razor clams, a preferred food for coastal crabs, have led to closures of the Dungeness crab fishery due to toxin contamination. Currently, crab testing is limited to coastal areas, focusing specifically on domoic acid levels. There is known correlation between toxin levels in razor clams and Dungeness crabs, but testing extends only to domoic acid. There are questions regarding domoic acid such as the effect of domoic acid on the different life stages of Dungeness crabs. Prior laboratory studies indicated that exposure to domoic acid slowed the reaction time of crabs.

Fish: Salmon can eat filter-feeding fish. There are studies conducted on fish to determine whether toxins concentrate in their stomachs or migrate into their meat. Salmon and other fish should be collected to test for toxins.

Sea mammals: Seals have been documented dying on the beach after consuming toxic shellfish contaminated with domoic acid.

Birds: Birds have been observed losing their ability to waterproof their feathers after exposure to toxic algae.

New and emerging HABs. While there are programs in place to identify new and emerging HAB species, it will be necessary to address associated data gaps. There will also be a lack of historical data. Anything that is new and emerging inherently entail significant data gaps.

Monitoring for new and emerging HABs typically employs two methods. The first involves phytoplankton monitoring. Tests can be conducted to detect problematic blooms. The second method uses high performance liquid chromatography (HPLC) for amnesic shellfish poisoning (ASP) and liquid chromatography/mass spectrometry (LC/MS) for diarrhetic shellfish poisoning (DSP). A new toxin, Azadinium, which produces AZA toxin, was identified through a sediment core and cyst bed study conducted as part of another research project. This toxin has also been discovered in Washington State waters, but currently, the necessary equipment for testing it is unavailable. Azadinium is considered a species of concern.

Notably, in recent years, HAB species previously unknown to inhabit Washington waters have been identified, including certain benthic species. Installing infrastructure in the ocean could potentially provide a substrate for these species to attach to and thrive, thereby influencing what happens in the coast.

Efforts are underway to survey the entire phytoplankton community, supported by comprehensive programs aimed at predicting the emergence of harmful algal species. The ORHAB program is a key initiative that studies the entire phytoplankton community using innovative techniques like environmental DNA (eDNA) analysis. In addition, NOAA is collecting eDNA samples during fishery surveys and at the ESP mooring off La Push to monitor species presence.

Termination of HABs. There is a fundamental understanding of how HABs terminate. These events can end due to various factors such as nutrient depletion, windstorms, and changes in temperature. HAB species can have specific optimal environmental conditions. However, there are uncertainties regarding the precise reasons behind bloom terminations, their duration, and the factors influencing their decline. Due to insufficient sampling, there is limited information on several factors, such as whether blooms are transported offshore by winds and currents, leading to their persistence in reduced numbers. Additionally, it remains unclear whether blooms cease due to nutrient depletion or other factors, such as fungal infections or growth inhibitors.

For *Pseudo-nitzschia*, it is generally understood that blooms typically terminate towards the end of the upwelling season. This termination is often associated with the reversal of currents, nutrient depletion, and storms that mix the water. However, the specific drivers of bloom termination within the upwelling season are still unclear. If nutrient depletion is not the cause, other factors such as diseases or grazing pressure might be involved. Accurate measurements that identify the presence or absence of nutrients are crucial for determining the underlying cause of bloom termination.

Monitoring of environmental parameters for HABs. Shellfish are collected from designated sites and sent to the Washington State Public Health Laboratories for toxin analysis. Currently, there is insufficient funding to analyze environmental parameters such as nitrogen, iron, or copper concentrations at these designated sites. ORHAB currently collects limited environmental parameters, but these efforts do not extend to the specific areas where shellfish tissue data are collected. There is a need to expand environmental data collection at shellfish harvesting sites. Enhanced environmental data would facilitate better predictive capabilities.

Offshore wind data gaps

- Effect of offshore wind structure on HABs
- Effect of offshore wind on presence and abundance of HAB species
- Effect of electromagnetic fields from offshore wind on HABs
- Effect of light and shade from offshore wind structures on HABs

Effect of offshore wind structure on HABs. The potential impact of offshore wind structures on harmful algal blooms (HABs) is uncertain, with concerns focused on the local mixing effects and disturbances these structures may cause. For example, a minor response in *Pseudo-nitzschia* was observed to slight wind disturbances, which were sufficient to mix some nutrients to the surface. HABs can also produce cysts—dormant stages of certain algae capable of surviving harsh conditions and germinating when conditions improve. These cysts can be transported by ocean currents, fish, or humans, facilitating their spread to new areas. Additionally, if offshore wind cables come into contact with the seabed or disturb the bottom layer, they could potentially influence bloom dynamics by stirring up deposited cysts or altering nutrient availability. While the anticipated effect is considered small, mapping cyst beds would still be valuable for siting purposes. In this context, the impact of disturbances should take precedence over other factors, such as shading. Another question is whether offshore wind structures could provide habitat for algal species. However, the specific implications of these factors remain unclear, and various hypotheses need further exploration. Monitoring will be essential to establish baseline conditions and assess the impact post-installation.

Effect of offshore wind on presence and abundance of HAB species. Offshore wind is unlikely to have a significant effect, as the currents originate offshore. Coastal currents and climate cycles play pivotal roles in transporting HABs events along the coastline and knowledge of HAB hot spots is well-established. For instance, in the Strait of Juan de Fuca, upwelling can generate a gyre that supports HAB blooms if cells are present. Storms originating from the north, such as those from Alaska, can also transport HABs to coastal areas, potentially impacting local industries. Winds are also capable of carrying HABs from their origin sites. Given the scale of these natural cycles, the potential effects of offshore wind remain uncertain.

Navigating this issue is quite complex. Offshore structures and offshore data already highlight a data gap. There is a limited understanding of temporal and spatial patterns of HABs and phytoplankton communities in offshore areas. Current insights are largely based on sporadic snapshots from research cruises. The introduction of offshore structures adds another layer of perturbation to these environments, which are already undergoing significant, unprecedented changes, including OA and warming. Attributing changes to specific causes will be challenging, but it may be possible to identify the key mechanisms influencing these changes through dedicated monitoring and modeling efforts.

Additionally, offshore wind structures could function as fish aggregating devices (FADs), raising questions about how nutrient loading might be affected and how shifts in nutrient dynamics could influence blooms within the ecosystem. Lastly, the transport of cysts by ballast water has been observed in some instances, but its impact is deemed less concerning, as shipping vessels now follow best practices to limit the risk of introducing invasive species.

Effect of electromagnetic fields from offshore wind on HABs. The potential influence of electromagnetic fields on HAB species is currently unknown. It is speculated that any effect would likely be minimal, given that the cables are relatively small and would only affect a limited area. However, the specific nature of any impact remains unclear. While electromagnetic fields have been used to control populations of burrowing shrimp, the effects on algae and cysts are uncertain and would require further study.

Effect of light and shade from offshore wind structures on HABs. The impact on light availability would largely depend on the scale of the infrastructure. Offshore wind installations are expected to have minimal effects on light availability, unless the structures are large enough to create substantial shading. Different HAB species have specific requirements for light, nutrients, temperature, and ocean conditions to thrive, which defines their ecological niche. Altering these factors can influence the composition of the algal community. Regarding shade from structures, there has been some research on the photoperiod, but its specific effects remain uncertain. As currents flow beneath platforms, the duration of shading might be sufficient to stress algae, though this aspect requires further investigation. Light conditions can also affect the swimming behavior of plankton, with some species exhibiting vertical migration in response to light changes within the water column.

The potential impacts of these structures are expected to be minimal in offshore locations, where continuous water currents and natural mixing processes occur. However, in relatively stagnant water bodies like bays in Puget Sound, the impacts may be more significant.

Offshore aquaculture data gaps

- Effect of offshore aquaculture on presence and abundance of HAB species
- Effect of nutrients, waste, and chemicals from offshore aquaculture on HABs
- Effect of offshore aquaculture structure on HABs

Effect of offshore aquaculture on presence and abundance of HAB species. Offshore aquaculture can influence species presence and abundance by introducing nutrients, which have varying effects. These nutrients could lead to low oxygen events, trigger toxic blooms, or promote the growth of non-toxic algae. Non-toxic blooms might suppress the growth of toxic algae species by occupying open water and reducing competition, potentially causing shifts in species composition or broader ecosystem changes. Warmer waters are more likely to support the emergence of new species. Additionally, offshore aquaculture facilities may function as FADs, further influencing nutrient loading in their vicinity. Excessive nutrient inputs could, in turn, exacerbate bloom events.

If shellfish aquaculture is implemented, it could potentially have both top-down and bottom-up effects, depending on the specific HABs species and the shellfish involved. Some shellfish species like mussels may help control HAB populations by filtering plankton from the water and effectively clear nutrients from the water column.

Kelp aquaculture can uptake carbon dioxide (CO_2) from seawater, potentially mitigating local ocean acidification and influencing the presence and abundance of certain HAB species.

Effect of nutrients, waste, and chemicals from offshore aquaculture on HABs. The effect of offshore aquaculture is scale dependent. However, it is difficult to imagine that any operation will introduce enough nutrients to rival the inputs from natural upwelling processes. Upwelling supplies substantial amounts of nutrients to the surface, likely exceeding what artificial sources can introduce. However, offshore aquaculture will provide a consistent nutrient source over time. Specific nutrients and minerals are known to influence competition and inhibition, potentially altering the duration of blooms. These nutrient inputs could potentially fuel HABs, leading to increased occurrences over both space and time. They may sustain a seed population, ensuring a persistent presence that can capitalize on upwelling events. This could alter the local community dynamics, potentially promoting the persistence of certain species that might not otherwise thrive. Changes in input can influence growth, competition, and overall survival within the ecosystem.

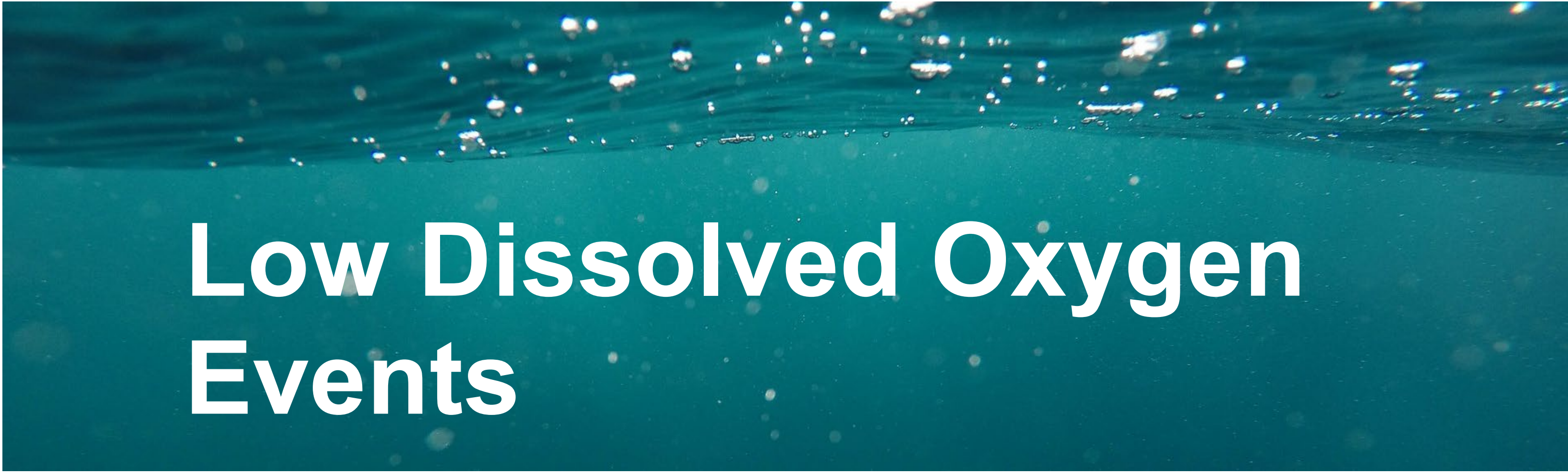
The amount of nutrients present is also crucial, as they can either foster low oxygen events or initiate blooms of toxic or non-toxic algae. Non-toxic blooms may suppress the growth of toxic algae producers, which thrive in open water with less competition. This scenario could lead to the emergence of new species or other ecological changes.

Effect of offshore aquaculture structure on HABs. The physical structure itself is unlikely to have a significant impact. However, local mixing and disturbances could potentially affect the environment. For example, there has been an observation of a minor response in *Pseudo-nitzschia* to slight wind disturbances that bring nutrients to the surface. However, this remains uncertain, and various hypotheses could be explored. Monitoring would be essential to establish baseline conditions and assess the impact post-installation.

Resources

Table 33. Resources relevant to HABs.

NAME	ACCESS	TYPE	DESCRIPTION
An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions	https://agupubs.onlinelibrary.wiley.com/doi/pdfdirect/10.1002/2016GL070023	Published article	Demonstrated that the outbreak of toxigenic diatom *Pseudo-nitzschia* in the spring of 2015 was initiated by anomalously warm ocean conditions.
Marine harmful algal blooms (HABs) in the United States: History, current status and future trends	https://www.sciencedirect.com/science/article/pii/S1568988321000020?via%3Dihub	Published article	Reviewed the status of complex array of marine HAB problems in the US, providing historical information, trends, and future perspectives.
NANOOS: Harmful Algal Blooms	https://www.nanoos.org/products/habs/home.php	Website	Provides information, real-time data, and forecasts on HABs and hosts the Pacific Northwest HAB Bulletin which gives an early warning of HABs to coastal managers.



Low Dissolved Oxygen Events

Key Data Gaps

General Data Gaps

- Distribution, status, and trend of low dissolved oxygen events
- Effect of large-scale ecological drivers on low dissolved oxygen events
- Effect of production and bottom respiration rates on low dissolved oxygen events
- Effect of low dissolved oxygen events on biology

Offshore Aquaculture Data Gaps

- Monitoring the effects of offshore aquaculture on low dissolved oxygen events
- Effect of added nutrients, waste, and chemicals from offshore aquaculture on low dissolved oxygen events

Other Data Gaps

Offshore Wind Data Gaps

- Risk of intensification of low dissolved oxygen events due to offshore wind, including the effect of potential sediment disturbance and shift in oxygen exposure
- Effect of offshore wind structure on low dissolved oxygen events
- Monitoring the effect of offshore wind on low dissolved oxygen events

Offshore Aquaculture Data Gaps

- Risk of disease intensification

Background

Dissolved oxygen sustains marine life and is influenced by factors such as temperature, atmospheric exchange, and source. Dissolved oxygen levels may decrease due to high levels of respiration, stemming from nutrient-driven decay of organic matter or prolonged absence of photosynthesis in deep ocean waters. Warmer water holds less oxygen, and deep ocean areas beyond the continental shelf typically exhibit low concentrations.

Hypoxia, a state of low dissolved oxygen concentration, occurs in Washington's shelf and coastal waters due to upwelling, which brings oxygen-depleted water to the surface and causes periods of low or no oxygen. The nutrients brought by upwelling also promote primary productivity, leading to large phytoplankton blooms. These blooms produce waste products that are decomposed by bacteria. In the process of decomposition, bacteria consume dissolved oxygen, further depleting the oxygen levels in the water.

The Washington coast experiences a seasonal cycle in dissolved oxygen concentrations. In winter, deep waters exhibit relatively high dissolved oxygen concentrations due to reduced biological productivity and more frequent storms that generate winds conducive to downwelling. In summer, deep waters experience reduced dissolved oxygen levels, often reaching hypoxic conditions, due to prevailing winds that promote upwelling and increased biological productivity. Additionally, along the upper continental slope, there is a layer of deep water extending to depths greater than 1,000 meters that has persistently low oxygen. This is called the oxygen minimum zone. Historical data indicates that this zone is showing trends of warming and even lower oxygen levels.

Decreased oxygen levels can stress marine communities and lead to widespread mortality. In 2006, hypoxic conditions off the coasts of Washington and Oregon intensified, causing significant fish and invertebrate die-offs. Low dissolved oxygen events are especially harmful to seafloor habitats, where they act as physical stressors. These events can cause stress or mortality in organisms, particularly immobile or slow-moving benthic invertebrates, potentially disrupting the seafloor food web.

Hypoxia effects are expected to grow rapidly in intensity and extent in the future due to climate change. Global climate models predict a decline in dissolved oxygen concentrations as rising ocean temperatures reduce oxygen solubility. Additionally, increased sea surface temperatures and lower salinity from rising freshwater inputs will enhance ocean stratification. This enhanced stratification will limit the mixing of deeper, denser waters with surface waters, prolonging respiration at depth and further depleting dissolved oxygen in subsurface waters. It is projected that increased severity and frequency of hypoxia will reduce species diversity, decrease organism sizes, and lower the efficiency of energy transfer between trophic levels.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to low dissolved oxygen events:

General data gaps

- Distribution, status, and trend of low dissolved oxygen events
- Effect of large-scale ecological drivers on low dissolved oxygen events
- Effect of production and bottom respiration rates on low dissolved oxygen events
- Effect of low dissolved oxygen events on biology

Distribution, status, and trend of low dissolved oxygen events.

Distribution: Overall, the region performs well in monitoring efforts, with notable patterns observed from north to south. However, there may still be less-documented hotspots or refugia that require further investigation. Washington is well-positioned in terms of spatial coverage, thanks to the Olympic Coast National Marine Sanctuary (OCNMS) program, which maintains a network of moorings and other observing assets such as gliders. Within the OCNMS, seven moorings monitor bottom oxygen levels from April to September each year, capturing critical data during periods when low oxygen conditions typically occur. Additionally, there are cruises, such as those conducted by National Oceanic and Atmospheric Administration's (NOAA) Pacific Marine Environmental Laboratory (PMEL), which focus on specific transects to ensure survey repeatability. To fully understand the intensity of low oxygen events, comprehensive spatial and temporal coverage is essential.

In addition, Oregon State University has conducted significant research on time series oxygen measurements. A dedicated monitoring station was established at a location that experiences annual anoxic and hypoxic conditions. This station has gathered millions of measurements; however, the spatial extent of low oxygen events and how that extent varies over time are still unknown. There remains a notable lack of exhaustive spatial coverage and consistent temporal measurements.

While it may seem that distribution has been adequately addressed, low-oxygen events are highly heterogeneous. Much of the existing knowledge is derived from individual mooring time series, which provide data from only one location and, if fortunate, a couple of depths. Conditions at one site do not necessarily reflect those at others. Installing additional sensors and increasing monitoring resolution in nearshore areas and deeper waters, areas which have historically posed challenges due to rough conditions that can lead to equipment loss, are needed. Furthermore, obtaining real-time data remains a significant gap. It is essential to understand events as they occur. The necessary resources are available, and it is critical to sustain and enhance their capabilities.

Status: Definitions of low dissolved oxygen events often rely on arbitrary thresholds, focusing on whether oxygen levels fall above or below these set points. However, to fully understand these events, it is essential to consider their intensity, volume, and persistence. There is a lack of understanding regarding the severity, three-dimensional extent, and duration of oxygen depletion. Additionally, understanding metabolic variability in relation to phenomena such as El Niño, La Niña, and fluctuations in upwelling is crucial. Integrating mechanistic model simulations with improved data products is necessary to gain a comprehensive understanding of oxygen depletion and its impacts. This approach will provide a more nuanced grasp of the complexities involved.

Trend: Data on ocean oxygen levels extend back to the 1960s, with significant contributions from Oregon. However, data on low-oxygen events prior to the 1980s were discarded due to concerns about data quality issues. Although the data was considered reliable at threshold levels, collection methods were inadequate at very low concentrations. The exclusion of these data has influenced the perspective on persistent declines in oxygen levels.

A time series spanning two decades is available for select sites, with the data publicly accessible through the National Marine Sanctuaries website. Additionally, NOAA Fisheries and survey cruises have been collecting oxygen sensor data for nearly two decades, much of which is also publicly available. NOAA and its partners are working to update and improve the quality control of these data to transform it into a data product that others can use.

Feedback on importance: It's essential to establish a local baseline before any environmental modifications are made. While there is significant information available for Washington waters, there is notable variability both north to south and from offshore to inshore areas. Gathering data from locations frequented by fishers and interested or affected parties would be a crucial step. These data will be helpful for making informed decisions about environmental conditions.

Effect of large-scale ecological drivers on low dissolved oxygen events. There is a growing recognition that climate-related factors drive low oxygen events. Recent advancements in science enabled researchers to make this connection more clearly. For instance, upwelling and river inputs interact to create the conditions that drive low oxygen events. This interaction also relates to ocean acidification, as carbon dioxide uptake and seasonal corrosive hypoxia events are significantly enhanced by local regional processes. Furthermore, large-scale basin circulation influences the origins of the water masses that upwell onto the Washington shelves.

In particular, there are two drivers on the open shelf. The first is the oxygen content of waters from the open ocean that interact with the shelf, particularly during upwelling events. Upwelled water is naturally and persistently low in oxygen. Recent discussions suggest a potential trend of low oxygen levels in these open ocean waters, a topic that has been equivocal for some time. A comprehensive long-term analysis on whether this trend is cyclical or secular was conducted. While it was previously thought to be cyclical, there is evidence of a long-term trend. However, the trend in the water mass composition is relatively minor compared to the intensity of the low oxygen events observed. The second driver is the metabolic process occurring on the shelf. Oregon and Washington coasts are more susceptible to low oxygen events due to nutrient dynamics. The water that contributes to upwelling in the North Pacific contains a significant excess of nutrients necessary for phytoplankton blooms, which is influenced by the water's previous location at the surface. This combination of water characteristics and upwelling makes the region vulnerable to low oxygen events. While there is a slow trend in the source water, the amplitude of metabolic processes occurring on the shelf is substantial.

Other factors also significantly influence low dissolved oxygen events. Warming water alters the circulation, mixing, and ventilation dynamics of low-oxygen events. Nutrients such as nitrate and phosphate are also crucial, as they stimulate phytoplankton blooms and initiate metabolic processes. Circulation patterns are critical as well. These patterns influence the origins of the water masses that are upwelled along the shelves, and if upwelling occurs too rapidly and lacks sufficient exposure to surface area, significant blooms may not occur. Low dissolved oxygen events represent a holistic, system-wide concept. Although measuring oxygen levels is important, a comprehensive understanding of these interconnected factors is essential for capturing the complete picture. It is important to note that pH is not a significant driver of low oxygen events. While the conditions leading to low oxygen events may coincide with low pH, there is no evidence suggesting that low pH directly exacerbates or mitigates these events metabolically.

While advances in science have helped connect low oxygen events with climate factors, changes in circulation patterns or shifts in productivity could potentially weaken the robustness of these connections. Given the rapid pace of climate change, insights gained over the past decade may become less reliable as the system undergoes swift transformation. Addressing these challenges require a climate-ready observation network. Such a network would enable stronger correlations between low-oxygen events, atmospheric forcing, and coastal oxygen availability over varying time scales. There are critical questions on whether external forces alter low-oxygen events and if there are directional changes in forcing that are altering how the ocean responds.

Feedback on importance: To connect large-scale drivers to low oxygen events, comprehensive spatial and temporal data coverage is essential. Such coverage would allow attributing low dissolved oxygen events to, for example, on-shelf metabolic processes driven by La Niña. This data gap is critical and has immediate relevance.

It is also crucial to differentiate between the effects of natural processes, influenced by large-scale climate change, and the effects of human interventions. This distinction is fundamental to understand baseline conditions.

Effect of production and bottom respiration rates on low dissolved oxygen events. At the broad spatial scale of the Washington shelf, hypoxia is a concern due to subsurface respiration rates driven by biological production. Initially, the water brought to the shelf by ocean currents is not hypoxic. The expansive continental shelf of Washington fosters significant biological activity, which, through biological processes, reduces oxygen levels to near zero.

Allocation of resources to study production and respiration rates is needed. Existing data can be used to develop new models that can enhance understanding of primary production levels in surface waters and bottom respiration rates.

Feedback on importance: Understanding the effect of low dissolved oxygen events on production and bottom respiration is critically important because it provides foundational baseline information which are essential to comprehend how activities like dredging alter environmental conditions. This requires quantifying production and respiration rates.

Effect of low dissolved oxygen events on biology. There are natural shifts in oxygen availability. Organisms may perish or disappear during periods of low oxygen and return when oxygen levels rebound. There are global syntheses that explain how various organisms are affected by changing dissolved oxygen levels. However, very few studies specifically target species in the Pacific Ocean, and even fewer focus on those that are consumed.

There are two primary monitoring methods for studying the effect of oxygen availability on species. The first method involves assessing mortality among crabs caught in crab pots. High mortality rates typically indicate low oxygen events; notably, 2006 marked the worst recorded event for crabs. Crabbing seasons following low oxygen events often see massive impacts. The second method employs submersible surveys to observe rockfish habitats. Using remotely operated vehicles (ROVs) equipped with cameras, researchers count rockfish over specified time intervals. During low oxygen periods, reefs often appear barren as rockfish vacate the area. However, they return once oxygen levels recover. Some species retreat deeper into reefs during low oxygen and suffer mortality. The spatial extent and duration of low oxygen conditions significantly affect long-term mortality rates.

Feedback was shared on the state of knowledge for specific species:

Krill: A crucial aspect of marine ecosystem management, experts are working on exploring and setting up a system to study oxygen sensitivity.

Dungeness crabs: It is unclear what level of oxygen availability Dungeness crabs need for survival and how long they can withstand low oxygen events. Sporadic die-off events have been observed. These events may be triggered by various reasons such as low oxygen levels during molting, stress from slight temperature increases, or prolonged periods of extremely low oxygen. The cumulative impacts on populations are also uncertain, with current knowledge focused on acute responses rather than long-term effects. However, despite the significant climate variability observed so far, Dungeness crab harvests have remained productive and sustained. The question remains whether harvests will continue to stay this way.

Salmon: Chinook salmon inhabit deep parts of the water column, presenting bycatch challenges with the hake trawl fishery. In Oregon, the sensitivity of salmonids to oxygen levels has been investigated. Low oxygen events have the potential to influence salmon distribution, potentially altering the area they occupy and intensifying or de-intensifying bycatch risks. These events may push marine life towards the surface, affecting management strategies for mitigating bycatch mortality rates.

Predators (ex: marine mammals): Predators are likely to be indirectly affected by low dissolved oxygen events due to impacts on prey species. For instance, forage fish, an important prey for various species, are particularly sensitive to oxygen levels.

Feedback on importance: The effect of low dissolved oxygen events on biology presents a high level of uncertainty. This information can be used to provide context for interpreting all other available data related to the exposure to low dissolved oxygen events.

Offshore aquaculture data gaps

- Monitoring the effects of offshore aquaculture on low dissolved oxygen events
- Effect of added nutrients, waste, and chemicals from offshore aquaculture on low dissolved oxygen events

Monitoring the effects of offshore aquaculture on low dissolved oxygen events. In the event of offshore aquaculture development, there will be a lack of historical observations to inform practices. This highlights the need for an ongoing monitoring program to examine the effects of offshore aquaculture, including the effects on low dissolved oxygen events. Good quality sensors are available. Existing oxygen sensors are generally reliable and accessible.

Any offshore aquaculture permit granted would likely include specific monitoring requirements. It would be beneficial for the state to consider developing guidelines that outline the necessary levels of uncertainty and data requirements. The guidelines could include standards for data finalization, quality standards, and the dissemination of information. Careful thought should be given to the pipeline for data submission—determining who will receive this information and how it can be utilized for broader public benefit. It is crucial that the industry does not solely self-report; there should be a transparent process in place. Data should be accessible to ensure accountability and informed decision-making.

Feedback on importance: If offshore aquaculture is implemented, monitoring will be essential. This represents a future gap that must be addressed as part of this activity.

Effect of added nutrients, waste, and chemicals from offshore aquaculture on low dissolved oxygen events. Phytoplankton blooms along the Oregon and Washington coasts are already significant contributors to productivity. However, adding nutrients to surface waters can enhance phytoplankton productivity. While the specific impact would depend on the scale of the project, it could alter production rates and provide additional fuel for respiration in benthic waters. For example, in net pens, the use of fish meal can increase the potential for eutrophication in the system. The effects of fish pellets can be compared to the natural system to assess their impact. Additionally, some waste may reach the seabed, potentially exacerbating hypoxia and acidification events.

In particular, it is important to examine the potential impact on harmful algal blooms (HABs), especially given the presence of several different HAB species. Observations indicate that the frequency and severity of HABs appear to increase during heat waves and under specific conditions.

The effect of added nutrients, wastes, and chemicals from offshore aquaculture on low dissolved oxygen levels will also depend on several factors, including the type of aquaculture, feeding practices, and the location of the pens. For instance, salmon aquaculture in Canada typically occurs in isolated deep waters with poor circulation, which increases oxygen demand in areas with limited mixing. In enclosed bays, the risk of low oxygen events is also significant. However, along the open coast, unless the operation is particularly intensive, it is challenging to envision a substantial impact. The volume of organic matter naturally entering the ocean far exceeds any input from a fish farm. For instance, the hake fishery discards a substantial volume of waste into offshore areas, yet there is no evidence linking this occurrence to low oxygen events.

The overall environmental impacts of aquaculture remain unclear and require careful consideration of these variables. It is worth noting that due to the destructive storm events regions like Washington and Oregon experience, the survivability of net pens is questionable and there may be severe operational restrictions.

Feedback on importance: This is the type of information that would be collected through offshore aquaculture monitoring efforts. There is a need for modeling and obtaining information from HAB experts for baseline context.

Other Data Gaps

The following are the remaining data gaps:

Offshore wind data gaps

- Risk of intensification of low dissolved oxygen events due to offshore wind, including the effect of potential sediment disturbance and shift in oxygen exposure
- Effect of offshore wind structure on low dissolved oxygen events
- Monitoring the effect of offshore wind on low dissolved oxygen events

Risk of intensification of low dissolved oxygen events due to offshore wind, including the effect of potential sediment disturbance and shift in oxygen exposure. It is unlikely that any scientist would assert that changes in bottom ocean oxygen levels are amongst the top threat posed by offshore wind development. Potential offshore wind sites in Oregon are located in deep waters at approximately 800 meters, and the turbines will be floating, which suggests that near-bottom oxygen conditions are unlikely to be significantly disrupted. However, there is a gap in clear scientific consensus and communication regarding this issue. The scientific community has not effectively articulated the associated risks, leaving room for improvement in conveying what is well understood. There is a need to communicate this knowledge to the public more effectively and in a way that addresses their concerns.

The surface expression of a wind turbine presents many uncertainties, but it is unclear how this would specifically affect low oxygen events. It is likely to resemble the impact of having a boat anchored in the area with substrate-limited species, such as barnacles, populating the infrastructure. Anti-biofouling coatings can be applied to mitigate organism attachment. Additionally, the notion that there will be a noticeable change in the wind field downstream of a wind turbine is unlikely. The overall power generated and extracted by a single turbine represents a relatively small change. Unless there is a continuous line of turbines, significant alterations to the wind field are improbable. If the structures are installed in shallower waters, there may be some effect, but this remains uncertain.

Sediment disturbance from dredging may exacerbate low dissolved oxygen events. Depending on the seasonality of these disturbances, the resuspension of inorganic carbon and the mixing of low-oxygen sediments could worsen hypoxia and potentially prolong low oxygen events. However, depending on seasonality there could also be significant mixing that disperses low-oxygen events.

Sediment disturbance from dredging can exacerbate low dissolved oxygen events. The resuspension of inorganic carbon may worsen hypoxia and potentially prolong its duration, depending on the seasonality of the disturbance. Most sediment disturbance is expected during construction activities, such as installing power transmission infrastructure, burying cables, setting anchors, and deploying devices. For cable installations, the target burial depth is typically between 1 and 2 meters, which involves sediments that are already anoxic. While there is nothing inherent about the cable itself that would affect low dissolved oxygen events, digging up and then re-burying these sediments will expose anoxic material to oxygen, potentially affecting microbial colonies that are sensitive to oxygen levels. Additionally, reduced trace metals present in these sediments may become mobilized and exposed to oxygen during the process. While these activities will cause some mixing, the effects are not expected to be persistent, as construction typically lasts only a few months. There may be temporary impacts, but it is unclear whether these would significantly influence low dissolved oxygen events. Additionally, the scale of the sediment disturbance will also play a crucial role in determining its effects. Experts do not expect any significant post-construction impacts.

To minimize impacts, it may be necessary to consider circulation patterns and plan dredging efforts during times when there is a reasonable assurance that the disturbed sediment can be circulated offshore, allowing for dilution of any adverse effects. Typically, winter is a more favorable season for this. Modeling the potential impacts would be beneficial in guiding these decisions, helping to assess the effects and determine whether seasonal mitigation strategies can be implemented.

Effect of offshore wind structure on low dissolved oxygen events. Biofouling, the accumulation of organisms on submerged surfaces, may occur on these structures. This could create conditions that increase respiration rates, potentially reducing oxygen levels. However, overall, offshore wind structures are unlikely to have a significant impact on low dissolved oxygen events.

Monitoring the effect of offshore wind on low dissolved oxygen events. Sensors are available to monitor low dissolved oxygen events, and if offshore wind development occurs in Washington, there is an opportunity to leverage the turbine infrastructure for additional data collection. It will be essential to monitor the effect of offshore wind on various species, including during the installation phase. While the process for requiring developers to implement ecological monitoring remains unclear, it is important that these structures provide benefits to the public. Sufficient resources are necessary to gather baseline data, and while models can help address data gaps, establishing comprehensive baseline data over several years would be highly advantageous.

Offshore aquaculture data gaps

- Risk of disease intensification

Risk of disease intensification. The risk of disease intensification is a concern associated with any concentrated farming activity, as higher densities of organisms can facilitate the rapid spread of pathogens. Disease intensification occurs when environmental stressors or changes in population dynamics lead to an increase in disease prevalence, potentially impacting both farmed and wild populations.

With offshore aquaculture, because an increase of nutrients in surface waters can stimulate phytoplankton productivity, there is a need to carefully consider the potential effects on harmful algal blooms (HABs). Changes in oxygen and carbon dioxide (CO_2) systems, coupled with temperature shifts, will also need to be considered. The region hosts several HAB species and there is an increase in the frequency and severity of HABs during heat waves and specific environmental conditions. Waste reaching the seabed could also exacerbate hypoxia and acidification events.

Resources

Table 34. Resources relevant to low dissolved oxygen events.

NAME	ACCESS	TYPE	DESCRIPTION
Northwest Association of Networked Ocean Observing Systems (NANOOS): National Visualization System (NVS) Data Explorer	https://nvs.nanoos.org/Explorer	ArcGIS	Provides access, visualization, and analysis of data related to ocean and coastal ecosystems.
West Coast Ocean Acidification and Hypoxia Monitoring Inventory	https://geo.maps.arcgis.com/apps/webappviewer/index.html?id=a8b5c0ecfbe7451e950def767c55335e	ArcGIS	Visualizes Ocean Acidification and Hypoxia monitoring assets along the West Coast.

Marine Debris

Key Data Gaps

General Data Gaps

- Concentration, presence, distribution, and trend of marine debris
- Effect of marine debris on microorganisms
- Effect of marine debris on macroorganisms
- Source of marine debris
- Effect of chemicals in plastic debris and its effect on species
- Degradation of plastic debris

Other Data Gaps

General Data Gaps

- Trend in the influx of marine debris
- Role of marine debris in the context of invasive species
- Effect of marine debris on hypoxia

Offshore Wind Data Gaps

- Effect of offshore wind structure on marine debris
- Effect of offshore wind on risk of exposure to marine debris

Offshore Aquaculture Data Gaps

- Effect of offshore aquaculture structure on marine debris
- Effect of offshore aquaculture on marine debris and food security
- Effect of offshore aquaculture on marine debris and the shoreline
- Effect of offshore aquaculture effluent and byproducts on the quality and quantity of marine debris

Background

Marine debris poses significant ecological and economic challenges globally and is a significant stressor in the MSP Study Area. For instance, wildlife entanglement and ingestion are prominent issues, causing harm and mortality in sea turtles, seabirds, and marine mammals. Economic consequences include reduced tourism, cleanup costs, habitat degradation, vessel damage, and navigation hazards. Additionally, marine debris can introduce invasive species, compounding ecological and economic impacts in affected areas.

Figure 12. Numerous plastic bottles bundled in a thin net.

Approximately 92% of outer coast beach debris in Washington is comprised of plastics. Marine debris in the MSP Study Area originates from diverse sources, including local beach activities, upland sources, fishing, shipping, and from international locations around the Pacific Rim. Following the 2011 Japanese tsunami, debris items such as construction materials and boats, some carrying hazardous materials and non-native species, began washing up intermittently on Washington's beaches. Efforts led by the National Oceanic and Atmospheric Administration (NOAA), state agencies, and partners have been ongoing to monitor and safely remove tsunami debris, though recent reports have become less frequent. Regular marine debris removal efforts continue to be a daily challenge along Washington's coastlines.

Several volunteer cleanup events on beaches within the Study Area are held every year, most led by Washington CoastSavers and involving various nonprofits, businesses, and government agencies. While CoastSavers has coordinated cleanup events since 2007, community groups have held cleanup events on the Washington coast as early as 1971. Groups like Washington State Parks, Coastal Marine Resources Committees, Grassroots Garbage Gang, and Surfrider Foundation also contribute to beach cleanups. These cleanup efforts have collected significant debris, with CoastSavers reporting up to 320 tons during April events from 2000-2012 and 115 tons in a single cleanup from Moclips to Long Beach in July 2015. Separate efforts are underway to remove derelict fishing gear from Washington’s Pacific coast. Tribes, the State (including the Washington Department of Natural Resources’ Restoration and Derelict Vessel Programs), and The Nature Conservancy are collaborating to remove lost crab pots, benefiting both marine life and fisheries. Additionally, fisheries are mandated to use biodegradable escape mechanisms in gear design. Derelict gear, such as trawl nets and fishing lines, pose ongoing hazards to wildlife through entanglement. New ocean activities must manage their gear and waste effectively to prevent introducing debris into the environment. Marine debris programs also focus on prevention through education and outreach.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to marine debris:

General data gaps

- Concentration, presence, distribution, and trend of marine debris
- Effect of marine debris on microorganisms
- Effect of marine debris on macroorganisms
- Source of marine debris
- Effect of chemicals in plastic debris and its effect on species
- Degradation of plastic debris

Concentration, presence, distribution, and trend of marine debris. Understanding of marine debris varies depending on its type—shoreline debris differs from derelict fishing gear or smaller micro-debris found in water and on land. However, there is always a lack of sufficient data. This data is crucial for gauging the scale of the marine debris issue and determining whether resources are being allocated effectively. Establishing baseline trends and concentrations is key to informed decision-making. Moreover, long-term, reliable tracking of debris types, composition, and origin—whether local or distant—is necessary to understand the cyclical nature of marine debris and monitor changes over time. Collecting this data, however, remains a significant challenge.

Macro debris: This information is hard to get. Quantifying debris requires documentation of waste and there are limitations related to the availability of staff capable of analyzing the debris. Data collection is also unevenly distributed, with remote and inaccessible areas having limited data compared to more accessible locations that may be oversampled. Nonetheless, there is a general understanding of debris concentration, presence/absence, and distribution over time along Washington's outer coast. Resources like NOAA's Marine Debris Monitoring and Assessment Project[118] (MDMAP), International Coastal Cleanup[119] organized by Ocean Conservancy, and the Surfrider Foundation's beach cleanup database[120] can provide insights into the quantity and locations of debris.

Maco debris is unevenly distributed. For example, concentrations are often higher in bays and on "catcher beaches," where debris accumulates in pockets along the shore, often lodged in driftwood. In contrast, other beaches experience debris being washed ashore and then carried back into the ocean by wave action. Marine debris can also travel long distances, often carried by currents like the California Current, potentially originating from distant garbage patches in the Pacific Ocean. The accessibility of a given area plays a significant role in debris accumulation. In more accessible areas, debris levels may be higher due to increased human

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[118] https://marinedebris.noaa.gov/monitoring/marine-debris-monitoring-and-assessment-project
[119] https://oceanconservancy.org/trash-free-seas/international-coastal-cleanup/
[120] https://cleanups.surfrider.org/

activity, but the impact can be lessened as people are able to remove debris. In remote locations, such as wilderness areas accessible only by hiking, large accumulations of debris can be found. People who manage to reach these areas often set the debris aside to prevent it from being carried back into the ocean, but it remains temporarily stored rather than properly removed from the environment.

There is broad information available on temporal trends, albeit at a coarse scale. The ocean acts as a vast reservoir where debris can linger for varying durations before reaching shorelines. Typically, there is a decrease in debris during summer followed by an increase in winter, especially in observed fragments. Winter storms, often accompanied by king tides and dune erosion, contribute to fragments washed ashore.

Micro debris: Generally, there is information on presence or absence of microdebris. However, information regarding concentration, distribution, and trends are lacking.

While the concentration of microplastics is measurable, detecting microplastics in sediment or water poses significant challenges. Only two relevant studies in Washington have focused on microplastics; however, these prior research efforts did not involve identifying the chemical composition of the plastic. As the field emerged, stricter protocols were put in place to distinguish plastics from other materials. However, identifying the chemical composition is costly and time-consuming. The required equipment costs approximately $132,000 and is complex to operate. The University of Washington has one of these units, and it is the only one available in the Pacific Northwest. Although other less expensive machines can identify plastic types, they are not suitable for analyzing microplastics.

Feedback on importance: There is a need to understand how much debris is out there. Without a comprehensive understanding of the problem, developing effective solutions for prevention and cleanup is challenging. Investing in this data gap will be challenging because it may not immediately provide a clear path to solutions. However, failing to do so can result in inefficient processes and ineffective outcomes. Although some data on marine debris distribution and abundance exists, baseline information is especially needed in areas where offshore activities are proposed. Understanding the amount and source of debris is essential to assess changes over time and guide future efforts.

> **WCMAC:** This data gap is important for establishing a baseline to compare future developments. Due to the many remote areas involved, quantifying the concentration, presence, and distribution of marine debris along the Washington Coast is challenging, making it difficult to determine where debris is accumulating and at what scales. The diverse types of shorelines contribute to the accumulation of various kinds of debris, and research on the quantity and locations of debris can be improved. The Coastal Observation and Seabird Survey Team[121] (COASST) conducts a volunteer-led survey that generates and monitors weekly plots of debris. However, there remains a lack of clear understanding regarding what drives different marine debris events.

[121] https://coasst.org/

> Additionally, it is important to identify whether specific types of debris originate from local sources. Debris is not just about items drifting in from afar. If local sources of debris are present, tracking methods and strategies for mitigation are needed. This kind of data would be invaluable, particularly for items like oyster ropes.

Effect of marine debris on microorganisms. The effect of marine debris on microorganisms is a data gap overall. If not removed, large debris eventually breaks down into micro-sized particles, which organisms can ingest. Microorganisms are known to consume plastic particles. Plankton or larvae may mistake plastic for food, ingesting debris that can make them feel full but ultimately lead to starvation. There are a few studies that suggest certain levels of debris have a particular effect on microscopic foundational animals in the food chain.

There are also studies that indicate debris can affect ecosystems by smothering habitats, causing abrasion, and altering oxygen availability. Novel microorganism communities have also been observed colonizing plastic, while parasites, bacteria, or viruses attach themselves to plastic and spread to new areas. Species show varying resilience to these impacts, necessitating comprehensive studies that include protein expression, eDNA, plastic additives, chemical composition, and hydrophilic compounds. There is a need to identify which species are most significantly affected by debris and to determine the criteria for selecting species to study. The choice of species to study will also depend on geographic location. Notably, the geographic range of organisms may shift with climate change.

Assessing the impact on microorganisms also necessitates understanding the diverse composition of debris. Specifically, plastics are complex materials made up of various components, including additives, and have the ability to absorb and release chemicals. This complexity makes it challenging to understand their behavior and their impacts on species.

Feedback on importance: Microorganisms serve as vital indicators of ocean health. There is a need to better understand the effect of debris on these microorganisms, including whether debris impacts microbiomes—communities of microorganisms.

> **WCMAC:** While unfamiliar with the specific effects of marine debris on microorganisms, its harmful nature is known.

Effect of marine debris on macroorganisms. Debris has the potential to alter chemistry, physiology, and habitat of macroorganisms. There is a need to study the physiological effects of debris on organisms across all levels of the food chain, including humans, and to assess the risk of exposure at the molecular level. Determining whether a particular type of debris is significantly harmful will aid in evaluating future activities to prevent the introduction of potential sources of such debris. While the specific impacts on physiology at both species-specific and population levels are not fully understood, there are clues and there is a wholistic understanding of the effect of debris on species.

The overall impacts of macro-debris are well documented. For instance, container ships, with their increasing size and high shipping activity, can significantly affect macroorganisms. When containers fall overboard, the full implications—such as the potential dispersal of chemicals and their impact—remain uncertain. Understanding the issues that arise as a result of containers falling overboard and breaking apart or floating into international waters where regulations are limited, is particularly challenging. Furthermore, species are at risk of ingesting debris or becoming entangled in it. For example, certain bird species are more prone to ingesting specific types of debris than others. Relevant data are available through COASST, a citizen science project that focuses on marine and beach-cast birds—those found dead or dying along shorelines, often washed up by the tide. The physical impacts of ingesting macro-marine debris are straightforward, as this material is capable of causing blockages in the digestive tract with a single appropriately sized piece. Researchers have extensively studied the effects of debris on important species such as salmon and large marine animals. Entanglements, such as by whales, are also well-understood.

The ecological and biodiversity impacts of smaller plastic debris remain largely unexplored. It is well-established that plastics in the environment absorb surrounding contaminants, which can then enter an animal's body upon ingestion and bioaccumulate up the food chain. However, the long-term effects of chemical exposure, including lethal and safe doses, and how these chemicals interact within organisms' bodies are not well understood. For instance, nanoplastics may be able to cross the blood-brain barrier. There are no conclusive answers.

There are published papers on feeding experiments. In Washington, researchers have investigated the effect of plastics on shellfish species. While plastics were observed in wild oysters, they were not at concentrations reported by other countries or at a level that would be concerning. Bivalves appear to cope well with debris due to their efficient filtering capabilities, enabling them to eliminate undesirable substances. Less is understood for organisms that cannot filter water. It remains unclear whether ingested debris can be expelled as waste. There is some evidence that indicate the associated toxins can have an effect.

There is also a wealth of information that is not specific to Washington state. Researchers are actively studying filter feeders to understand impacts to growth. The impacts of contaminants vary depending on dose and chemical composition, and the scientific community has not reached a consensus on safe thresholds. There is also insufficient understanding of debris ingestion. While ingestion can harm organisms internally, the specific contaminants leaching from debris and their subsequent impacts remain unclear. New chemicals are continually produced and released into the environment without a complete understanding of their effects. Wildlife also do not live in isolation and are exposed to a wide array of stressors such as viruses, heavy metals, and persistent organic pollutants. Tracking these chemicals in tissues through laboratory analysis is an expensive undertaking.

Feedback on importance: Understanding how marine debris affects organisms is crucial. While foreign substances are generally seen as harmful, it is essential to determine which types pose the greatest threat, especially to sensitive species and habitats. This is particularly important for species like salmon, which are economically and recreationally valuable and critical for food security and community well-being. Studying the impacts on these organisms also provides insights into potential effects on humans. Understanding the physiological effects on non-human species can inform how debris impacts human health.

> **WCMAC:** It is challenging to foresee a time when data gaps will be eliminated in this area. There is still much that remains unknown about how microplastics and marine debris—whether Styrofoam or tire rubber—affect complex systems and food webs.

Furthermore, the potential for invasive species to hitch a ride on debris must also be taken into account. The impact of marine debris on various species requires further exploration for a more comprehensive understanding.

Source of marine debris. Marine debris originates from human activities, both locally and from places connected to the ocean. Overall, there is an understanding of the major types of debris, and it is possible to infer the source of collected debris. However, existing data collection efforts typically do not focus on specific types of debris and are limited to whatever debris is encountered. The shoreline is the most accessible area to search for debris. Obtaining data from the ocean and seafloor poses greater challenges. While weathering analysis of debris can estimate the duration of the debris in the ocean, it does not reveal the source of the debris.

Determining the source of long-distance debris is complex. A foreign product may not have come from overseas. Products from various global origins are often imported, used, and disposed of in the United States (US). To determine whether debris originated from a foreign location, local waste can be examined. However, this can be expensive or otherwise impractical. Washington waste collection efforts depend on municipalities. There is no overarching entity that controls this effort. The lack of centralized waste management complicates efforts to understand local versus external debris sources. There is a critical need for improved methods to trace debris back to its sources and establish accountability measures.

Data on the sources and distribution of microplastics in Washington state waters is also severely lacking. Because micro-plastics can accumulate and pose many potential dangers for important species in Washington, there is a need to obtain a baseline on the presence of microplastics in sediment and water.

Figure 13. A person holding a translucent white trash bag with a plastic bottle.

Feedback on importance: While overseas issues cannot be addressed locally, identifying what is locally sourced can make a meaningful impact. There is a need to spend time to identify the problem, understand the sources, and develop solutions. Addressing the problem at its source will result with less pollution. The focus should be on identifying the most detrimental pollutants, particularly those affecting sensitive species and habitats.

WCMAC: Identifying the source of debris is crucial for addressing the marine debris issue effectively. There is particularly significant work to be done on locally sourced debris. This includes examining whether high-traffic areas, such as beaches where parties occur, contribute to point-source pollution, as opposed to debris carried by currents and weather patterns in the Great Pacific Ocean and plastic gyres affecting specific locations. Investigating local sources, such as oyster ropes, offers an opportunity for research in this area.

Effect of chemicals in plastic debris and its effect on species. Studies addressing this data gap are just beginning in Washington. While some aspects are well understood, many additives used in plastics are proprietary and producers do not disclose their formulas, making it difficult to identify these additives. This lack of transparency complicates efforts to understand the effects of chemicals in plastics. Additionally, as new chemicals are continually developed, understanding their impacts will remain a dynamic challenge.

Feedback on importance: The effect of chemicals is an eternal moving target. Producers are constantly innovating and changing the composition of items, such as plastic, that can eventually become marine debris. There will be a need to stay on top of this data gap.

WCMAC: There is a vast amount to explore regarding the effects of chemicals in plastics on various species, and much remains speculative. It is clear that these chemicals are detrimental. Research focused on understanding how these chemicals interact with the food web, including implications for human consumption, should be prioritized.

Degradation of plastic debris. The process of degradation in plastics is reasonably well understood, but the extent of plastic degradation remains largely unclear. There is a critical need to investigate the complete life cycle of plastics in various environmental conditions. The ocean presents a challenging environment for degradation, as plastics require specific conditions to break down effectively. Factors such as pressure, light exposure, temperature variations, and geographic location play significant roles in the degradation process. Some regions harbor bacteria that may naturally degrade plastics. Additionally, new types of debris are continually being introduced into the environment. The degradation rate can vary significantly based on the type, size, and structural format of the plastic debris.

Feedback on importance: This data gap will help to better understand the effect of structures that currently exist.

WCMAC: There is considerable data on how plastics degrade, likely including proprietary research on the effects of UV light, sunlight, and water on this process. It is essential to investigate how different materials degrade or remain intact. Clarity is also needed regarding the types of plastics included in definition of “marine debris,” such as whether polystyrene is part of that classification. The scope should be more inclusive. Note that other common marine debris, such as rubber, various metals, glues, and polymers, are non-biodegradable and have harmful environmental impacts.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Trend in the influx of marine debris
- Role of marine debris in the context of invasive species
- Effect of marine debris on hypoxia

Trend in the influx of marine debris. Determining whether the influx of marine debris is changing is challenging. Because Washington's population is increasing, any potential change over time in marine debris abundance may not reflect the actual per capita rate at which debris is entering Washington's waters. Additionally, with increasing plastic usage, the effectiveness of debris prevention measures remains uncertain. Identifying the most effective strategies and necessary actions to address this issue is crucial.

Role of marine debris in the context of invasive species. The role of marine debris is understood. There are biosecurity concerns due to the persistence of plastics in the environment. Historically, invasive species faced obstacles traveling across the Pacific Ocean because natural materials would degrade over time, losing their structure and transport capability. Plastics, however, persist longer and can become colonized by invasive species, potentially serving as vectors for global transport. Climate change further complicates this issue by altering habitats, enabling invasive species to thrive in new areas. This dynamic scenario means that what may not pose a problem presently could become a significant issue in the future.

Effect of marine debris on hypoxia. There is no evidence to suggest that plastic has any contributing effect toward hypoxia events.

Offshore wind data gaps

- Effect of offshore wind structure on marine debris
- Effect of offshore wind on risk of exposure to marine debris

Effect of offshore wind structure on marine debris. New activities can contribute toward the introduction of new types of marine debris. Infrastructure, construction processes, and human activities are significant sources of debris. If offshore wind components are made of plastic, the addition of debris through these structures is expected to be statistically insignificant in the context of all of the plastic that enter the ocean from existing sources. As microplastics are ubiquitous, the structures are not expected to alter the overall concentration of plastic already present in the ocean. However, with the potential for stronger storms due to climate change, components of offshore wind structures, including cables, could break loose and wash ashore or impact protected habitats. The size and design of these structures may influence the transportation of its components or other materials via ocean currents. Additionally, if currents are altered near the structure and cause water to circulate in a pattern, there is a risk of material accumulating on the surface. Similarly, if offshore wind changes sand migration patterns, the distribution of marine debris may also be altered.

It's uncertain if an offshore wind structure would act as a marine debris aggregator. It might intercept debris through entanglement, converting freely floating items into trapped ones with long-term consequences. Such structures, for example, can ensnare fishing gear. Increased structure may attract more wildlife, thereby raising the risk of entanglement.

Effect of offshore wind on risk of exposure to marine debris. The risk of exposure to marine debris is not anticipated to change significantly with offshore wind. Especially for plastic debris, any additional plastic debris introduced into the ocean through offshore wind structures is unlikely to have a substantial impact compared to the volume released from all current sources.

However, if offshore wind structures aggregate marine debris, they may alter a species' risk of exposure. Items that were once freely floating could become trapped, resulting in long-term consequences. If debris and organisms aggregate, this overlap in distribution increases the risk of exposure or ingestion for species. Moreover, if the structures attract species, this could also lead to an aggregation of predators, further heightening the risk of exposure for all species involved. The potential impact would also hinge on the location of the turbines and whether they overlap with the existing distribution of a specific species. For example, some bird species are offshore divers and are known to consume debris. If turbines are sited within their foraging areas, these birds may encounter higher levels of debris, increasing their exposure and potential risk.

Offshore aquaculture data gaps

- Effect of offshore aquaculture structure on marine debris
- Effect of offshore aquaculture on marine debris and food security
- Effect of offshore aquaculture on marine debris and the shoreline
- Effect of offshore aquaculture effluent and byproducts on the quality and quantity of marine debris

Effect of offshore aquaculture structure on marine debris. While the effect depends on the scope and type of aquaculture, any aquaculture structure has plastic or metals involved and some percentage is expected to be released unintentionally into the environment. There is a relationship between the materials that are used in aquaculture operations, the processes, and the likelihood of those materials becoming marine debris. Sources of debris include associated buoys, the plastic lines used for shellfish aquaculture, and plastic bags. There is a need to think about the life cycle and weathering of aquaculture gear as it may release small particles even if it appears intact. Offshore aquaculture might also create a hazardous environment. The structure may cause entanglement, entrapment, ghost fishing, and alter habitat. There are efforts to prevent aquaculture activities from becoming a meaningful source of debris.

Effect of offshore aquaculture on marine debris and on food security. The risk of human exposure to marine debris through farmed species varies depending on the species involved. For example, unlike shellfish, there is less concern about humans ingesting marine debris through fish consumption because humans typically do not consume the stomach or organs of fish species. If a single species is farmed extensively, the risk to consumers could shift depending on how and where debris is accumulated within that species, potentially affecting public health and food security.

Currently, microplastic concentrations in farmed species are not considered problematic, but there may be risks to humans and other species if species with bioaccumulated debris are consumed. Concerns arise from both the plastic particles themselves and the chemicals they may carry. There are also uncertainties regarding potential health risks beyond physical effects and understanding the molecular-level and population-level impacts of this exposure. To safeguard public health and ensure consumer awareness, comprehensive debris tracking will be essential for informing regulations.

Effect of offshore aquaculture on marine debris and the shoreline. In the Gulf of Mexico, floating oyster cages are employed for aquaculture. During storms, these cages can become dislodged and drift into inaccessible habitats. Therefore, it is vital to not only identify suitable locations for aquaculture activities but also to assess potential areas where these structures may end up if they are washed ashore. Preventing these cages from becoming stranded in remote or inaccessible locations, where retrieval would be difficult, is essential.

Effect of offshore aquaculture effluent and byproducts on the quality and quantity of marine debris. It is crucial to investigate the effect of offshore aquaculture effluent and byproducts on the quality and quantity of detritus in the marine environment. For example, debris from oyster farms pose a significant issue. The release of oysters involves cutting and disposing of the lines they grow on. These lines can be sources of microfibers and microplastics that are subsequently consumed by filter-feeding species like oysters.

Resources

Table 35. Resources relevant to marine debris.

NAME	ACCESS	TYPE	DESCRIPTION
Coastal Observation and Seabird Survey Team (COASST)	https://coasst.org/	Website	Provides data and information on beached birds and marine debris from surveys conducted across California, Oregon, Washington, and Alaska.
DNR: Vessel inventory and removal lists	https://www.dnr.wa.gov/programs-and-services/aquatics/derelict-vessels/derelict-vessel-inventory-and-funding	Website	Updated quarterly, provides a list of vessels DNR identified as potentially derelict or abandoned and a list of vessels that were moved through the Derelict Vessel Removal program are provided.

NAME	ACCESS	TYPE	DESCRIPTION
MyCoast: Washington	https://mycoast.org/wa	Database	In collaboration with the Washington Department of Natural Resources, US Geological Survey, Washington Sea Grant, the Snohomish County Marine Resource Committee, the Northwest Straits Initiative, and other partners, information is collected to characterize beach change and the impact of nearshore hazards.
NOAA: Marine Debris in the Pacific Northwest	https://marinedebris.noaa.gov/your-region/pacific-northwest	Website	Provides reports, blogs, and newsletters and shares information on current projects, regional collaboration efforts, regional topics, regional partners, and abandoned and derelict vessels.
NOAA: Marine Debris Monitoring and Assessment Project	https://mdmap.orr.noaa.gov/	Database	Provides information on the amount and types of marine debris on shorelines.
NOAA: Washington Marine Debris Action Plan	https://marinedebris.noaa.gov/regional-action-plans/washington-marine-debris-action-plan	Report	Describes work planned for 2021-2022 on marine debris and establishes a framework for strategic action to reduce the effect of marine debris on the state and its coast, people, and wildlife.
Ocean Conservancy: International Coastal Cleanup	https://oceanconservancy.org/trash-free-seas/international-coastal-cleanup/	Website	Provides data, information, and resources on the International Coastal Cleanup, an effort to remove trash from the world's beaches and waterways.

NAME	ACCESS	TYPE	DESCRIPTION
Surfrider Foundation: Beach Cleanups	https://cleanups.surfrider.org/	Website	Provides data and information on Surfrider Foundation’s beach cleanups.

Ocean Acidification

Key Data Gaps

General Data Gaps

- Effect of ocean acidification on species
- Effect of carbonate system parameters on marine organisms
- Factors that affect the duration of harmful ocean acidification conditions

Offshore Wind Data Gaps

- Potential for offshore wind to affect the severity and intensification of ocean acidification
- Potential for offshore wind to cause an ocean acidification localization effect

Offshore Aquaculture Data Gaps

- Potential for offshore aquaculture to cause an ocean acidification localization effect

Other Data Gaps

General Data Gaps

- Trend of ocean acidification in time, space, and intensity
- Relationship of ocean acidification with eutrophication
- Human impacts and social consequences of ocean acidification

Offshore Wind Data Gaps

- Monitoring the effect of offshore wind on ocean acidification
- Effect of offshore wind on ocean acidification processes

Offshore Aquaculture Data Gaps

- Effect of chemicals, wastes, and nutrients from offshore aquaculture on ocean acidification
- Risk of disease intensification from ocean acidification
- Effect of offshore aquaculture on severity of ocean acidification and risk of intensification
- Effect of offshore aquaculture on duration of harmful ocean acidification conditions
- Effect of kelp aquaculture on ocean acidification

Background

Ocean acidification (OA) occurs as carbon dioxide (CO_2) dissolves in seawater, lowering pH, disrupting biogeochemical cycles, and creating a corrosive environment harmful to shell-forming organisms. CO_2 in the ocean can come from several sources. OA primarily results from the ocean absorbing elevated levels of atmospheric CO_2, currently at significantly elevated levels compared to historic conditions due to the burning of fossil fuels.

While OA is a global phenomenon, there are local factors that increase the occurrence of regional acidification. Upwelling, nutrient and organic carbon input from land, and absorption of other acidifying gases from the atmosphere all contribute to OA on Washington's Pacific coast. Upwelling caused by seasonally shifting winds brings corrosive waters to the surface, making acidified waters most prominent in the spring through late summer months. These acidified waters are transported up to the continental shelf, reach surface waters in some places, and enter the estuaries. In estuaries, they mix with land-based nutrients and organic matter, resulting in even more corrosive waters than those found offshore.

Ocean uptake of CO_2 reduces pH and carbonate availability, lowering the saturation state of calcium carbonate biominerals aragonite and calcite which marine species use to form shells and exoskeletons. This affects the survival of shell-formers such as oysters, crabs, corals, pteropods, and phytoplankton. Beyond reduced calcification, OA affects reproduction, egg survival, fish larvae development, behavior, tissue and organ structure, olfaction, and can alter populations, species distributions, food webs, disease prevalence, and mortality. For instance, recent studies showed that lower pH slows Dungeness crab larvae development and reduces survival rates. This likely has population-scale effects and negatively affects fisheries. OA also potentially affects otolith development in bony fishes. These inner ear organs are used for orientation and acceleration. Fish exposed to high CO_2 levels showed larger otoliths compared to those in current seawater conditions. These impacts to species ripple through ecosystems as affected species provide crucial habitat, shelter, and food for other organisms. For instance, pteropods, which are crucial to marine food webs, are experiencing significant shell dissolution, with over 50% of their population showing signs of this issue in some areas. Fisheries species like herring, mackerel, and salmon rely on pteropods as a key food source and are therefore, indirectly vulnerable to OA.

The Washington coast's heightened OA risk has also impacted the oyster industry, with hatcheries experiencing mass mortalities and low natural recruitment in the mid-2000s. Monitoring revealed that water intake during those failure events had low pH and saturation levels. To enhance hatchery success, the industry has implemented monitoring equipment and pH buffering.

A projected outcome of climate change, OA and its associated effects are expected to intensify. Since the mid-1700s, surface waters have become 30% more acidic and it is projected to increase by 38% to 109% by 2100 compared to 1986-2005 levels. This is equivalent to a 150% to 200% increase compared to pre-industrial levels. This intensification is anticipated to pose challenges for fishing industries and result in unknown effects to Pacific Northwest (PNW) species, habitats, and economies. Scientific studies indicate that heavily calcified organisms such as calcified algae, corals, mollusks, and echinoderm larvae are particularly vulnerable to the negative effects of OA. Mollusk shell formation rates are expected to reduce by 40% by 2100. Effects may extend to the human health and the economy. Ongoing research aims to understand and plan for these impacts to prepare industry responses and resource management actions.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to OA:

General data gaps

- Effect of ocean acidification on species
- Effect of carbonate system parameters on marine organisms
- Factors that affect the duration of harmful ocean acidification conditions

Effect of ocean acidification on species. There is some knowledge about the effects of OA on certain species, but given the multitude of species that are affected, understanding the effect of OA on species remains limited. Additionally, most studies concentrate on individual species in isolation. Understanding of community- and ecosystem-level effects of OA is likely lacking, partially due to the substantial baseline variability that complicates such investigations.

Invertebrates: There is a better understanding of shellfish than other groups of species, with pteropods being the most studied. Efforts are increasing to understand the effects of OA on Dungeness crabs in its different life stages.

Finfish: Fish species are likely impacted by OA conditions. Studies on salmon have shown that OA negatively affects their cognitive functions, neuro-perception, sense of smell, ability to detect predators, navigation, and use of magneto-receptors.[122]

Marine mammal: The effects of OA on marine mammals remain uncertain. Isolating the impacts of OA on these animals is challenging due to the numerous other factors affecting their well-being. Since many marine mammals are predators, understanding how OA affects their prey species will be important and will provide insights into the effect of OA on marine mammals.

Understanding the effects of OA on species is complex. Translating laboratory results to field contexts is challenging due to the dynamic nature of environmental parameters. There are more gaps than definitive knowledge. While there is some understanding of the spatial variability of oxygen, long-term changes in acidification parameters, and effects on species, there remains uncertainty about how ocean conditions influence species distribution and their subsequent exposure to fisheries exploitation. Species may be compelled to migrate to more favorable habitats, potentially affecting predation and susceptibility to fishing efforts.

[122] https://www.washington.edu/news/2018/12/18/salmon-may-lose-the-ability-to-smell-danger-as-carbon-emissions-rise/

The influence of water quality on species distribution is not well-understood. In cases where a species is sensitive and conditions are adverse, they may aggregate in less affected areas, potentially increasing their vulnerability to fishing activities. Addressing such conditions requires coordinated efforts among state agencies to integrate management strategies effectively. Enhancing collaboration between water quality and fisheries managers is essential. However, it is important to recognize that solutions to mitigate OA for certain species may not be universally applicable, and efforts to reduce CO_2 levels may sometimes conflict with existing marine activities.

Feedback on importance: There is a significant risk that wild populations may reach OA thresholds in the near future. It is crucial to assess the feasibility of hatchery support for species like Dungeness crabs as soon as possible. Gaining insight into this potential will inform better policy decisions.

> **WCMAC:** Extensive research is currently being conducted on the effects of OA on various species. Researchers are identifying which species are at the greatest risk. Availability of ions in ocean water is crucial for shell formation, particularly during critical periods in an organism's life cycle. If these ions are not available due to OA at pivotal moments, it can have detrimental consequences for those species.

Effect of carbonate system parameters on marine organisms. This is an important data gap. Coastal Tribal fishery managers have observed various species wash up on beaches due to oxygen depletion. Different species exhibit varying sensitivities to pH, CO_2 levels, and saturation states. Methods are in place to estimate these parameters using proxy variables such as oxygen, temperature, and salinity.

There has been extensive research on the impacts of OA parameters on marine organisms in Washington State. Considering the lack of knowledge in other areas of the world, it may seem odd to express concerns about data gaps in Washington; however, there is a lack of understanding for certain species in the state. For example, there have been few experiments conducted on salmon, limited research on geoducks and oysters, and some studies on Pacific oysters and pteropods. Pteropods, which are considered an indicator species for OA, have transparent calcium carbonate shells and can serve as a proxy for assessing the impacts of OA. While they may not have commercial value, they play a crucial role in the food web.

In the early stages of OA research, the focus was primarily on oysters, which later expanded to include other shelled species of commercial and ecological significance. On the outer coast, there is considerable attention given to razor clams, but substantial data gaps still persist. Anecdotally and through traditional ecological knowledge, there have been reports that shells weaken over time, but formal experiments validating this are lacking. Razor clams are particularly challenging to spawn, propagate, and maintain in captivity compared to other shellfish species. Their unsuitability as lab organisms complicates experimental studies. Furthermore, inconsistencies in observations contribute to the complexity of the issue. Razor clams appear resilient in conditions once considered corrosive or thrive in some areas while struggling in others. Additionally, despite showing no obvious signs of stress, their population numbers may be lower, or individuals may be smaller. This suggests that factors beyond OA and hypoxia are likely influencing these trends.

The effects on other economically and culturally significant species are better understood. There is growing research on Dungeness crab. Initially, it was believed that crustaceans were less vulnerable to OA due to their chitin-based shells. However, it was discovered that during early life stages, their shells contain calcium carbonate and are more susceptible to corrosion in acidic conditions. Subsequent net tows and shell condition assessments revealed direct impacts of OA on juvenile crabs. There are also indications that OA may affect sensory perception in the sensory hairs on their claws. Rather than OA, based on the limited knowledge on the crab population, hypoxia may pose a greater threat.

Relating to the effect of OA on different carbonate system parameters, there is a need for more direct validation measurements that can be integrated with benthic time series data to assess progress on various parameters. While estimates are informative, they are constrained by uncertainties. Currently, there is a lack of high-quality CO_2 sensors, and there is reliance on discrete sampling methods. There is a need for additional equipment, more time for analyses, and enhanced baseline and monitoring efforts in specific areas. Conducting a comprehensive analysis in the Olympic Coast National Marine Sanctuary (OCNMS) also could yield sufficient insights into the impacts of installations.

Feedback on importance: The effect of various carbonate system parameters on marine organisms has long been a critical question. It is a priority issue and has the potential to drive policy action.

> **WCMAC:** Reflecting on their service on the blue-ribbon panel, it is evident that there was a solid understanding of how various carbonate system parameters affect different organisms, such as larval oysters. This affect raises grave concerns, particularly in light of an incident where low pH levels led to failures in oyster hatcheries. Years ago, the water quality of Bone River in Willapa Bay did not meet water quality standards due to excessive acidity caused by natural processes. Similarly, the upper half of the Chehalis Basin was found responsible for emitting 50% of acidic waters. The carbon system in these regions includes forested land in its natural state, where the accumulation of leaf litter and rainfall plays a significant role in influencing local water chemistry. This natural vegetation can affect pH levels, as the decomposition of leaf litter contributes organic matter and nutrients, which can lead to fluctuations in acidity. In some bays, such as Willapa, the natural conditions may be on the edge of what is suitable for oysters. This underscores the importance of returning oyster shells to the bay to reintroduce carbonate into the system.

Factors that affect the duration of harmful ocean acidification conditions. There is a need to better understand the factors influencing the duration of OA conditions. Duration is likely influenced by the drivers of low dissolved oxygen (DO), with buffering capacity being a key factor. The ratio of acidifying to buffering agents in the system plays a crucial role, introducing nonlinearity that complicates the ability to predict these conditions accurately.

OA is occurring, and the use of renewable energy sources like offshore wind could potentially mitigate this by reducing CO_2 emissions, depending on the scale of the project. Offshore wind activities could also potentially influence the duration of harmful OA conditions if they significantly affect upwelling and downwelling, though this is unlikely. Such an impact would require a large-scale deployment of turbines of substantial height. Detailed modeling would be necessary to explore these potential effects. It's important to note that continental wind patterns are unlikely to be altered by concentrated infrastructure like offshore wind farms.

Feedback on importance: No feedback provided.

> **WCMAC:** The primary factor affecting the duration of harmful OA conditions is the increasing levels of carbon in the atmosphere. Elevated atmospheric carbon interacts with ocean surface waters, forming carbonic acid. This cycle is well understood, and the current trajectory is concerning. As carbon levels rise, the interaction with ocean surface waters intensifies, leading to greater production of carbonic acid.
>
> While the ocean has a significant capacity to absorb carbon, this process presents future challenges. Efforts are underway to explore passive methods for mitigating these issues and to engineer potential solutions. For example, Prince of Wales Island has implemented a strategy of pulverizing carbonate and applying it to beaches, which aids in absorbing and neutralizing carbon without generating additional acid. There was also a recent study involving the application of pulverized olivine to beaches which demonstrated remarkable carbon absorption results. The practice of pumping CO_2 underground is met with skepticism due to its high costs and complexities.

Offshore wind data gaps

- Potential for offshore wind to affect the severity and intensification of ocean acidification
- Potential for offshore wind to cause on ocean acidification localization effect.

Potential for offshore wind to affect the severity and intensification of ocean acidification. It is difficult to envision how the installation of offshore wind farms could directly affect carbonate chemistry. Offshore wind itself does not introduce effluents or large quantities of dissolvable alkaline materials into the water and therefore, does not directly affect OA conditions. On a larger scale, however, transitioning away from fossil fuel-based electricity generation—such as by adopting offshore wind—could help reduce the intensification of OA, as fossil fuel combustion is a significant driver of OA.

If offshore wind activities were to extract energy from the system, they would likely impact wind-driven processes, upwelling, and microcirculation. It is hard to imagine that these processes would remain unaffected. The extent to which offshore wind would influence continental wind patterns is unclear. Upwelling, which is naturally high in CO_2 and low in pH, and downwelling play a significant role in influencing OA. Any changes in the intensity of upwelling caused by offshore wind could alter OA conditions.

If offshore wind activities were to reduce upwelling, it could alter the amount and timing of naturally more acidic seawater reaching the surface. This may or may not result in a less corrosive water column. Additionally, other natural processes such as stratification and hypoxia could be affected. Since upwelling also brings vital nutrients, disruptions to this process could impact primary productivity, which in turn influences calcification rates and potentially alters OA levels. However, the specific impacts of these changes remain unclear. Furthermore, the biological pump, which includes calcifiers, releases CO_2 during calcification, thereby exacerbating acidification.

Sediment disturbance and the localized effects of biofouling on hardware could influence the severity of OA. Resuspension of inorganic carbon may exacerbate hypoxia, potentially prolonging its duration depending on the timing and seasonality of such events. To mitigate these effects, it may be necessary to consider circulation patterns and time dredging efforts to ensure that resuspended waters can be effectively dispersed offshore, where the impacts can be diluted. Winter conditions are typically more favorable for this. Modeling the potential impacts would be valuable in guiding these decisions, helping to assess the effects and determine whether seasonal mitigation strategies are feasible. Additionally, increased boat traffic associated with offshore wind activities could also contribute to pollution, further worsening OA.

While East Coast installations like Block Island provide valuable insights, information from the West Coast would be more relevant due to the differences in oceanographic conditions between the two coasts. Key factors to consider include the size, location, and operational timing of the offshore wind turbines.

Feedback on importance: In an upwelling system, it is essential to understand how removing atmospheric energy will impact wind-driven processes.

> **WCMAC:** It is unlikely that offshore wind has a significant effect on ocean acidification. Intuitively, the effect appears to be somewhat neutral. The risks associated with offshore wind development seem to be more political in nature.

Potential for offshore wind to cause an OA localization effect. It is believed that offshore activities may not have as significant an impact on OA as those closer to shore. For example, along the northern outer coast, severe hypoxia is observed in certain areas, notably in the Quinault waters. Influencing factors include outflows from the Columbia River and bottom geography, such as the Quinault canyon. However, in open water bodies, different regions can exhibit unique chemistry and carbon concentrations mix extensively within the water column. The potential effects of offshore wind on these dynamics remain uncertain.

Feedback on the potential localized effects of OA was mixed. One perspective suggested that OA is primarily driven by large-scale coastal processes and is not typically localized. In contrast, another viewpoint indicated that changes in specific factors could influence the localization of OA. For instance, offshore wind projects may alter circulation patterns. While the direction and consistency of their impact on OA remain uncertain, these shifts could result in minor positive effects in some cases, while in others, they may lead to negative effects.

Localized effects could also potentially arise from sediment disturbance or biofouling on offshore hardware. The installation of new human infrastructure in the ocean, such as hard structures, could attract marine organisms and create surfaces for their growth. For example, if algae and barnacles die and decompose on these structures, they will release CO_2 and consume oxygen, potentially contributing to localized OA effects. These processes could subsequently affect marine chemistry.

Feedback on importance: The potential magnitude and extent of localized ocean acidification (OA) effects is a key concern in aquaculture. These effects are likely to be site-specific, raising questions about the significance of their impact in different locations.

> **WCMAC:** It is unlikely that offshore wind has a significant effect on ocean acidification. However, offshore wind could potentially reduce upwelling, thereby limiting the upward movement of water. The consequences of this reduced upwelling are uncertain. It is important to note that upwelling not only involves nutrient-rich waters but also includes factors such as hypoxia and more acidic waters. Further investigation into whether offshore wind has a localized effect would be valuable.

Offshore aquaculture data gaps

- Potential for offshore aquaculture to cause an ocean acidification localization effect

Potential for offshore aquaculture to cause an ocean acidification localization effect.

Feedback on the potential localized effects of OA was mixed. One perspective suggested that OA is primarily driven by large-scale coastal processes and is not typically localized. Another viewpoint indicated that changes in specific factors could influence the localization of OA. In this view, offshore aquaculture operations could act as point sources, with the most significant effects occurring near the aquaculture activity. Waste from aquaculture operations may also reach the seafloor, potentially exacerbating hypoxia and acidification events. Additionally, this waste could affect primary production, further complicating OA risks due to the non-linear dynamics that influence OA severity and duration. Localized effects may also result from sediment disturbance and biofouling on infrastructure.

Feedback on importance: The potential impact of offshore aquaculture on the localization of OA is a key question in the field. While the expectation is that this effect will be local, the critical inquiry is how significant it will be, likely varying by specific sites.

> **WCMAC:** There is a preference for aquaculture activities to take place in coastal bays. In particular, offshore seaweed aquaculture is intriguing. Some individuals in California have been successfully cultivating seaweed for the marketplace. While offshore seaweed aquaculture may have an impact on the localization of OA—albeit a minor one—it is important to note that carbon is absorbed by seaweed, finfish, and shellfish as they grow. These organisms are then brought ashore, consumed by humans, and eventually excreted. The carbon is part of the natural cycle, moving from the atmosphere to organisms and back again, unless it enters a septic system and becomes sequestered. The fate of carbon that goes through sewage systems or landfills is less

clear; it is uncertain whether landfills are capped or if the carbon becomes locked into the soil, and how this process interacts with the acidification cycle.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Trend of ocean acidification in time, space, and intensity
- Relationship of ocean acidification with eutrophication
- Human impacts and social consequences of ocean acidification

Trend of ocean acidification in time, space, and intensity. Cold water has a higher capacity to hold gases compared to warm water, so upwelled water, being colder and older, contains elevated levels of CO_2. While this upwelling process is natural, it is amplified by OA. The variability in carbonate chemistry further complicates the interpretation of data.

The trend of OA, influenced by temporal and spatial scales, is well understood. Studies conducted every four years show consistent trends, along with seasonal variations in intensity and duration. Projects like LiveOcean[123], which provides 48-hour forecasts with high spatial resolution, and the Observing Network, which is valuable for tracking seasonal and decadal trends, have made significant contributions. However, there is still a need for more observations. To address this gap, the Interagency Working Group on Ocean Acidification has developed a comprehensive monitoring plan[124].

NANOOS serves as the central hub for this type of data, overseeing the monitoring and curation efforts. While the NANOOS Data Explorer[125] indicates comprehensive coverage of the outer coast, it's crucial to ascertain the operational status of its monitoring assets; some may be offline or require servicing. The presence of transect lines does not guarantee active data collection, highlighting gaps in coverage. There is a need for additional monitoring assets and trained personnel to effectively translate data into actionable information. Moreover, understanding the data on NANOOS may require guidance, especially for those outside the field of oceanography. Fortunately, there are instructional resources such as 'how to' videos available to facilitate navigation and comprehension of the data provided.

Data gaps always exist, but they depend on the specific question being addressed. If the goal is to understand OA at the state level in Washington, there is no significant data gap. Washington leads the world in OA monitoring, with extensive data streams providing strong insights into the region's conditions. Several programs contribute to this robust monitoring: Ecology monitors 26 stations monthly; the Washington Department of Natural Resources (DNR) has two continuous sampling sites in the Acidification Nearshore Monitoring Network[126] (ANeMoNe) located on the

[123] https://faculty.washington.edu/pmacc/LO/LiveOcean.html
[124] https://oceanacidification.noaa.gov/iwgoa-home/
[125] https://nvs.nanoos.org/Explorer
[126] https://storymaps.arcgis.com/stories/8b277d4e0258487ba0254f87a4764ba7

coast, one in Grays Harbor and one in Willapa Bay; the University of Washington conducts three seasonal cruises; NOAA collects samples during major cruises (every 2-4 years for the West Coast OA cruises); and there are three to six buoys equipped with sensors to collect OA data. While acidification measurements have been recorded only since 2018, numerous experiments also generate valuable data over shorter time frames.

Despite these efforts, some areas in Washington lack OA monitoring. With exception to Willapa Bay and Grays Harbor, monitoring off the coast is largely absent due to challenging sampling conditions. Additionally, natural phenomena, such as El Niño and La Niña, can cause significant fluctuations. Data are still being gathered to determine whether trends will remain consistent over time. Ongoing monitoring efforts are in place to address these questions as they evolve.

Understanding the impact of regional or local acidification also demands additional resources. There's a potential limitation with current observational and modeling capacities. Addressing this would require dedicated local monitoring resources, robust modeling capabilities, and sufficient long-term datasets to ensure the strength of the data collected.

There is also more information available for deepwater than for surface water along the Washington coast. Additionally, while bottom waters are relatively well-monitored, there is a lack of direct measurements for OA in these regions. Much of the available information relies on using oxygen and temperature as proxy variables to estimate carbon chemistry. Increasing the number of sensor measurements would enhance the capability to monitor OA more accurately. However, this approach may not be universally applicable, particularly in environments prone to anoxic conditions, where carbon dynamics can change independently of oxygen levels. In Puget Sound, it is possible to observe decoupled oxygen and CO_2 conditions. There is a need to expand observations in critical areas, including identified hotspots and regions experiencing hypoxic and anoxic conditions.

Related to trends, there is some understanding of acidification as a stressor on marine organisms, with its effects being more intense in certain areas. Some species thrive in environments with high concentrations of acidification. For instance, the Whidbey Basin experiences more intense acidification stress compared to the more favorable conditions found in South Puget Sound. These regional differences are well-documented. Measurements taken by buoys provide some data but may not fully capture the complexities of acidification stress. While using sensors for measurements is cost-effective, the more costly method of collecting and analyzing water samples provides higher accuracy, crucial for making informed regulatory decisions. Ecology collects water samples for OA measurements, which are subsequently analyzed in a laboratory. These samples primarily focus on measuring concentrations of CO_2 or inorganic carbon. Additionally, while pH sensors are available, accurately measuring pH remains challenging.

Relationship of ocean acidification with eutrophication. The connection between OA and eutrophication is not considered a significant data gap. This relationship is more prominent in the Salish Sea than along the coast. Ecology is leading initiatives to investigate the impact of local, land-based nutrient inputs on OA in the Salish Sea. Assuming a relationship between eutrophication and OA, richer data can be used to provide more informed statements regarding eutrophication. There is likely fundamental work that could enhance understanding in this area.

Currently, there is more available data on oxygen levels than on pH. Additionally, there may be scenarios where OA is underestimated due to the proxies that are currently considered.

The ocean naturally undergoes upwelling processes that bring nutrients and low oxygen conditions. Excessive nutrient inputs lead to low oxygen levels and higher CO_2 concentrations. It is unclear where there could be excessive human input along the coast. In these areas, it is important to assess the extent of nutrient enrichment and observe how this is altering surface production using models. This requires the use of oxygen and CO_2 sensors to gauge how these changes impact bottom water oxygenation and enhance OA and hypoxia. The NOAA Pacific Marine Environmental Lab plays a significant role in data collection efforts. They are actively involved in conducting West Coast OA survey cruises from Mexico to British Columbia every four years and support fixed mooring monitoring. While some efforts are directed towards monitoring water quality parameters, there is no specific point source currently monitored for studying parameters relevant to OA.

Additionally, studying nitrogen and phosphorus input, nutrients that play a significant role in the process of eutrophication, generally involves modeling efforts. There is an in-house group that uses the Salish Sea Model to address such inquiries. In 2017, Ecology published a report on wastewater inputs and their eutrophication effects on OA. This study highlighted human nutrient contributions significantly impact OA conditions in internal inlets and deeper layers of the water column. Subsequently, there have been several peer-reviewed publications focusing on modeling studies, along with two national initiatives. The Southern California Coastal Water Resource Program models and conducts simulations to assess the impact of wastewater on OA, and similar efforts are underway in the northeastern United States.

One aspect that remains unexplored is a comprehensive assessment of the impact of human-induced eutrophication compared to other factors driving OA. In 2021, Ecology released a paper examining the individual and combined impacts of anthropogenic activities on OA. The study concluded that eutrophication contributes minimally to OA stress compared to CO_2 emissions, with its effects being relatively small and localized to specific areas.

Eutrophication should not be confused with deoxygenation. While deoxygenation can be caused by eutrophication which increases demand for oxygen through decomposition, deoxygenation can also occur independent of eutrophication. Global ocean oxygen levels are undergoing changes due to warming and stratification, as detailed in the International Panel of Climate Change's (IPCC) report on climate change.

Human impacts and social consequences of ocean acidification. There are groups dedicated to understanding and addressing human impacts and social consequences related to OA, such as the Marine Resource Advisory Council and the Blue-Ribbon Panel. It is particularly important to quantify OA effects such as threats to human health (e.g., harmful algal blooms) and impacts on commercial species. More of this information has become available in recent years.

Recently, a large OA research project[127] spanning four years was completed, focusing on impacts of OA on four coastal treaty Tribal communities. This interdisciplinary project involved Tribal leaders, oceanographers, fishery managers, biologists, and social scientists, among others. This project was based on extensive in-person interviews to assess the value and vulnerability of resources. It aimed to assess knowledge of ongoing changes, the implications of these changes for resources, and their effects on the health and availability of resources crucial to community wellbeing. The research findings have not yet been published.

Data collection and sharing are often inadequate to understand the effect of OA on human activities. For instance, obtaining fisheries data and correlating oceanic changes with observed impacts on specific fisheries is challenging. Data collection methods may be adjusted to enhance data usability and harmonize data streams. Additionally, improving the mutual utilization of diverse data streams presents numerous opportunities for enhancement. Aside from this project, there have been limited social science efforts in this area.

While specific effects on non-tribal coastal communities are not fully known, there have been initiatives involving discussions with coastal fishery managers. In a recent University of Washington project, natural resource managers were interviewed on topics like fisheries management and marine spatial planning. They were asked to prioritize issues such as hypoxia, warming, and OA in relation to resource management.

While there is considerable ongoing research, data gaps include:

1. Understanding the impact of acidification on human systems along the Washington coast, the effect on changed ocean uses, and how affected cultures will navigate these changes.
2. The magnitude of change that interested or affected parties are willing to accept. There is a need to explore how society can effectively balance progress with the need to mitigate climate change and how the impacts of human activities should be reconciled with those caused by OA.
3. Identify the actions that should be taken to address OA. Addressing practical and political opportunities to mitigate OA is of equal importance to studying its effects.

Offshore wind data gaps

- Monitoring the effect of offshore wind on ocean acidification
- Effect of offshore wind on ocean acidification processes

Monitoring the effect of offshore wind on ocean acidification. Existing monitoring assets could potentially be affected by offshore wind development. Surface monitoring tools such as buoys, gliders, and transects may be particularly vulnerable. Currently, there is one NOAA cruise conducted off the outer coast every 3 to 4 years, which covers a broad spatial scale and

[127] https://oceanacidification.noaa.gov/funded-projects/the-olympic-coast-as-a-sentinel-an-integrated-social-ecological-regional-vulnerability-assessment-to-ocean-acidification/

maintains established stations. The placement of offshore wind facilities could potentially interfere with these monitoring stations, depending on their proximity. If offshore wind installations are situated close to historic monitoring platforms that have generated valuable time series data, there is a possibility of interference, particularly if it affects water column mixing. Additionally, changes in wind speed caused by offshore wind could impact other data collected by these platforms, such as temperature measurements. Monitoring platforms submerged in deeper waters would likely experience less disruption from offshore wind developments.

Offshore wind infrastructure also has the potential to serve as new monitoring platforms. These installations could provide opportunities to deploy monitoring assets equipped with power and support crews for maintenance. Modeling various placement scenarios could help identify optimal locations for platforms, minimizing interference with existing monitoring stations while maximizing the benefits of new platforms for additional monitoring. Establishing monitoring requirements during the installation of hardware and dredging operations will be crucial. Adequate resources are necessary to gather baseline data. Additionally, having first-hand baseline data collected over a few years would be highly beneficial. However, there are challenges associated with CO_2 system sensors, as they tend to be more expensive, less readily available, or more complex to operate compared to other monitoring equipment.

Effect of offshore wind on ocean acidification processes. OA processes are generally understood. Large-scale basin circulation plays a critical role in determining the sources of water masses that upwell onto the shelves. Upwelling and river inputs interact which drives low oxygen events and interacts with OA. Seasonal corrosive hypoxia events are particularly influenced by a combination of local and regional processes.

Quantifying and understanding the potential impacts of offshore wind turbines on local arrays will be essential. Monitoring will help characterize the ocean environment and observe any resultant changes.

Offshore aquaculture data gaps

- Effect of chemicals, wastes, and nutrients from offshore aquaculture on ocean acidification
- Risk of disease intensification from ocean acidification
- Effect of offshore aquaculture on severity of ocean acidification and risk of intensification
- Effect of offshore aquaculture on duration of harmful ocean acidification conditions
- Effect of kelp aquaculture on ocean acidification

Effect of chemicals, wastes, and nutrients from offshore aquaculture on ocean acidification. Nutrient plumes and bacterial blooms can trigger acidification events. Increased nutrients in surface waters can enhance phytoplankton productivity, potentially altering production rates and supplying organic matter for benthic respiration. The effect of chemicals, nutrients, and waste from offshore aquaculture operations on OA depends on its type and scale. Aquaculture involving fish or shellfish generates waste and involves decomposition, which releases CO_2 into the environment. Waste products settling to the seabed may also exacerbate hypoxia and acidification events, affecting primary production and having nonlinear effects on severity and duration of OA. Shellfish are particularly sensitive to the aragonite saturation state and require favorable conditions for growth. Fish farming exhibits less variability in this regard.

The potential impact of offshore aquaculture would also depend on the chemicals used. If antibiotics are utilized, they could have a more substantial effect, though their use should ideally be restricted or regulated. Monitoring for Harmful Algal Blooms (HABs) will be crucial. There is knowledge of several different HAB species, with observed increases in both frequency and severity of these blooms during heat waves and under specific environmental conditions. However, in Puget Sound, where nutrients contribute to acidification, over 90% of these nutrients originate from ocean upwelling along the coast. Given the abundance of natural nutrients in the outer coast, the input from aquaculture is unlikely to have a significant broad-scale impact. However, it may have localized effects depending on specific site conditions.

In addition to the type of aquaculture, the effect depends significantly on its location. Finfish and, to some extent, shellfish aquaculture would cause greater stress from OA in areas with limited circulation. Finfish aquaculture in nearshore net pens is known to generate waste that can contribute to eutrophication. In these environments, aquaculture activities have been observed to exacerbate OA. For offshore aquaculture, the potential impact on acidification depends largely on its distance from the coast. Siting operations in regions with high water flow and low residence time, facilitating rapid flushing, should avoid or minimize impacts due to dilution. If situated far offshore, it would be surprising if aquaculture operations at a feasible scale had a significant impact on OA.

Seaweed and kelp farming can potentially mitigate OA by absorbing CO_2 through photosynthesis. The ability to quantify this effect largely depends on the farm's location. In confined or low-flow areas, such as a "bathtub-like" environment, it may be feasible to measure the benefits of CO_2 reduction. However, in dynamic and high-flow regions, measuring these benefits becomes challenging. An attempt to assess the impact on water chemistry at a kelp farm in Hood Canal was unsuccessful due to significant water mixing, which obscured the direct measurement of any effects.

Risk of disease intensification from ocean acidification. Offshore aquaculture can influence disease dynamics. Like other stressors in marine environments, aquaculture can serve as a potential source of disease, increase species vulnerability to existing pathogens, or create conditions conducive to the introduction of new pathogens. Risk of disease intensification is inherent in any concentrated marine farming activity.

There is a recognized link between disease outbreaks and ocean acidification. Eelgrass wasting disease is an example of a pathogen that is expanding due to ocean acidification, rising temperatures, or a combination thereof. Climate change, particularly changes in temperature, exerts a substantial influence on the spread of disease. Current literature extensively covers eelgrass wasting disease, primarily in Puget Sound, with potential extrapolations to the outer coast. Additionally, depending on environmental conditions, microbial pathogens can proliferate and potentially produce more toxic HABs. There is extensive literature on HABs.

Note that while phytoplankton may benefit from increased CO_2 availability, this alteration can also impact the overall energy balance within marine ecosystems.

Changes in temperature, oxygen levels and CO_2 dynamics must be considered. The interaction between OA, hypoxia, and warming represents a multi-stressor scenario that should be examined together to understand how they collectively intensify disease dynamics.

Effect of offshore aquaculture on severity of ocean acidification and risk of intensification. Shellfish aquaculture is generally more affected by OA rather than contributing to it. The effects of finfish aquaculture to OA depend on its proximity to the shore, and kelp aquaculture requires harvesting to sequester carbon. There is a concern that kelp aquaculture could exacerbate OA if large quantities of kelp sink into the ocean, decompose, and release CO_2 back into the water. The rate of decomposition is not well understood. There are studies in deep water (>1000 meters) that are investigating this process. Additionally, at the surface where kelp is cultivated, nutrient availability is crucial for kelp growth. Intensive farming could potentially deplete these nutrients, impacting plankton species that rely on them. This could lead to a cascade of effects throughout the ecosystem, affecting marine biodiversity.

The introduction of nutrients can enhance phytoplankton productivity. Given the known presence of various HAB species, the potential effect on HABs will need to be considered. HABs appear to occur more frequently and with greater severity during heat waves and specific conditions. Waste from aquaculture operations may also reach the seafloor and potentially affect primary production and contribute to an increased severity of hypoxia and acidification events. However, it is challenging to predict the precise changes in productivity rates or the potential support for respiration in benthic waters without understanding the scale of the project. While the potential effect, especially in the open ocean, largely hinges on the scale of the offshore aquaculture operation, at a practical level, aquaculture farms should not exacerbate OA. In this regard, offshore locations in the deep ocean may be more suitable for aquaculture operations than nearshore farming.

Effect of offshore aquaculture on duration of harmful ocean acidification conditions. Offshore aquaculture activities could influence the duration of OA if it poses a risk of disease intensification; causes localized effects; or its chemicals, waste, or nutrients affect the ecosystem. The effect will depend on the scale of the aquaculture operations, as large-scale operations will be necessary to affect the duration of OA.

Effect of kelp aquaculture on ocean acidification. The effect on OA will be influenced by various factors such as bed size and kelp management practices. Growing kelp and harvesting it can reduce surface water CO_2 levels but may not impact deep waters significantly. Additionally, kelp calcification can lower pH levels by reducing alkalinity, elevating CO_2 levels, and increasing the partial pressure of CO_2 in the water. Modeling would be necessary to understand the effect of kelp aquaculture on OA, although existing models may already cover some of these factors.

Resources

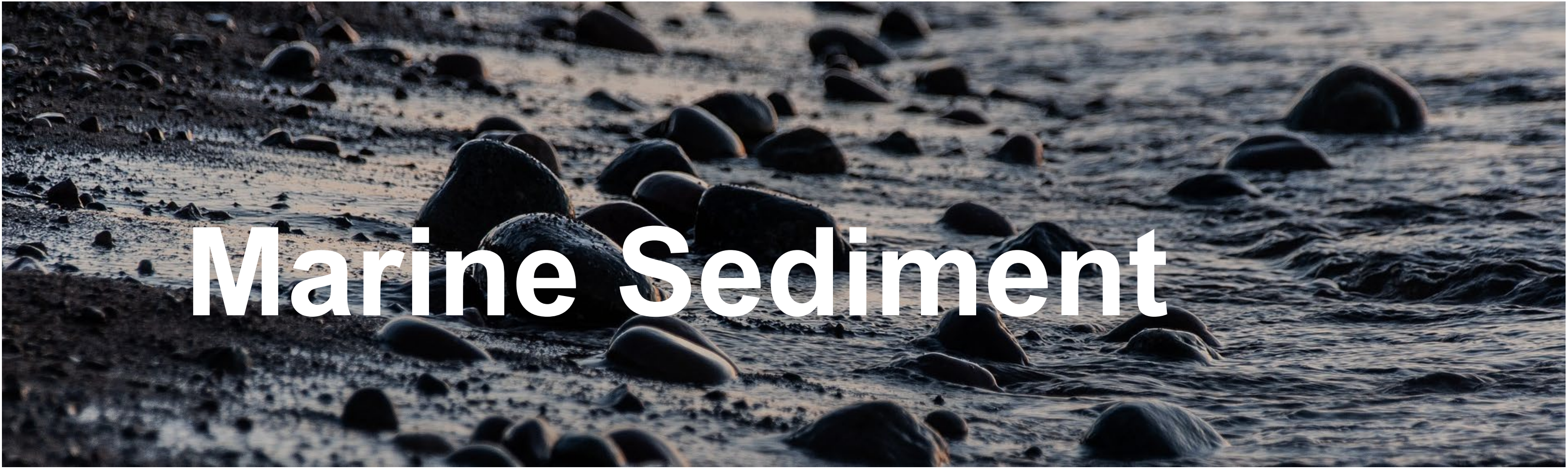
Table 36. Resources relevant to ocean acidification.

NAME	ACCESS	TYPE	DESCRIPTION
CA Current Acidification Network	https://c-can.info/	Website	An international collaboration to understand OA, C-CAN's website provides information, news, projects, and resources relevant to OA.
Environmental DNA metabarcoding reveals winners and losers of global change in coastal waters	https://royalsocietypublishing.org/doi/full/10.1098/rspb.2020.2424	Published article	Discusses a survey conducted on planktonic taxa across a gradient of temperature, salinity, dissolved oxygen, and carbonate chemistry in nearshore marine habitats.
Global Ocean Acidification Observing Network (GOA-ON) Data Portal	http://portal.goa-on.org/	Data Portal	Provides access and visualization of OA data and data synthesis products collected internationally.
Intergovernmental Panel on Climate Change (IPCC)'s Special Report on the ocean and cryosphere in a changing climate: Changing Ocean, Marine Ecosystems, and Dependent Communities	https://www.ipcc.ch/srocc/chapter/chapter-5/	Report	Chapter 5 of the special report on the ocean and cryosphere in a changing climate. Discusses ocean warming, acidification and oxygen loss, and changes in nutrient cycling and primary production.
Joint OAH Monitoring Task Force: West Coast OAH Monitoring Inventory	https://geo.maps.arcgis.com/apps/webappviewer/index.html?id=a8b5c0ecfbe7451e950def767c55335e	ArcGIS	Provides an inventory of ocean acidification and hypoxia monitoring infrastructure on the West Coast from Alaska to California.
LiveOcean	https://faculty.washington.edu/pmacc/LO/LiveOcean.html	Website	Provides the output of a computer model simulating ocean biology and chemistry.

NAME	ACCESS	TYPE	DESCRIPTION
Monitoring Ocean Acidification within State Borders: Lessons from Washington State (USA)	https://www.tandfonline.com/doi/full/10.1080/08920753.2021.1947130	Published article	Studies ocean acidification (OA) in greater Puget Sound to create a CO_2 dataset distinguishing human impacts from natural variability, analyzes the role of rivers and freshwater in OA conditions, and assesses cumulative anthropogenic effects on the region.
Northwest Association of Networked Ocean Observing Systems (NANOOS): National Visualization System (NVS) Data Explorer	https://nvs.nanoos.org/Explorer	ArcGIS	Provides access, visualization, and analysis of data related to ocean and coastal ecosystems.
NOAA National Marine Sanctuaries: The Olympic Coast as a Sentinel Resilience Actions for Tribal Community Well-Being in the Face of Ocean Change	https://sanctuaries.noaa.gov/education/teachers/olympic-coast-as-a-sentinel.html	Webpage	Provides Dr. Melissa Poe's presentation on the risks of ocean change to tribal community well-being and resilience actions rooted in Indigenous priorities.
NOAA National Marine Sanctuaries: Meeting the Challenge of Climate Change: A Makah Tribal Leader Seeks Solutions to an Ocean Out of Balance	https://sanctuaries.noaa.gov/news/feb22/makah-ocean-out-of-balance.html	Webpage	Discusses the effect of climate change and ocean acidification on the Makah Tribe's traditional waters and their cultural and spiritual links to the marine environment.
NOAA Ocean Acidification Program: Understanding the impact of ocean acidification on tribal communities, cultures, and economies in the Pacific Northwest	https://wsg.washington.edu/wordpress/wp-content/uploads/OAP_CongresssionalBriefing_WestCoast-July-2021.pdf	Document	Discusses the cultural significance of local marine life and NOAA Ocean Acidification Program's approach to building resilient communities.

NAME	ACCESS	TYPE	DESCRIPTION
NOAA Ocean Acidification Program (OAP)	https://oceanacidification.noaa.gov/WhatsNew/Publications.aspx	Website	Provides publications from NOAA's funded research to share information about ocean acidification and its effects.
OAP: Interagency Working Group on Ocean Acidification (IWG-OA)	https://oceanacidification.noaa.gov/iwgoa-home/	Website	Provides information on IWG-OA's efforts to coordinate OA research, monitoring, and engagement across the federal government to understand the effects of OA on marine ecosystems and coastal communities.
OAP: The Olympic Coast as a Sentinel: An Integrated Social-Ecological Regional Vulnerability Assessment to Ocean Acidification	https://oceanacidification.noaa.gov/funded-projects/the-olympic-coast-as-a-sentinel-an-integrated-social-ecological-regional-vulnerability-assessment-to-ocean-acidification/	Website	Introduces a project with the four Tribes in the Olympic Coast and researchers to understand the social and cultural risks of ocean change, identify research priorities, and develop adaptive strategies.
Ocean Acidification: The Other Carbon Dioxide Problem	https://www.pmel.noaa.gov/co2/story/Ocean+Acidification	Website	Provides information on OA and links for additional information and research efforts.
Tracking the Effects of an Eelgrass Epidemic	https://hakaimagazine.com/news/tracking-the-effects-of-an-eelgrass-epidemic/	Internet article	Discusses a study on the effects of eelgrass wasting disease.
University of Washington (UW): How Dungeness crabs' complex lifecycle will be affected by climate change	https://www.washington.edu/news/2021/10/28/how-dungeness-crabs-complex-lifecycle-will-be-affected-by-climate-change/	Webpage	Discusses a study on the impact of climate change across all life stages of Dungeness crabs.
UW: Salmon may lose the ability to smell danger as carbon emissions rise	https://www.washington.edu/news/2018/12/18/salmon-may-lose-the-ability-to-smell-danger-as-carbon-emissions-rise/	Webpage	Discusses a study on the effect of ocean acidification on coho salmons' sense of smell.

NAME	ACCESS	TYPE	DESCRIPTION
WA Dept. of Ecology Salish Sea Model: Ocean Acidification Module and the Response to Regional Anthropogenic Nutrient Sources	https://apps.ecology.wa.gov/publications/documents/1703009.pdf	Report	Quantifies the influences of regional nutrient sources on acidification in the Salish Sea.
WA Dept. of Natural Resources: Acidification Nearshore Monitoring Network (ANeMoNe) Toolbox	https://storymaps.arcgis.com/stories/8b277d4e0258487ba0254f87a4764ba7	ArcGIS	Provides information and data relating to the Aquatic Nearshore Monitoring Network.
WA Sea Grant: The Olympic Coast as a Sentinel – Tribal Communities at the Forefront of Ocean Change	https://wsg.washington.edu/community-outreach/olympic-oa-rva/	Webpage	Discusses project that assessed current and projected Olympic Coast vulnerabilities associated with OA.



Marine Sediment

Key Data Gaps

General Data Gaps

- Centralized data repository or a data archive on marine sediment
- Spatial coverage of marine sediment
- Offshore sediment movement
- Effect of human activities on marine sediment in the offshore area
- Effect of ecological shifts on marine sediment and the effect to the embayment community
- Data of marine sediment on outer coast beaches

Other Data Gaps

General Data Gaps

- Quality of marine sediment
- Effect of estuarine mixing and heat from ocean waters on marine sediment
- Physical circulation of marine sediment within an embayment

Offshore Wind Data Gaps

- Effect of cables from offshore wind on marine sediment
- Effect of shift in upwelling from offshore wind on marine sediment

Offshore Aquaculture Data Gaps

- Effect of nutrients, waste, and chemicals from offshore aquaculture on marine sediment
- Effect of offshore aquaculture structures on marine sediment

Background

Sediment plays a crucial role in diverse habitat types, influenced by various physical factors and impacting species in numerous ways. It is also relevant to existing anthropogenic activities and is likely to be affected by future activities.

Sediment movement along the coast is primarily driven by seasonal wave and current patterns. During winter, storm events push sediment northward, while calmer summer waves transport it southward. In the Columbia River Littoral Cell, sediment transport is predominantly northward, especially in subcells located north of the Columbia River along Washington's coast.

While most of Washington's shoreline is stable or accreting, chronic erosion is notable at North Cove near Willapa Bay, where long-term erosion rates average 30 meters per year and short-term rates can reach up to 56 meters annually. Erosion occurs when large waves strike the shore at steep angles, a scenario exacerbated during El Niño events when sea levels are elevated during the winter. In particular, southwest Washington beaches are characterized by dynamic sediment systems that fluctuate with seasonal changes in wave energy and direction. Coastal erosion in this region is driven by factors such as reduced sediment supply, rising sea levels, and a northward shift in Pacific winter storm patterns. Climate change is expected to exacerbate these factors, likely leading to continued or increased erosion due to rising sea levels and more frequent, severe storms.

Additionally, localized erosion during storm events, as well as anthropogenic influences such as jetties and dams, have caused changes in erosion and accretion along the shoreline. Storms, even those occurring at a distance, can significantly affect the MSP Study Area's coastline by elevating wave heights and altering wave direction. These changes can lead to erosion and the redistribution of sediment, which in turn impacts shallow marine and intertidal habitats. Climate change is expected to increase the intensity and frequency of storms on a global scale. On anthropogenic changes, sediment delivery to Washington's coast decreased due to mainstem dams on the Columbia River, diminishing the supply needed to replenish beaches. Washaway Beach exemplifies severe erosion. Since the 1880s, it has lost an average of 65 feet of beach annually. These changes can lead to erosion and the redistribution of sediment, impacting shallow marine and intertidal habitats.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to marine sediment:

General data gaps

- Centralized data repository or a data archive on marine sediment
- Spatial coverage of marine sediment
- Offshore sediment movement
- Human effects on marine sediment in the offshore area
- Effect of ecological shifts on marine sediment and the effect to the embayment community
- Data of marine sediment on outer coast beaches

Centralized data repository or a data archive on marine sediment. This data gap applies to both embayment and offshore data. There is a need for a centralized data repository. Currently, there are no known centralized data repositories, and instead, numerous separate sources of information are relied upon. It is difficult to determine which datasets contain the specific data needed. The Environmental Information Management database[128] managed by the Washington State Department of Ecology (Ecology) offers extensive parameters, including grain size data. However, navigating and accessing this database can be challenging, particularly in extracting the required information. There is a wealth of data available within Puget Sound, some information on the outer coast, and abundant information off the Columbia River. However, given the variety of parameters, it is uncertain which data is available for each location. Another source is the United States (US) Geological Survey's (USGS) usSEABED dataset[129], which is somewhat helpful, but has limited data coverage and relies on older datasets. Additionally, there is the National Science Foundation data repository that contains information from core samples.

Methods for data collection include multibeam sonar, which captures bathymetry and backscatter data, offering a preliminary view of sediment characteristics. Grab samples or core samples can also be collected. Depending on the timescale investigated, it can provide specific sediment details.

Feedback on importance: There is a scattered selection of resources with no clear method to consolidate all data into an easily accessible format. Information is dispersed across various separate sources. While considerable work is underway in Washington on marine sediments, it is unclear where this data is ultimately being compiled.

Spatial coverage of marine sediment. The distribution of knowledge varies across different regions of Washington's coastline. The understanding of the Puget Sound shelf is robust,

[128] https://apps.ecology.wa.gov/eim/search/default.aspx
[129] https://cmgds.marine.usgs.gov/usseabed/

whereas less is known about the outer coast. Data gaps are particularly evident in the northern outer coast near Rialto and Quinault, with virtually no information available around Quinault Canyon. In contrast, considerable efforts have focused on studying the southern coast. The Cascadia Coastlines and Peoples Hazards Research Hub[130] (Cascadia CoPes Hub) concentrates its research efforts from Taholah to Tokeland, primarily in the nearshore zone, resulting in a more comprehensive understanding of nearshore conditions compared to offshore areas. Furthermore, the USGS has conducted mapping activities at the Long Beach Peninsula and its spit extension. Significant research has also been dedicated to Astoria Canyon; a significant submarine canyon linked to the Columbia River. Consequently, areas such as Willapa Bay, Grays Harbor, and the Columbia River estuary have received extensive study, resulting in comprehensive datasets being available for these regions.

There is interest in studying sites with substantial sediment supply, such as river mouths and embayment entrances where sediment fluxes are frequent. However, due to the absence of a centralized data repository, it is challenging to pinpoint locations that already have sampled information across the shelf.

Feedback on importance: No specific feedback provided.

Offshore sediment movement. Current models can integrate circulation, currents, waves, and sediment supply to a certain extent, but their accuracy remains limited. While these models perform adequately for present conditions, their forecasting capabilities are hindered by significant errors. For instance, the models struggle with predicting the future movements of sandbars or the deposition locations of muddy sediments. While some fundamental principles apply, there are numerous exceptions.

Generally, materials are kept in suspension by waves, currents are responsible for their movement, and there is a constant supply for these processes to operate effectively. Timing plays a crucial role in their interactions. Offshore, particularly across isobaths, it is essential to understand the transport of sediment and everything it carries. This includes understanding how sediment traverses across isobaths, with a specific focus on sediment gravity flows where sediment flows as a flurry.

There is also a data gap regarding how sediment transitions from being suspended to being part of the seabed. This process is non-linear and lacks a standardized framework; it varies significantly between sites and is influenced by biological factors. For instance, how organisms affect sediment resuspension into the water column remains poorly understood. Addressing these complexities will require examining small-scale interactions between the seabed, water column, and particle dynamics.

Lastly, there are also numerous uncertainties regarding sediment quality along the coast. For instance, there is limited knowledge about pollutants attaching to sediment and there is a pressing need to better understand plumes. However, there is a relatively good understanding of how sediment escapes from these plumes.

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[130] https://cascadiacopeshub.org/

Feedback on importance: No specific feedback provided

Effect of human activities on marine sediment in the offshore area. Human activities significantly influence sediment distribution and zonation. In coastal areas, sediment types are categorized by their proximity to shore: sandy nearshore, muddy mid-shore, and predominantly sandy continental shelf. Altering inputs, such as sediment supply, can profoundly impact offshore dynamics. Small scale activities like jetties can have substantial local effects, but their influence on broader offshore environments is relatively minor. On a broader scale, climate change is reshaping the entire shelf environment. There are significant uncertainties about the quantity and composition of sediment reaching shorelines, due to factors like increased storm intensity, changes in river discharge from dams, and shifting precipitation patterns.

The majority of studies on the Washington shelf are from the late 1960s and early 1970s. While these studies provided valuable baseline data, there has been a lack of comprehensive, multi-disciplinary projects across the continental shelf since then. Bio-irrigation could be crucial to understand dynamics on the Washington shelf. This process plays a significant role in shaping the Puget Sound ecosystem. Burrowing activities of worms and benthic shrimp disturb sediment layers, potentially altering the usual sequence of processes. This irrigation also brings bottom water, potentially oxygenated, that would otherwise be conducive to sulfate reduction.

Feedback on importance: No specific feedback provided.

Effect of ecological shifts on marine sediment and the effect to the embayment community. Human activities can significantly alter seabed texture, impacting species such as oysters. For instance, forestry can lead to widespread sedimentation, particularly of mud, which can alter the texture of the seabed. This shift can smother organisms that are adapted to sandy environments. In Willapa Bay, significant changes in sediment type have contributed to oyster mortality and reduced harvest yields, ultimately reshaping the entire bay ecosystem. The presence of ghost bay shrimp, a native species, may further drive these changes. These shrimp burrow into the sediment, and if their population becomes too dense, they can decrease sediment bulk density, increase erosion, and reduce the content of fine sediments. The redistribution of mud by the shrimp alters sediment dynamics, impacting benthic organisms in the area. Research is ongoing to better understand these interactions and their broader implications.

Shifts in sedimentation rates are also crucial, as they affect organisms differently—some prefer sedimentation, while others do not. For example, the amount of suspended sediment, such as fine grains, can affect light penetration. Excessive sediment can reduce light availability and inhibit photosynthesis. Hence, turbid conditions can make it harder for seagrass to recover. Since seagrass plays a critical role in stabilizing sediment, its decline can result in increased sediment instability and higher turbidity, creating a negative feedback loop.

Additional related data gaps include:

- How grain size is changing and the effect of changes in mouths of embayment on the interior. Additionally, because this does not involve a uniform change, there is a need to understand the cascading effects throughout the ecosystem.

- The effect of *Zostera japonica* on flow dynamics and sedimentation. There is not enough known about this non-native species which has been expanding across the state.
- The role of Columbia River sediment on the rest of the coast.
- The role of European Green Crabs on sedimentation.

Feedback on importance: The ecological issues within embayments have far-reaching implications for numerous interested or affected parties. There is a growing interest in understanding the response of embayments to climate change and how these changes will impact the economy and society.

Data of marine sediment on outer coast beaches. The outer coast remains relatively understudied, with limited fieldwork conducted in this area and few significant scientific inquiries pursued. Consequently, it is challenging to assess changes based on baseline data, particularly concerning variations in river discharge. Sediments reaching the coast originate mainly from nearby mountains. It is anticipated that climate changes will bring substantial impacts. There is an interest in understanding these environmental shifts.

Feedback on importance: There is increasing development in offshore regions. Given the high potential for wind energy along the open coast, this area warrants significant attention. Coastal Tribes, needing better information for decision-making, face challenges due to a lack of available data in this area.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Quality of marine sediment
- Effect of estuarine mixing and heat from ocean waters on marine sediment
- Physical circulation of marine sediment within an embayment

Quality of marine sediment. There is a significant gap in the data concerning the quality and characteristics of sediment. Sediment serves as a crucial substrate for carbon attachment and eventual sequestration. The key issue is the amount of carbon currently being sequestered into the seabed without being re-mineralized and released back into the environment.

Effect of estuarine mixing and heat from ocean waters on marine sediment. This creates a significant data gap. The movement and shifting of estuarine mixing lead to variable sedimentation patterns, which in turn affect the type of sediment found on the seabed. While flume studies provide a solid understanding, areas with complex morphology present challenges. In regions like Grays Harbor and Willapa Bay, where fluvial and marine sources mix extensively, residence times are relatively well-documented. However, there is a need to understand how biological factors, such as seagrass, influence mixing in physics-based models. Most current models do not account for seagrass, despite its ability to significantly alter mixing dynamics due to its roughness.

Physical circulation of marine sediment within an embayment. There is a solid foundation in understanding circulation dynamics and identifying dominant forces in specific regions. Generally, materials are kept in suspension by waves, currents are responsible for their movement, and there is a constant supply for these processes to operate effectively. Timing plays a crucial role in their interactions. There is sufficient knowledge to develop models that integrate circulation, currents, waves, and sediment supply effectively. Numerical models, particularly 3D systems, are well-established tools for studying physical processes. However, their forecasting capabilities are hindered by significant errors. For instance, the models struggle with predicting the future movements of sandbars or the deposition locations of muddy sediments. While some fundamental principles apply, there are numerous exceptions.

There is a relatively robust body of modeling data available for embayments, with the USGS providing detailed grids and conducting a consulting survey at Willapa Bay, which has been refined over the years. Willapa Bay is influenced by offshore waves, which affect sediment distribution, varying from north to south. Sediments primarily accumulate in the southern part of the bay and exit through the northern outlet. The southern reaches are sandier, reflecting a blend of oceanic and riverine influences. To further enhance understanding of the region, the Cascadia CoPes Hub project is developing a model that using existing USGS grids and consulting reports.

There is a need to better understand physical circulation to predict the fate of resuspended sediment. However, the complexity of geomorphology makes it challenging to precisely characterize circulation at specific sites. Embayments, in particular, exhibit intricate geomorphic features, with a patchwork of sand and mud creating diverse habitats for species such as oysters and shrimp. Embayments also undergo continuous natural changes over timescales that far exceed human memory. These changes, such as the extension of peninsulas, affect sediment sources, landscapes, natural habitats like eelgrass beds, and aquaculture areas. Many ecological concerns are tied to sediment dynamics, highlighting the need to differentiate between human-made impacts and natural processes. Understanding these distinctions is crucial for identifying which changes can be adapted to and which may require intervention.

Offshore wind data gaps

- Effect of cables from offshore wind on marine sediment
- Effect of shift in upwelling from offshore wind on marine sediment

Effect of cables from offshore wind on marine sediment. Given the substantial number of cables already in place, adding a few more does not raise significant concerns. However, placing cables near canyon heads raises significant apprehensions due to known mass wasting events. Such placements could potentially trigger slope failures or expose cables to risks from seismic activities. Instances of slope failures affecting cables have been documented in regions like the East Coast and Europe, where turbidity currents have compromised cable integrity.

Apart from careful placement to avoid significant sediment disturbance, standard wear and tear is not likely to be a major concern. However, the installation process itself will disturb sediment and disrupt marine organisms. Dredging removes a substantial amount of sediment, which can significantly alter the local ecosystem. Achieving precise lines of dredging is challenging, and sediment may not settle in desired locations. Additionally, cables in the water column may cause localized resuspension, while those along the seafloor can influence flow patterns, potentially affecting sedimentation. Understanding factors like grain size, sediment type, and benthic biota is crucial for site selection and assessing environmental impacts.

Effect of shift in upwelling from offshore wind on marine sediment. While changes in upwelling may affect sedimentation, the impact is likely to be minimal. Understanding the grain size, sediment type, and benthic biota is crucial for site selection and assessing impacts.

Offshore aquaculture data gaps

- Effect of nutrients, waste, and chemicals from offshore aquaculture on marine sediment
- Effect of offshore aquaculture structures on marine sediment

Effect of nutrients, waste, and chemicals from offshore aquaculture on marine sediment. Data is available from one station on the Washington shelf, two or three stations beyond the slope, and several stations across the deepest waters of the Cascadia Basin extending to the Juan de Fuca Ridge.

There is information about the sequence of reactions occurring along ocean margins, primarily driven by organic matter. This sequence is well understood. When organic matter reaches the sediment, it undergoes a series of transformations. Initially, bacteria consume oxygen, followed by nitrate, then reduce manganese, and eventually go through methane fermentation. These processes have been observed in the main basin of Puget Sound and are evident in the deepwater of the Cascadia Basin as well. The data clearly shows the progression of the reactions. The progression of these reaction sequences within sediment depends on boundary conditions, specifically the concentrations of nutrients in the water column just above the sediment interface. Oxygen and nitrate levels will influence the sequence of reactions in the sediments, and changes in the concentration will affect both the depth zone and rate at which these reactions occur.

There is a foundational basis for predicting how an increase in an organic matter will impact the sequence of reactions in sediments. Considering the substantial existing organic matter content, incremental increases from offshore aquaculture may not significantly alter sediment dynamics. To date, no modeling studies have explored how much of a difference offshore aquaculture will make. It might require a eutrophic environment with additional organic matter to observe noticeable changes. Such conditions may be found in the southern part of Hood Canal.

Additionally, contaminants from various sources tend to adhere to mud particles, where they can become deposited and sequestered, posing risks to benthic organisms. If these contaminants are resuspended, they can spread to distant areas, far from their point of origin. Understanding the persistence of these contaminants is crucial, including how often they can reattach to particles. Any substance introduced into the environment has the potential to be recycled. Waste products, in particular, can significantly affect bioturbators—organisms that disturb sediment layers. To note, the composition of sediment-dwelling organisms also influences sedimentation dynamics. For example, an increase in sessile organisms may lead to nutrient accumulation, which can stimulate benthic biomass blooms and alter ecosystem interactions. A surplus of algae on the sediment can enhance stability, reducing erosion rates. Biofilms, which are common along coastlines, also play a role, though their precise ecological impacts are still uncertain.

There is also a data gap regarding how aquaculture or additional organic matter may influence settling velocity. Settling velocity is largely influenced by the amount of cohesive material present that bind particles together. Increased amounts of sticky substances (such as those from aquaculture activities, which organisms can consume) can accelerate settling rates. The addition of organic materials and fertilizers can also impact particles reaching the seabed, potentially altering accumulation rates and sediment quality. These factors collectively highlight potential effects on sediment dynamics and quality.

It is important to mention that there is often concern about the introduction of chemicals into the environment, assuming they are harmful, but long-term studies tracking their effects are lacking. This predisposition to view chemicals as inherently bad may influence concerns without comprehensive evidence to support them.

Effect of offshore aquaculture structures on marine sediment. Depending on its structure, offshore aquaculture may have a localized impact, but it would not be a significant effect. However, for kelp aquaculture specifically, kelp plays a role in dissipating wave energy. There has been extensive research on the wave-dissipating properties of kelp. Depending on its location and density, kelp cultivation could alter wave dynamics reaching the shore, potentially influencing sediment movement in nearshore areas. This effect could lead to changes in how sediment responds along the coast. Swell waves may be reduced in areas where kelp is cultivated.

Resources

Table 37. Resources relevant to marine sediments.

NAME	ACCESS	TYPE	DESCRIPTION
Benthic nutrient regeneration and denitrification on the Washington continental shelf	https://www.sciencedirect.com/science/article/abs/pii/0198014987900513	Published article	Studies benthic nutrient regeneration on the Washington continental shelf using vertical profiles of pore-water nutrient concentrations and whole sediment sulfate reduction rates.

NAME	ACCESS	TYPE	DESCRIPTION
The Cascadia Coastlines and Peoples Hazards Research Hub (Cascadia CoPes Hub)	https://cascadiacopeshub.org/	Website	Provides information on the Cascadia CoPes Hub's efforts to increase resilience and advance knowledge of the natural hazards and climate change risks faced by coastal communities.
Organic matter diagenesis in the northeast Pacific: transition from aerobic red clay to suboxic hemipelagic sediments	https://www.sciencedirect.com/science/article/abs/pii/019801499090029U	Published article	Studies diagenesis as a function of the flux of organic carbon to the sediment-water interface.
Quantifying Benthic Nitrogen Fluxes in Puget Sound, Washington – A Review of Available Data	https://pubs.usgs.gov/sir/2014/5033/pdf/sir20145033.pdf	Report	Reviews existing approaches to measure benthic nitrogen flux and evaluates and conducts a literature search to summarize known benthic nitrogen fluxes in Puget Sound.
US Geological Survey: usSEABED EEZ	https://cmgds.marine.usgs.gov/usseabed/#home	Database	Contains georeferenced point data in US waters and provides data on the character and nature of the seafloor.
Washington State Department of Ecology: Environmental Information Management System	https://apps.ecology.wa.gov/eim/search/default.aspx	Database	Allows users to search, view, and download environmental monitoring data for air, water, soil, sediment, aquatic animals, and plants.

Wind Driven Upwelling

Key Data Gaps

General Data Gaps

- Effect of upwelling on ocean acidification
- Effect of upwelling on hypoxic conditions
- Physical drivers of upwelling
- Effect of upwelling on key phytoplankton species
- Effect of climate change on upwelling
- Effect of upwelling on the food web

Other Data Gaps

General Data Gaps

- Effect of upwelling on the dynamics of base ocean properties
- Data on the coastal sea level
- Subsurface data
- Effect of upwelling on marine heat waves

Offshore Wind Data Gaps

- Effect of offshore wind turbines on upwelling
- Effect of offshore wind structures on upwelling
- Effect of offshore wind on upwelling and the subsequent effect to food supply
- Effect of offshore wind on upwelling and the subsequent effect on base ocean properties
- Effect of offshore wind on upwelling and the subsequent effect on ecosystems and species
- Effect of energy transmission from offshore wind on upwelling
- Effect of movement above water line from offshore wind on upwelling

Background

The Pacific Northwest, including Washington's Pacific coast, is strongly influenced by the California Current System (CCS), characterized by complex seasonal and daily variability. This system includes the southward-flowing California Current offshore and the northward-flowing Davidson Current, alongside other currents with distinct properties sourced from various Pacific waters. Seasonal circulation patterns bring these currents' diverse properties into the region, profoundly impacting productivity, larval fish and shellfish transport, plankton distribution, and other ecological processes. Upwelling and downwelling, driven by seasonal wind patterns, are key components of this dynamic. Upwelling predominantly occurs during spring and summer and pushes deep nutrient-rich waters into the sunlit upper layers of the ocean (photic zone). This process enhances nutrient availability for phytoplankton, which forms the foundation of the coastal and oceanic food webs. Upwelling exhibits variability on a multi-day scale, with periods of intensified upwelling alternating with relaxed wind and reduced upwelling. Downwelling typically occurs in fall and winter, characterized by southerly winds pushing warmer, less saline, and nutrient-poor waters towards the coast. Monitoring parameters such as sea surface height and chlorophyll-a concentration helps detect these seasonal upwelling and downwelling events. In addition to upwelling, other features such as the Juan de Fuca Eddy and the Columbia River Plume influence ocean and coastal productivity along the Washington coast.

The effect of upwelling on water quality and habitats, along with the potential implications of climate change, are summarized below.

a. Water Quality

Dissolved oxygen: Upwelling plays a pivotal role in the dynamics of dissolved oxygen levels in Washington's coastal waters. It brings oxygen-depleted water from the bottom to the surface, occasionally leading to hypoxic or even anoxic conditions. Oxygen levels can be further reduced by nutrients transported through upwelling, which trigger algal blooms. These blooms contribute to the accumulation of sinking organic matter, and as it is respired, it further depletes oxygen levels.

These reduced oxygen conditions stress marine communities and can lead to mortality events. Historical data show an increasing frequency, intensity, and extent of hypoxic events off Oregon's shelf waters since 2000, with hypoxic conditions severe enough to cause widespread fish and invertebrate mortality along the Washington and Oregon coasts in 2006.

Nutrients: Nutrient concentrations along Washington's Pacific coast are naturally elevated due to the influence of upwelling, the Juan de Fuca outflow, and the Columbia River Plume, all which enhance coastal productivity. Specifically, Grays Harbor and Willapa Bay are heavily influenced by ocean currents and upwelling, as well as inputs from rivers like the Chehalis and Columbia during downwelling winds from the south. Monitoring data from the Washington State Department of Ecology's (Ecology) Environmental Assessment Program indicate no significant changes in nitrogen or phosphorus levels from 1999 to 2013 within these estuaries.

Carbon dioxide and ocean acidification (OA): The Washington coast is highly susceptible to ocean acidification due to the natural upwelling processes that bring low-pH waters to the coastline. The impacts of low aragonite saturation states have been documented in the oyster industry.

Harmful Algal Blooms (HABs): HABs along the coast are recognized as a natural phenomenon. Nutrient enrichment and water retention within the Juan de Fuca Eddy foster conditions conducive to high productivity, potentially leading to HABs. Fluctuating winds and upwelling/downwelling dynamics can influence the movement of the eddy, pushing HABs closer to shore.

Temperature: The Pacific Ocean and Washington coastal waters experience varying temperatures influenced by large-scale oceanographic processes, including upwelling, downwelling, currents, and climatic phenomena like the El Niño-Southern Oscillation and the Pacific Decadal Oscillation. Sea surface temperature varies across the shelf (nearshore to offshore) due to local upwelling/downwelling forces. Average sea surface temperatures range from about 8^{o}C to 16^{o}C (46^{o}F to 61^{o}F) annually.

b. Habitats

Pelagic Habitat: Upwelling plays a crucial role in the dynamic pelagic zone off the Washington coast, affecting primary productivity, community composition, and species survival. Nutrient-rich waters brought to the surface through upwelling sustain a highly productive phytoplankton community. Energy from phytoplankton is transferred to higher trophic levels by zooplankton, such as copepods, which exhibit seasonal shifts influenced by climatic factors like El Niño events and the Pacific Decadal Oscillation. Cold water copepods, rich in lipids, are abundant during summer upwelling, supporting pelagic fish, whereas warm water copepods are more prevalent in winter, albeit with lower lipid content.

Seafloor: Large zooplankton like euphausiids (krill) play a crucial role in the seafloor habitat food web, forming a significant part of many groundfish diets. Observations indicate that the abundance of dominant krill species is notably higher during periods of high upwelling compared to low upwelling conditions.

Kelp Forests: Strong storm events and nutrient-poor waters associated with El Niño events can reduce kelp coverage, while cold, nutrient-rich La Niña events support robust growth conditions. Light penetration also plays a significant role. Increased sediment runoff from heavy rains or landslides may decrease bull kelp densities.

Rocky Shores: Upwelling enriches the rocky intertidal system with nutrients, plankton, and larval recruits. Wave energy is believed to enhance the productivity of the rocky intertidal systems by promoting competitive advantages for wave-tolerant organisms, replenishing nutrients, and improving light uptake by algae.

Sandy Beaches: Key physical drivers for the sandy intertidal beach habitat include sediment deposition, wave energy, beach slope, upwelling, and climate variability. Upwelling plays a crucial role by delivering nutrients and food to beach habitats. Weather and climate factors, such as hot sunny days and strong winter storms, create diverse environmental conditions that influence the organisms inhabiting sandy habitats.

Large Coastal Estuaries: Washington's large coastal estuaries exhibit diverse sediment types, including gravel, sand, mud, and silt. Wave exposure varies across these estuaries, with sand flats replacing mud flats in areas more exposed to coastal wave energy. The dynamics of these estuaries are profoundly influenced by ocean upwelling and downwelling processes.

c. Climate Change

Ocean temperature: Climate change may weaken upwelling circulation patterns by increasing sea surface temperatures. This potential weakening could lead to declines in fish populations, impacting seafood supply and jobs in the fishing industry.

Dissolved oxygen/Hypoxia: Hypoxia is associated with large-scale ocean circulation, productivity, and upwelling. Climate change is expected to affect the concentration of dissolved oxygen. Upwelling waters low in dissolved oxygen but high in nutrients promote increased primary productivity. As phytoplankton bloom and produce organic matter, bacteria break down these waste products through respiration, further depleting dissolved oxygen levels. This process contributes to seasonal cycles of dissolved oxygen concentrations. On the Washington coast, the seasonal cycle is particularly evident, with deeper waters experiencing a drop in dissolved oxygen levels during the summer, often reaching hypoxic conditions.

OA: Upwelling is one of the sources that drive acidification in Washington. Other sources include hypoxia, local input of nutrients, nitrogen oxides, and sulfur oxide gases. Projections indicate significant increases in acidity along Washington's coast by the end of the century, posing risks to marine life and ecosystems sensitive to pH changes.

HABs: HABs on the Washington coast are influenced by climate change factors such as sea surface temperature and upwelling patterns. Over the past three decades, HAB frequency and distribution have increased, leading to more human illnesses and economic losses due to fishery closures. The Juan de Fuca Eddy also plays a role by transporting toxic blooms to Washington's coastal waters through currents, winds, and shifts in upwelling and downwelling patterns. Climate change is expected to exacerbate these impacts by potentially prolonging and intensifying HABs through rising temperatures, altered wind-driven upwelling patterns, and changes in nutrient dynamics from land runoff into coastal estuaries. Climate-induced shifts in winds can potentially affect bloom frequency and transport dynamics.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to wind driven upwelling:

General data gaps

- Effect of upwelling on ocean acidification
- Effect of upwelling on hypoxic conditions
- Physical drivers of upwelling
- Effect of upwelling on key phytoplankton species
- Effect of climate change on upwelling
- Effect of upwelling on the food web

Effect of upwelling on ocean acidification. While the effect of upwelling on OA is generally understood, there remains a significant knowledge gap regarding the broader drivers of this process. Experts are still uncertain about the factors contributing to variability in upwelling and how these changes may affect OA or hypoxia. Typically, upwelling brings deeper waters—where aragonite saturation is usually lowest—to the surface. However, climate change may intensify, diminish, or alter the timing of upwelling and how these changes will affect OA is not understood. It is anticipated that climate change will lead to increased upwelling, with waters becoming lower in oxygen and more acidic. While existing upwelling indices provide valuable insights, incorporating additional direct biogeochemical measurements would significantly enhance understanding in this area.

Feedback on importance: Understanding the effects of upwelling on OA is crucial, as OA can significantly impact marine organisms and ecosystems. Gaining insight into this dynamic is essential for predicting how changes in upwelling may influence both OA and the health of marine environments.

> **WCMAC:** Upwelling involves the movement of water that has been at the bottom of the Pacific for 25 to 30 years, which is generally more acidic than surface waters, low in oxygen, and rich in nutrients. While factors such as low oxygen levels and increased acidity are often viewed negatively, it is important to recognize that they are integral components of the natural system known as the California Current Ecosystem (CCE). Although these conditions may seem detrimental, the nutrients provided by upwelling are essential for sustaining marine life. This process has been occurring along the entire West Coast since time immemorial, contributing to the productivity of sport and commercial fisheries.
>
> The scientific understanding of the relationship between upwelling and ocean acidification is well established. Having served on Governor Gregoire's blue-ribbon panel, there is confidence in the scientific principles underlying this phenomenon, including the relevant chemistry and the interactions between the atmosphere and the ocean's surface. However, uncertainty remained regarding the origins of the old water that resides at the ocean's bottom. It was understood that this phenomenon is generally associated with the North Pacific, where cooler water sinks; nonetheless, the precise locations of where the water sinks were not predictable. There is an interest in learning whether there have been any updates on this aspect of the research.

Effect of upwelling on hypoxic conditions. In the northwest, hypoxic waters correlate with intense upwelling. Upwelling plays a critical role in establishing the boundary conditions that dictate the emergence and development of hypoxic events. Therefore, understanding the variability in upwelling drivers is crucial to assessing their impact on hypoxic conditions. However, the factors driving upwelling variability and their implications for OA or hypoxia remain unclear. While existing upwelling indices offer useful information, additional direct biogeochemical measurements are necessary to gain deeper insights.

Feedback on importance: Hypoxia can affect organisms and ecosystems. Understanding this dynamic is critical. Sharp feedback has been observed at local sites between the physical drivers of upwelling and hypoxic conditions.

WCMAC: The effect of upwelling on hypoxic conditions is understood, yet it remains an area of ongoing research for universities and scientists. Water at the ocean's bottom undergoes processes that deplete its oxygen content; the longer it remains there, the greater the depletion. When that water upwells, its origins and the reasons for its low oxygen levels at that moment can be determined.

Physical drivers of upwelling. The physical drivers of upwelling are well understood in theory, yet there are always nuances and site-specific processes to consider. Upwelling off the coast of Washington differs significantly from that along the California coast. Rather than focusing on basin-wide dynamics, it is essential to examine these idiosyncrasies. Wind acts as the primary driver of upwelling, with secondary effects influenced by the stratification of the water column. The energy required to push water against a gradient differs from that needed under homogeneous conditions. While wind primarily drives upwelling, factors such as water temperature, salinity, and density can modify its intensity locally. Ongoing research aims to understand how variations in wind and sea level affect the strength and structure of upwelling, as well as the nutrient and chemical content of upwelled waters. Understanding the role of surface waves in structuring upper ocean mixing will also be valuable, as this determines the rates of mass transport that drive upwelling.

Better understanding the physical drivers of upwelling requires access to coastal sea level data and a more detailed characterization of nearshore wind patterns. Although satellite-derived wind products are available, their resolution is often inadequate for nearshore applications. Obtaining a cross-shore profile of wind patterns may require deploying a series of moorings off the coast. Currently, there is a lack of such mooring arrays in the United States. The National Aeronautics and Space Administration (NASA) is exploring the potential of satellite technology to enhance data collection efforts in this area.

Additionally, climate change will affect these physical drivers in unknown ways. While scientific consensus is beginning to emerge on whether climate change will shift upwelling patterns, it remains generally unclear for the Washington region.

Feedback on importance: The influence of wind and waves on the variability of upwelling along the coast is not well understood. Understanding how changes in physical drivers, including climate change, impact upwelling is crucial, as ecosystem dynamics are heavily influenced by upwelling. For instance, climate change is expected to affect source waters by altering wind patterns and large-scale circulation.

WCMAC: Regarding the physical drivers of upwelling, the CCE is one of only six systems globally that are understood. In the winter, prevailing winds typically originate from the south and runs counter to the CCE. Conversely, during the summer, the winds shift and come from the north, aligning with the current and displacing surface water. This dynamic facilitates the occurrence of upwelling.

Effect of upwelling on key phytoplankton species. This represents a significant data gap. While it is recognized that upwelling supports productivity, the variability in this relationship, particularly how fluctuations in upwelling influence plankton growth, remains poorly understood. There is a prevailing notion of a balance between upwelling and relaxation phases, however further study is needed to understand these dynamics and determine the optimal conditions, or "sweet spot," for plankton growth. Additionally, while upwelling impacts nutrients, water temperature, and the physical stability of the water column, factors such as light availability and micronutrient concentrations also influence the growth of phytoplankton species. Predicting which species will bloom under specific conditions is difficult. The underlying causes of one species blooming over another remains elusive. Understanding these dynamics in relation to harmful algal bloom (HAB) species is also needed.

Feedback on importance: Phytoplankton is the base of the food web, supplying nutrients to all trophic levels. Understanding the impacts on key phytoplankton species is crucial for ecosystem health and human well-being, as harmful algal species can proliferate under certain conditions.

> **WCMAC:** There is a limited understanding of the effects of upwelling on key phytoplankton species. Experiences in recreational and commercial fishing have fostered an awareness of the complexity of the marine environment and the numerous factors influencing the ocean.

Effect of climate change on upwelling. Current research efforts focus on understanding the drivers of upwelling and predicting how they might evolve over the next century. How upwelling will respond to climate change remains uncertain. Addressing this question extends beyond merely understanding the direct impact of wind on upwelling. Climate change can influence broader factors such as circulation patterns, altering the types of water masses present in the Washington region. If climate change changes large-scale circulation patterns, upwelling events could introduce novel water masses that differ from those historically observed in the state. The source waters involved in upwelling may also shift due to these climate-driven circulation changes.

Feedback on importance: Climate change has the potential to alter wind patterns, ocean circulation, and key oceanic properties like temperature and salinity. Given the significant investments in offshore resources, it is important to consider what conditions may prevail in the next 50 years.

> **WCMAC:** There is less understanding of the effects of climate change on upwelling compared to other data gaps. Climate change may influence the timing and intensity of wind patterns, which are critical for upwelling processes. This complexity warrants further investigation, and it would be prudent to defer to experts in the field to elucidate how these changes may unfold in the future.

Effect of upwelling on the food web. The overall impact of upwelling on the food web is understood in a general sense. Upwelling systems such as the CCE have been extensively studied, including variations under seasonal conditions. However, this understanding may not fully capture regional specifics. There is also a critical need to delve deeper into how upwelling affects individual organisms and the transfer of energy through trophic levels. Given the inherent complexity of food webs, this remains a substantial data gap.

Feedback on importance: Understanding the effect of upwelling on the food web is crucial, particularly in the context of offshore resource utilization. It is also essential to comprehend the broader implications of food webs.

WCMAC: Regarding the effect of upwelling on the food web, it is understood that upwelling is highly nutrient-rich, leading to significant phytoplankton blooms that sustain the entire marine ecosystem. It is essential to recognize that upwelling plays a critical role in the prosperity of fisheries along the West Coast.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Effect of upwelling on the dynamics of base ocean properties
- Data on the coastal sea level
- Subsurface data
- Effect of upwelling on marine heat waves

Effect of upwelling on the dynamics of base ocean properties. Upwelling significantly influences the dynamics of fundamental ocean properties. For example, upwelling redistributes waters of specific temperatures or salinities, determining whether they remain at depth or rise to the surface. Temperature and salinity directly affect water density, which is crucial for understanding marine dynamics. The density profile influences the abundance and types of plankton present. It also plays a key role in mixing of the ocean water which in turn, affects the concentration or dispersal of signals from OA or hypoxia. Depending on the origin of the upwelled ocean water, upwelling can also introduce varying chemicals and other properties.

While the effect of upwelling on large-scale ocean circulations is well documented, there are ongoing efforts to better understand interactions between upwelling and specific properties, such as the relationship between upwelling and surface wave dynamics. The effect of climate change on upwelling and the implications for fundamental ocean properties are also not understood.

Data on the coastal sea level. Upwelling has a negligible impact on sea level change. While upwelling can determine the type of water interacting nearshore, it does not alter sea level. However, variations in sea level along the coast play a crucial role in upwelling circulation dynamics. Accurate data on coastal sea level fluctuations are essential for understanding these processes.

Subsurface data. This represents a significant data gap and a critical need in upwelling research. Subsurface data is essential for inferring circulation patterns. Unlike surface observations, which benefit from satellite monitoring, subsurface data is more challenging to acquire and less abundant. While efforts like coastal buoys and gliders from organizations such as the Northwest Association of Networked Ocean Observing Systems (NANOOS) and the Ocean Observatories Initiative (OOI) provide some data, coverage remains limited. There is a pressing need for data on variables such as oxygen levels, nitrate concentrations, pH, salinity, temperature, water velocity, and density stratification, among others. Understanding what is happening in the water column is crucial for accurately assessing the intensity of upwelling and the various forcing conditions involved.

Effect of upwelling on marine heat waves. Upwelling transports cooler water to the surface, serving as a physical barrier against heat waves. However, heatwaves can alter the location of upwelling. Understanding the relationship between heat waves and upwelling is a needed area of research.

Offshore wind data gaps

- Effect of offshore wind turbines on upwelling
- Effect of offshore wind structures on upwelling
- Effect of offshore wind on upwelling and the subsequent effect to food supply
- Effect of offshore wind on upwelling and the subsequent effect on base ocean properties
- Effect of offshore wind on upwelling and the subsequent effect on ecosystems and species
- Effect of energy transmission from offshore wind on upwelling
- Effect of movement above water line from offshore wind on upwelling

Effect of offshore wind turbines on upwelling. Offshore wind turbines are unlikely to directly influence upwelling, although this could vary depending on the scale of the turbines. Assessing this effect requires consideration of the extraction of wind energy and alteration of the water column's mixing dynamics. The extent of wind reduction within the wind field must be quantified and scaled appropriately.

Efforts are underway to determine whether the effects of offshore wind on upwelling are negligible compared to the potential effects of climate change. Localized effects may be significant for the affected ecosystem. Using atmospheric and ocean circulation models, initial studies of upwelling off California suggest discernible impacts from offshore wind structures, particularly downstream of wind farms. Downstream of the turbine, models indicated increased upwelling offshore and decreased upwelling nearshore. While this one study provides some insight, understanding the effect of turbines on upwelling is still in the early stages. Ongoing research aims to understand the effects of wind turbines on ocean chemistry and productivity.

Effect of offshore wind structures on upwelling. Apart from turbines that interact with wind, other physical structures are generally not anticipated to significantly affect upwelling. However, the specific effects of these structures have not been thoroughly studied, and there is interest in exploring this topic. The depth of these platforms relative to the stratification of the water column is an important consideration. Water column stratification varies seasonally and during events.

If these structures disrupt stratification and enhance vertical mixing, especially in thin surface layers, there could be noticeable effects on upwelling dynamics. Investigating these potential impacts necessitates conducting site-specific process studies.

Effect of offshore wind on upwelling and the subsequent effect to food supply. Rather than through direct effects of offshore wind on upwelling, changes in food supply are expected to be influenced by the physical structures of offshore wind installations. While the extent of this effect will depend on the density and number of wind units, experts anticipate that offshore wind will cause physical changes that impact food resource availability. Ongoing research aims to clarify how offshore wind installations may affect productivity at the base of the food web.

Effect of offshore wind on upwelling and the subsequent effect on base ocean properties. If base ocean properties refer to temperature and salinity, it is unclear how upwelling would affect base ocean properties through offshore wind activities. There may be minor changes in heat exchange rates between the atmosphere and the ocean. It is also possible that heating and cooling patterns in the ocean may be influenced. However, definitive conclusions on these effects would require further research.

Effect of offshore wind on upwelling and the subsequent effect on ecosystems and species. Upwelling is associated with increased biological activity, so any changes to upwelling patterns could potentially affect ecosystems and species accordingly.

Effect of energy transmission from offshore wind on upwelling. The energy transmission associated with upwelling is not expected to affect upwelling.

Effect of movement above water line from offshore wind on upwelling. The movement of offshore wind structures is not expected to directly influence upwelling. These movements above the water line are likely to be captured by the effects of ocean circulation. The influence on upwelling will primarily stem from the extraction of wind energy, which depends on the scale of the turbines, as well as the associated boat traffic and increased human presence needed to maintain the offshore wind farms.

Resources

Table 38. Resources relevant to upwelling.

NAME	ACCESS	TYPE	DESCRIPTION
Projected cross-shore changes in upwelling induced by offshore wind farm development along the California coast	https://www.researchgate.net/publication/370001390_Projected_cross-shore_changes_in_upwelling_induced_by_offshore_wind_farm_development_along_the_California_coast	Published article	Examines changes to upwelling from offshore wind development via atmospheric and ocean circulation numerical models.

Socioeconomics

Aquaculture

Key Data Gaps

General Data Gaps

- Selection of farmed species and biosecurity concerns
- Location of aquaculture operations
- Effect of shift in environmental parameters on aquaculture
- Inventory of existing offshore aquaculture activities
- Economics and risks of aquaculture operations

Offshore Wind Data Gaps

- Effect of shift to water current, water quality, and sedimentation from offshore wind to existing aquaculture operations

Other Data Gaps

General Data Gaps

- Feasibility of aquaculture based on current environmental parameters
- Cultural sensitivity of proposed aquaculture locations

Offshore Wind Data Gaps

- Effect of offshore wind structure on existing aquaculture operations
- Effect of potential sites for land-based operations of offshore wind on existing aquaculture operations

Offshore Aquaculture Data Gaps

- Effect of shift to water current, water quality, and sedimentation from offshore aquaculture to existing aquaculture activities
- Effect of selection of farmed species and biosecurity concerns of offshore aquaculture on existing aquaculture activities
- Effect of potential sites for land-based and water-based operations of offshore aquaculture on existing aquaculture

Background

Marine aquaculture is deeply rooted in Washington state, featuring diverse shellfish species and marine plants. Outside of the Study Area, in Puget Sound, salmon have also been commercially cultivated since the 1970's.[131] The coastal estuaries of the MSP Study Area, notably Willapa Bay and Grays Harbor, are focal points for shellfish cultivation.

The management of the aquaculture industry involves multiple agencies with distinct roles. As of 2017, approximately 21,000 acres of state-owned water areas were leased for aquaculture. Within the MSP Study Area, shellfish aquaculture extensively utilizes both privately and publicly owned tidelands in Willapa Bay and Grays Harbor, comprising roughly 66% to 80% of the state's total shellfish aquaculture acreage. Additionally, the Washington Department of Fish and Wildlife (WDFW) manages approximately 10,000 acres in Willapa Bay as oyster reserves, with around 1,000 acres allocated for oyster production and licensed harvesting of naturally occurring oysters.

The aquaculture industry significantly contributes to both local and statewide economies. Pacific County ranked 3rd among all Washington counties and 15th among all US counties in aquaculture sales in 2012. Grays Harbor ranked 7th statewide, and 43rd nationally. Additionally, per a 2015 report[132], the aquaculture industry also generates significant sales and expenditures, fostering employment opportunities and labor income. Revenue from aquaculture land leases, license fees, and sales of access to state-owned reserves contributed to the state economy. Estimates on the expenditures, total employment, and total labor income for Pacific County and Grays Harbor County combined as well as for the state are provided below:

Table 39. Coastal and statewide aquaculture expenditures, employment, and income (MSP Table 2.5-4)

	EXPENDITURES	TOTAL EMPLOYMENT	TOTAL LABOR INCOME
Washington coastal region	$65.2 million	847	$50 million
Statewide total	$78 million	1,230	$73.2 million

The aquaculture industry has faced various challenges such as invasive species, climate change, changes to existing co-uses, and regulations. In particular, the emergence of invasive species prompted extensive adaptation and management efforts within the shellfish industry. Spartina and burrowing shrimp have disrupted estuary ecosystems, necessitating rigorous control measures. Other problematic species include Japanese eelgrass and non-native oyster drills. Existing and potential invasive species, coupled with environmental changes, pose unforeseen

[131] There is currently no commercial net pen aquaculture of finfish within the estuaries.
[132] https://drive.google.com/file/d/0B1EPSaZPERSXclZoTnZxVkNHemc/view?resourcekey=0-I1Ws0XJMfSwcAzDo_b7NCA

effects and are expected to continue creating operational, regulatory, and economic challenges for the industry.

Climate change also presents significant challenges, particularly in Washington's estuaries. Concerns include ocean acidification, sea level rise, and rising water temperatures. Ocean acidification hampers oyster shell growth, resulting in reduced production and higher mortality rates, with the oyster industry estimated to have lost over $110 million. In response, some companies have relocated hatcheries to Hawaii, and initiatives like the Washington Ocean Acidification Center was established to address this issue. Sea level rise threatens to shift intertidal zones, impacting access to aquaculture beds and optimal growing areas. Additionally, rising water temperatures reduce shellfish growth, reproduction, distribution, and health, while also increasing the risks of Harmful Algal Blooms (HABs) and bacteria, which can lead to illness outbreaks. The Department of Health (DOH) monitors these risks, but the emergence of new toxins and pathogens could result in significant negative economic impacts for the industry.

The aquaculture industry may also be influenced by shifts in the intensity and frequency of current co-uses. Activities like increased crude oil transportation, potential marine renewable energy projects, deepening of federal navigation channels, or potential net pen aquaculture pose significant concerns for the shellfish aquaculture industry. These activities may affect aquaculture conditions by oil spills, alterations to water flow, habitat loss, decreased production, and water quality deterioration. Industry participants must also navigate aquaculture industry regulations which are perceived as complex, costly, and time-consuming, hindering the growth of the aquaculture sector.

Despite facing challenges, the industry has demonstrated resilience and adaptability throughout its history. Experts believe the industry can continue to grow and thrive if it can innovate and adjust to changing conditions and other challenges.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to aquaculture:

General data gaps

- Selection of farmed species and biosecurity concerns
- Location of aquaculture operations
- Effect of shift in environmental parameters on aquaculture
- Inventory of existing offshore aquaculture activities
- Economics and risks of aquaculture operations

Selection of farmed species and biosecurity concerns. Extensive research has addressed aquaculture risks, including escaped fish and biosecurity. Biosecurity encompasses the strategic planning and implementation of measures designed to safeguard against disease.[133] This

[133] https://repository.library.noaa.gov/view/noaa/55554

primarily involves preventing the introduction and spread of disease agents. *Id*. There is an understanding of what types of species should be used and whether there is a need to use sterile fish.

Risk assessment depends on operation scale, with smaller operations posing less risk. However, biosecurity and disease risks are generally minimal due to limited pathogen overlap among species. Even within the same bacteria species, different strains affect different finfish species. Additionally, with proper control measures and minimal disease episodes, risk is low. Disease prevention methods also exist for controlled populations, and offshore areas require a high pathogen dose for fish illness due to the vastness of the ocean. While unforeseen circumstances are always a possibility, collaborative networks between the Pacific and East Coast enable effective monitoring and early detection of any emergent issues. Shellfish toxin concerns are also addressed through a year-round monitoring program by Sea Grant.

The risk of farmed species varies based on species interactions, which can be direct or indirect. Direct interactions include accidental releases which may impact breeding and habitat competition. Top shellfish aquaculture species include geoducks, Pacific oysters, and Manila clams, with no identified biosecurity concerns. Geoducks and Manila clams, both native species, are commonly found on public as well as privately owned beaches and do not affect native wild populations. The majority of the seed stock used in aquaculture operations is sourced locally within the Pacific Northwest region. Indirect interactions, like introducing domesticated species with bacterial and viral biomes, can affect environments and its natural occurring species. Data gaps exist, particularly regarding the susceptibility risks of natural species in those aquaculture areas. Structures may also attract wild species not typically found there. This is an area of research that requires additional funding.

Feedback on importance: Biosecurity poses a significant risk to aquaculture. There are uncertainties surrounding the spread of diseases and their potential impacts. Understanding biosecurity and species susceptibility to known or emerging diseases is crucial for alleviating concerns and establishing baseline data on risk.

Location of aquaculture operations. Information regarding the locations of all existing aquaculture operations in Washington is readily available. Processing facilities are also generally located close to each farm. Boats transport goods between farms and processing facilities.

As for new aquaculture operations, identifying new locations poses challenges. Determining the requirements for locating an aquaculture operation, including considerations for public resources and marine waters, is a data gap and poses considerable challenges. Both water and land-based aspects of the operation must be appropriately sited, with significant implications for surrounding communities. Operations typically occupy rural areas, leading to frequent conflicts between operational needs and the expectations of residents. While there are positive impacts, such as employment opportunities, there are also negative effects, including increased dock activity, boat and vehicle traffic, and potential odor issues. Additionally, access to private land and water sources is crucial. While recirculation technology offers a solution, it is at an added expense. Ideally, bases would be located where water can be pumped, released, or utilized for recirculation and align with NPDES permit regulations on net pen discharge.

Feedback on importance: For potential offshore aquaculture operations, the location of land-based operations may influence their siting. Collaboration with locally interested or affected parties can help identify optimal locations. Given that existing aquaculture activities are predominantly in estuarine areas, it may be beneficial to develop an inventory of areas best suited for offshore activities.

Effect of shift in environmental parameters on aquaculture. The ocean environment is changing, and research has made considerable progress on understanding the effect of shifting environmental parameters on aquaculture operations, especially for shellfish aquaculture. For instance, increased mortality among shellfish was observed after massive heat waves with extreme low tides. This research led to the creation of the Rapid Response Network for guidance, data monitoring, and data reporting to prepare for future similar events. However, there is still much to learn. There are still differing opinions on the effect of these shifts, such as the impact of ocean acidification on shellfish and the influence of changing pH on the health and reproductive capacity of finfish. Additionally, given climate change and rising temperatures, potential disease outbreaks among both wild and cultured species are anticipated. However, the emergence of new pathogens and diseases, and their effects on species resilience and migration patterns for wild species—especially in conjunction with warming conditions—remain uncertain. While some species thrive in colder temperatures and may migrate north, they may not grow as effectively or could become more susceptible to diseases. Many data gaps remain in understanding these dynamics.

There is also a need to better understand the effect of environmental parameters on substrate composition which affect shellfish species. The effect differs depending on the species' size and behavior. This includes effects from pests and invasive species. For instance, aquaculture operations interact with burrowing shrimp and eelgrass, two species currently researched. Burrowing shrimp poses the most significant challenge for shellfish farms. Burrowing shrimp can disrupt oyster beds by collapsing tunnels, burying, and suffocating oysters. Geoducks, inhabiting deeper depths than oysters, are more resilient due to their large siphons but may encounter difficulties in denser mud. Eelgrass, while not as widely discussed, garnered attention in recent years due to uncontrolled blooms that blocked sunlight and restricted water flow, resulting in dense clusters that suffocated shellfish.

Feedback on importance: This is a current concern and affects all types of aquaculture operations.

Inventory of existing offshore aquaculture activities. An inventory can be created with available data. Offshore aquaculture operations are established in various regions across the United States (US), including the Gulf of Mexico and the East Coast. Additionally, NOAA is actively identifying opportunity areas for further development. Aquaculture Opportunity Areas[134] (AOAs) were mapped for areas in the Gulf of Mexico and Southern California.[135]

[134] https://www.fisheries.noaa.gov/insight/faq-aquaculture-opportunity-areas
[135] https://coastalscience.noaa.gov/news/nccos-maps-options-for-aquaculture-opportunity-areas-in-the-gulf-of-mexico-and-southern-california-bight/

Feedback on importance: There is a need to understand what types of offshore aquaculture activities are being conducted and whether they are focused on raising oysters, mussels, seaweed, or other species. Additionally, other information such as the tidal elevation these activities typically occur at will help in understanding potential interactions of existing aquaculture operations with offshore activities. Some of this information may already be available, making this a lower priority.

Economics and risks of aquaculture operations. There is a notable gap in economic data concerning the feasibility of establishing both offshore and inshore aquaculture operations, as well as in assessing acceptable levels of risk. Success in aquaculture depends on various factors, including permitting processes, political considerations, and disease management. Additionally, climate-related changes present another significant risk. The evolving economic climate introduces considerable uncertainties that can affect workforce stability and the future landscape of the industry.

For species that are traditionally reared with a land-based component, gaps on economics and risks generally do not preclude their cultivation, as the requisite technology is available. Nonetheless, substantial investment is often necessary to facilitate successful implementation.

Feedback on importance: There is interest in understanding the time and financial investments required for aquaculture operations, as well as the potential risks posed by future developments such as offshore wind. These risks include the effect of degradation of wind farm areas and the broader effects of offshore wind on surrounding environments.

Offshore wind data gaps

- Effect of shift to water current, water quality, and sedimentation from offshore wind to existing aquaculture operations

Effect of shift to water current, water quality, and sedimentation from offshore wind to existing aquaculture operations. The effect of offshore wind activities on current aquaculture operations depends on the scale and location of the offshore wind projects. Significant influence on existing aquaculture operations would require close proximity. For Washington, any potential influence is currently expected to be minimal because there are no aquaculture operations off the coast and aquaculture enhancement endeavors, like salmon rearing and release, occur in bays at Puget Sound or Grays Harbor which are less exposed to ocean dynamics. However, there are data gaps. For instance, it is unknown whether offshore wind can alter currents and water quality enough to affect migrating salmon and other species produced in hatcheries or national reproduction programs. Additionally, if offshore wind alters circulation patterns, it may affect upwelling and cause water quality concerns. Vessel activities associated with offshore wind could also shift water current. If offshore wind and its relevant activities increases nutrient influx, while this shift could be beneficial, it may also cause sedimentation issues. For shellfish aquaculture in particular, any alterations in sediment levels must be delicately managed. Sediment is necessary for growth, but excessive amounts can result in suffocation. Aquaculture species thrive on a delicate balance of sediment.

Feedback on importance: The effect will depend on the scale of offshore wind. There are gaps and concerns. There is a need to explore all potential avenues of offshore wind and its implications for aquaculture, fisheries, invasive species, as well as for surrounding coastal communities and waterways.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Feasibility of aquaculture based on current environmental parameters
- Cultural sensitivity of proposed aquaculture locations

Feasibility of aquaculture based on current environmental parameters. The feasibility of aquaculture will depend on the environment and the species reared. At inshore and Puget Sound areas that have a long history of aquaculture, the environmental parameters necessary to raise fish species under those conditions are understood. For instance, for species already primed for farming, like marine black cod or salmonids such as steelhead, most water quality parameters are well known, leaving no significant data gaps. Similarly, there's a solid understanding of areas where shellfish can thrive. Established farms, often spanning generations, have adapted to environmental changes over time. However, more information is needed for pest management issues, such as those posed by burrowing shrimp. Pests have dramatically altered the landscape of some farms, causing some to sell their business. Although an integrated pest management working group exists and the effects of pests on aquaculture are apparent, research is scarce on the causes, movements, and control methods. Similarly, data gaps apply to disease-related issues as well.

Environmental parameters that are less well understood relate to the management of offshore conditions, such as assessing the environmental risks associated with locating facilities in extreme marine environments and determining the most effective site selection for such operations.

Cultural sensitivity of proposed aquaculture locations. Cultural sensitivity relates to the people and location involved. Although data is limited, through the aquaculture permitting process, there is a procedure to assess the cultural sensitivity of a location. Aquaculture operations require various permits, each necessitating adherence to specific processes. This includes local shoreline planning and permits, state licenses and, in the case of offshore operations, federal permits. NOAA serves as the primary regulator for offshore aquaculture. These processes can provide some information on a location’s cultural sensitivity. There is limited information on the cultural sensitivity of any given location. Questions remain regarding whether a location encroaches on culturally significant areas, if it is sacred or traditionally used by Tribes, and whether Tribes are interested in utilizing a specific area. More data is needed to address these questions. For non-tribal cultural sensitivities, Marine Resource Committees and port authorities may have some relevant information.

Offshore wind data gaps

- Effect of offshore wind structure on existing aquaculture operations
- Effect of potential sites for land-based operations of offshore wind on existing aquaculture operations

Effect of offshore wind structure on existing aquaculture operations. If cables cross an aquaculture site, the electrical currents they generate will interact with the marine environment and disperse into the seawater, potentially causing unforeseen effects. The impact of these currents on the growth or feeding of submerged pens is unknown. While research on electromagnetic fields (EMF) and invasive species exists, the extent of this research and its potential impacts remain uncertain.

Additionally, if the structure causes nutrient runoff or sedimentation by altering water flow patterns, leads to sediment resuspension during construction or operation, or attracts marine life, it could degrade areas used for aquaculture.

Effect of potential sites for land-based operation of offshore wind on existing aquaculture operations. Unless an offshore wind structure is near an aquaculture facility or significantly affects the surrounding water, land-based operations of offshore wind are expected to pose a greater threat to existing aquaculture operations.

Potential effects from runoff and sedimentation present a notable concern. Shellfish is unique in that they utilize the natural environment. If an aquaculture farm is raising shellfish that rely on shallow environments, shellfish will be vulnerable to disturbances caused by land-based activities associated with offshore wind. There is a need to understand the effect of offshore wind activities on shellfish and fish production and natural migration. These effects will depend on regulations governing the proximity of land-based operations to aquaculture farms.

Offshore aquaculture data gaps

- Effect of shift to water current, water quality, and sedimentation from offshore aquaculture to existing aquaculture activities
- Effect of selection of farmed species and biosecurity concerns of offshore aquaculture on existing aquaculture activities
- Effect of potential sites for land-based and water-based operations of offshore aquaculture on existing aquaculture

Effect of shift to water current, water quality, and sedimentation from offshore aquaculture to existing aquaculture activities. If offshore aquaculture activities influence currents to the extent that water quality, nutrient input, or sedimentation are affected, there could be negative consequences on existing aquaculture operations. However, aquaculture operations at Willapa, Grays Harbor, and Puget Sound are pretty well protected. Such effects would only occur with a significant shift in circulation patterns.

Water current: Offshore aquaculture is expected to have minimal impact on the flow and local circulation of water. Since an offshore aquaculture facility would be submerged, water currents and flows are likely to remain largely unaffected as they would pass through the structures.

Sedimentation: Offshore aquaculture presents limited risk of causing sedimentation issues because they are situated in deep waters. These locations have lots of flow and flushing. Moreover, while finfish may produce some solid waste as part of their metabolic process, solid matter discharge is not a significant concern for offshore aquaculture operations because this waste would be assimilated naturally in the open ocean environment.

Water quality: The influx of nutrients can have both positive and negative consequences. Increased waste could be detrimental. Location could mitigate potential water quality and circulation concerns. However, the extent to which the environment can assimilate these changes depends on scale and location. Offshore, sensitivity to environmental shifts is typically lower. However, measuring the impact is difficult. Given the vastness of water bodies, changes in water quality may not be detectable.

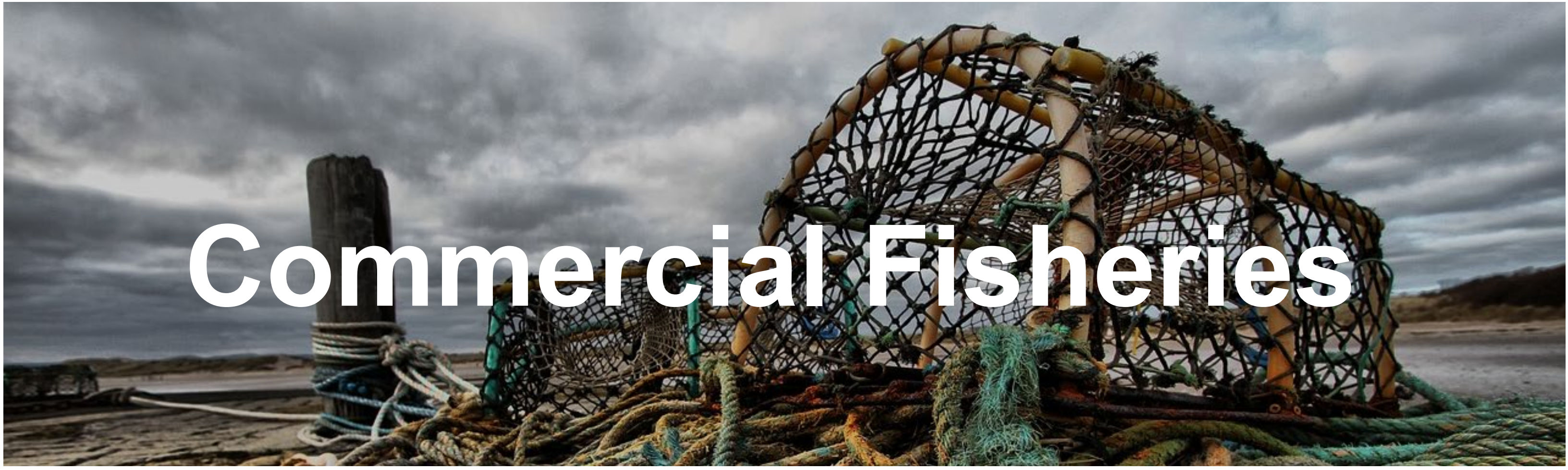
Effect of selection of farmed species and biosecurity concerns of offshore aquaculture on existing aquaculture activities. NOAA and the National Sea Grant Offices monitor biosecurity issues along the West Coast to prevent any potential spread and manage biosecurity concerns. One significant consideration is whether offshore activities will enhance water circulation and pose additional risks for biosecurity issues. There are concerns regarding disease interaction depending on the species attracted to the offshore aquaculture farms. The transmission of pathogens or diseases can occur in both directions: farmed species could contract diseases from natural fish, and vice versa. While further research is needed to fully understand this effect, due to the vast volume of water, the overall risk is expected to be very low.

Effect of potential sites for land-based and water-based operations of offshore aquaculture on existing aquaculture. Processing sites play a crucial role in the aquaculture industry, serving as the final step before products reach consumers. These facilities involve various personnel performing distinct tasks, typically within company-owned facilities rather than shared spaces. With offshore aquaculture, companies would have to establish their own processing facilities or negotiate sharing arrangements. This can potentially lead to increased competition for suitable locations for processing plants which requires space. These plants are often located near the water to provide convenient boat access, with docks dedicated for aquaculture use. Proximity to the aquaculture farm is prioritized to minimize processing time, ensuring product freshness. Regulatory guidelines dictate the duration products can remain at each processing phase, from harvesting to sale.

Resources

Table 40. Resources relevant to aquaculture.

NAME	ACCESS	TYPE	DESCRIPTION
NOAA Aquaculture Strategic Plan (2023-2028)	https://www.fisheries.noaa.gov/resource/document/noaa-aquaculture-strategic-plan-2023-2028	Report	Provides a five-year strategic plan to support the US aquaculture industry. The Plan establishes goals to manage sustainably and efficiently, lead science for sustainability, educate and exchange information, and support economic viability and growth.
NOAA: FAQ: Aquaculture Opportunity Areas	https://www.fisheries.noaa.gov/insight/faq-aquaculture-opportunity-areas	Website	Contains information on Aquaculture Opportunity Areas, geographic areas evaluated to determine their potential suitability for commercial aquaculture.
NOAA: Scientific Support for Health Management and Biosecurity for Marine Aquaculture in the United States	https://repository.library.noaa.gov/view/noaa/55554/noaa_55554_DS1.pdf	Technical memorandum	Provides an overview of the available science for health management and biosecurity throughout the marine aquaculture industry.



Commercial Fisheries

Key Data Gaps

General Data Gaps

- Location and intensity of commercial fisheries
- Cultural value of commercial fisheries
- Social value of commercial fisheries
- Processing data

Offshore Wind Data Gaps

- Economic effect of offshore wind on commercial fisheries
- Effect of restrictions to fishing grounds and spatial competition due to offshore wind

Other Data Gaps

General Data Gaps

- Status and trend of commercial fishing
- Comercial fisheries data collection method
- Economic value of commercial fisheries
- Effect of external factors on the behavior of fishers
- Food and nutrition

Offshore Wind Data Gaps

- Effect of offshore wind on the social and cultural values of commercial fisheries
- Effect of offshore wind on managed species and the management of species
- Effect of compensatory payments from offshore wind on commercial fisheries

Offshore Aquaculture Data Gaps

- Effect of offshore aquaculture on the social and cultural values of commercial fisheries
- Effect of offshore aquaculture on the economic value of commercial fisheries
- Effect of restrictions from offshore aquaculture on fishing grounds and spatial competition
- Effect of offshore aquaculture on managed commercial fishery species
- Effect of disease transmission and escapees from offshore aquaculture on commercial fisheries

Background

This section will not discuss tribal fisheries as they are conducted under special authorities held by tribal governments.

There are various commercial fisheries that operate within the Study Area. Fish receiving tickets, known as "fish tickets," serve as the primary source of information on commercial fishing activity. These tickets document transactions between vessel owners/operators and purchasers, detailing species landed, quantities, catch areas, and prices paid. They are submitted to the Washington Department of Fish and Wildlife (WDFW), stored in a state database, and shared via the Pacific States Marine Fisheries Commission's (PSMFC) Pacific Fisheries Information Network (PacFIN).

Commercial fisheries have direct and indirect economic effects. Cascade Economics prepared a report to specifically inform the MSP about these effects. "Direct" economic inputs to state and coastal economies were interpreted to encompass revenues from fishing operations through sale; barter or trade of their catch; and those earned by seafood businesses who process and facilitate transactions with restaurants, retailers, and other consumers. Ex-vessel revenues, which are income generated from the sale of species or species group at the point of landing, can circulate within the economy as fishing businesses use it for their operations and pay income. Spending on goods and services like fuel and gear, lead to "indirect" effects on the economy. The fishery's economic influence can extend to various sectors of the economy as owners and employees spend disposable income.

Seafood buyers and processors purchase catches from fishing operations. These products enter diverse markets, from human consumption to agriculture. In addition to paying ex-vessel revenues, seafood buyer and processors contribute to the economy through other means. For example, large processing facilities at ports provide substantial employment. In 2014, commercial fishing and primary seafood processing contributed an estimated 1,820 jobs and \$77.2 million in labor income to Washington coastal counties and 2,830 jobs and \$117.0 million statewide. However, these estimates are not comprehensive as they did not include the effects of secondary processing effects (e.g., fish oil production) or the effect of additional distribution and retail of seafood. They also omit imports, Alaskan catches, and landings into Oregon or Puget Sound. Economic contributions are affected by whether landings are processed out of state or whether out of state landings are transported to Washington.

The commercial fisheries that occur in the Study Area and described by the MSP is summarized below.

Groundfish: The groundfish fishery encompasses a diverse range of species preferring seafloor habitats, with over 90 species included in the PFMC Groundfish Fishery Management Plan (FMP). From 2004 to 2014, groundfish was the largest fishery by volume except during 2012 and 2013. Groundfish fisheries collectively yield substantial annual landings into coastal ports. Distinct fishery sectors operate within the study area, employing different fishing methods, targeting various groundfish species, and using different fishing grounds. The fixed gear sector primarily targets sablefish; the bottom trawl gear sector targets flatfish, sablefish, and others across the Study Area's continental shelf and slope habitats; and the midwater trawling sector focuses on schooling rockfish like yellowtail and widow rockfish.

Pacific whiting: The Pacific whiting fishery comprises both shore-based and at-sea catcher vessels, each reported separately due to their distinct economic contributions. All whiting catcher vessels use midwater trawl gear, designed for fishing in the water column, though sometimes near the seafloor. Shore-based vessels stay close to port, primarily operating off Washington and Oregon coasts. Landings from this fishery consistently dominate total commercial landings in weight, except for 2012 and 2013. At-sea vessels typically feature a larger vessel, enabling prolonged stays at sea. There are two distinct vessels: motherships and catcher processors. Mothership vessels only process whiting. Catcher-processor vessels both catch and process their own catch. Many are based in Puget Sound.

Salmon: Salmon are the second highest revenue-generating species in the region. Historic declines in commercial salmon fishing stem from population decreases, changes in harvesting practices following legal decisions, and other factors. Their overall fishery value is constrained due to limited allowable catches compared to other fisheries. Commercial salmon fishing in the region comprises two main sectors: ocean troll and gillnet fisheries, managed respectively by PFMC and WDFW, within a regulatory framework involving Washington, Oregon, California, Alaska, Idaho, Canada, and various tribal entities. The ocean troll method is widely used in ocean waters and primarily targets Chinook and Coho salmon. Gillnet fisheries operate in Willapa Bay, Grays Harbor, and the Columbia River, regulated separately by WDFW. This fisheries targets Chinook, Coho, and chum salmon. The primary challenge for the salmon fishery has been to balance harvesting between hatchery-raised and wild salmon populations while conserving at-risk wild stocks.

Albacore tuna: This fishery is managed under PFMC's Highly Migratory Species FMP. Albacore tuna is caught by troll or pole and line techniques. Canadian vessels make landings in Washington under a treaty with the United States (US). Fishing occurs in summer and fall, mainly 30 to 50 nautical miles offshore. With the highest participation level among the Washington coast fishery sectors, between 221 and 338 vessels land in Washington ports annually, with landings ranging from 10 to 18.6 million lbs. between 2004 and 2014. Ex-vessel values ranged from $11.3 to $28.2 million.

Pacific sardine: Off the coast of Washington, Pacific sardine and Northern anchovy are the main commercial species caught, with Pacific mackerel landed incidentally. Fishing occurs in late spring and summer. State waters are off-limits by law. Ex-vessel revenue in Washington ranged from about $0.5 million to $8.2 million between 2004 and 2014. PFMC closed the fishery in 2015 due to low stock biomass and remained closed in 2017.

Pacific halibut: The Pacific halibut fishery in Washington, Oregon, and California is managed by PFMC's Catch Sharing Plan (CSP). Commercial harvest occurs via an open access directed fishery and through incidental retention allowance. When open, the fishery is only open south of Point Chehalis. Participation depends on the timing and availability of other fishing opportunities.

Hagfish: The commercial hagfish (slime eel) fishery operates off Washington and Oregon, offering open access fishing opportunities with licenses available to those interested. Fishing occurs year-round using pot gear in depths of 300 to 480 feet. Landings, prices, and revenues in Washington have risen steadily, reaching about $2.27 million in 2012.

Shellfish:

Dungeness crab: Dungeness crabs are harvested along the entire Washington coast. Fishing is most intense in the southern third of the MSP Study Area. Pots are deployed on soft bottom in depths ranging from approximately 18 feet to 600 feet. WDFW, along with coastal treaty Tribes, manages the Dungeness crab fishery in coordination with Oregon and California agencies. WDFW may close the fishery for various reasons such as state-tribal agreements, crab quality delays, or to ensure a safe product if high levels of biotoxins are observed.

Dungeness Crab is the second highest participated fishery among the WA coast fishery sectors and the top revenue generator in commercial fisheries. Ex-vessel revenue ranged from $12.5 million to $43.5 million between 2004 and 2014. Highly valued locally and internationally, Dungeness crab earns the highest average price per pound on the coast. Abundance varies yearly based on ocean conditions that affect larvae survival and settlement.

Pink Shrimp: Harvested with trawl gear at depths of 300 to 750 feet, pink shrimp are abundant off the Washington and Oregon coasts from April to October. WDFW coordinates with Oregon to regulate the fishery. Landings have increased since 2012, reaching 30.5 million pounds in 2014, with revenues rising from $1.9 million in 2007 to $16.4 million in 2014. This expansion is attributed to factors such as increased abundance and processing capacity.

Spot Prawn: This fishery operates along Washington's outer coast from March to September, using primarily pot longline gear. Out of eight licenses, three to five are active. Ex-vessel revenues peaked at $754,585 in 2010 and dropped to $102,257 in 2013.

Razor Clams: The commercial razor clam fishery operates from May to June and landed exclusively in Pacific County and Grays Harbor. Harvest is limited to detached spits at Willapa Bay's mouth, accessible only by boat. Vessels are not directly involved in harvesting and catches are mostly sold as Dungeness crab bait. Most commercial licenses are issued to residents of Pacific or Grays Harbor Counties. Revenues ranged from $182,390 to $588,620 between 2004 and 2014.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to commercial fisheries:

General data gaps

- Location and intensity of commercial fishing
- Cultural value of commercial fisheries
- Social value of commercial fisheries
- Processing data

Location and intensity of commercial fishing. Data from vessel monitoring systems could address this data gap. Automatic Identification System (AIS), a tracking system, offers fishing location and intensity data, particularly for large vessels and those in federal fisheries. For example, the trawl groundfish fishery is extensively managed and monitored through vessel tracking, providing detailed information on fishing activities and catch locations. However, this data is often confidential due to its proprietary nature. Data is not equally available for all fisheries. Fisheries like Albacore tuna and Dungeness crab lack comparable levels of information. Salmon data primarily consists of landing records at the location and trip level, with limited additional details. Additionally, while NMFS collects some Tribal fisheries data, but its use is restricted to specific purposes such as stock assessments.

There are several sources of data for Washington. NOAA and PacFIN will have data on what is landed in Washington. NOAA has data for major federally managed fisheries, but it may not capture vessels outside the fisheries it tracks. For example, there are three sablefish regimes, and NOAA has strong tracking for two of them. Othe resources include fish tickets also provide information on fish landings in Washington; and Global Fishing Watch[136], which offers detailed data on vessel locations and fishing activity, especially for moderately sized vessels. Fisheries Economics of the United States[137] presents national, regional, and state tables based on federal data, primarily focused on landings and processing information. Funding is not consistently available for this effort.

There is ongoing collaboration with the PFMC to develop an innovative, integrated coastwide database and visualization tool, currently in a beta version with complete data for pink shrimp, groundfish trawl, and Pacific whiting. The database combines different sources of nontribal fisheries data. The full version, expected early next year, will encompass additional fisheries. In particular, Washington will have data on albacore tuna, swordfish, fixed gear groundfish, sardines, mackerel, Dungeness crab, and hagfish. However, data for some fisheries with low participation, like the hagfish fishery, may not be publicly accessible due to insufficient activity for meaningful data aggregation. Efforts are underway to explore the tool's availability for public use, albeit with considerations for aggregating confidential data and addressing user boundary-setting challenges. Some publicly available products are anticipated. Collaboration with states is ongoing.

Feedback on importance: Commercial fisheries are economically significant. Understanding the location and intensity of commercial fishing is essential for effective planning and to assess the effect of factors that affect this industry such as climate-related alterations in ocean conditions.

> **WCMAC:** The significance of data gaps regarding the location and intensity of commercial fishing is uncertain, but there appears to be a solid database on fishing activity locations. WCMAC has likely gathered data for the region off Washington.
>
> Some fisheries exhibit strong site fidelity. Groundfish bottom trawling is closely associated with bottom structures and because certain species also demonstrate site fidelity, some fishers return to the same areas repeatedly. While there are some differences trip by trip, there is a good understanding of where the groundfish fishery

[136] https://globalfishingwatch.org/map/index
[137] https://www.fisheries.noaa.gov/national/sustainable-fisheries/fisheries-economics-united-states

operates. In contrast, species like Pacific whiting do not display site fidelity. They are highly migratory, with their distribution influenced by oceanographic conditions. Pacific whiting is primarily caught from California to British Columbia, migrating from south to north in the spring.

Certain fisheries have less data for other reasons. There is less information available about commercial salmon trawling compared to groundfish. Unlike groundfish and whiting, commercial salmon trawls are not required to use a vessel monitoring system (VMS), a satellite tracking system, which may contribute to data gaps regarding specific fishing locations. For salmon, some species migrate northward from the Columbia River, traveling as far as 600 miles. Different life history traits must be considered. There may also be limited data on the albacore fishery, which is highly migratory and typically fished 35 to 100 miles offshore. In some years, significant fishing occurs in the southern half of Washington. Improving data on the albacore fishery is essential. The comprehensiveness of NOAA Fisheries' data in this area is unclear. There may be more information available than currently recognized.

Cultural value of commercial fisheries. When it comes to evaluating cultural value, it requires determining what measure would be most appropriate. It's doubtful that anyone is currently handling this task for Washington. It requires a better grasp of the state's data resolution and there is a shortage of people available to carry out this kind of work.

Sense of place is integral to the growth of communities and economies. Communities typically emerge due to specific economic activities such as farming or fishing, which in turn attract related industries and people, shaping the community's identity. This historical significance is fundamental to understanding the community's origins. For example, the commercial fishing industry not only provides employment but also shapes how individuals perceive their value within the community. Changes in the industry or climate could significantly impact these communities. While there is a desire for communities to become more resilient, achieving resilience often requires diversifying economic activities, which may erode the community's identity. This creates a dilemma between preserving identity and fostering resilience. However, it is important to recognize that while shifting identity may involve some losses, it can also open up new opportunities, with economic development offering the potential for positive outcomes.

Currently, there are some indicators available, but none that approach valuation. NOAA's Social Indicators for Coastal Communities[138] aggregates data to generate various indicators at the community level. These include measures like vulnerability and dependence on fisheries, which are utilized in regulatory processes to characterize communities and assess potential impacts. Some indicators are derived from the community census sample, which is updated every 5 to 6 years. Depending on the data source, others can be updated annually. Ongoing efforts are being made to address frequently asked questions.

[138] https://www.fisheries.noaa.gov/national/socioeconomics/social-indicators-coastal-communities

There are other data gaps that could inform the cultural value of commercial fishing. There is a significant data gap regarding the profile of seafood purchases in Washington, including information on volume, species composition, and regional origin. The value of fish species varies depending on the specific area. It is worth noting that almost all of Washington's fish is consumed outside the state, making it a critical aspect of state trade. At a broad level, it is important to understand the volume of sales made by retailers such as QFC, Safeway, and Costco, distinguishing between farmed and wild salmon, fish fingers, cod, and other products.

There is also a data gap concerning higher-order food processing. For instance, Trident operates battering plants where Alaska pollock is frozen into blocks, shipped to South Seattle, and processed into fish fingers and battered pieces. However, the scale of this operation, its prevalence elsewhere, and the number of facilities engaged in similar activities is uncertain. There are other businesses that also need to be considered for this data gap. Retail, restaurants, and other consumer facing businesses also have a cultural value that depends on commercial fisheries. For example, Pike Place Market is a regional identity.

Feedback on importance: Often a neglected area of data collection, it is important to consider the cultural value of commercial fisheries, in addition to their economic value.

> **WCMAC:** The cultural value of commercial fisheries encompasses both economic and human aspects. The cultural value intersects with the local economy, as recreational and commercial fisheries play a crucial role in the business community. For instance, Westport's businesses rely on fishing, including grocery stores, motels, and gift shops. The activities generated by fishing also help attract visitors to the community. Without these foundational fisheries, tourism could suffer significantly.
>
> For the human aspect, communities like Westport have a long-standing connection to commercial and recreational fishing, fostering a societal culture where fishing has been a way of life for generations. Many families have multiple generations involved in the industry, creating a rich heritage that could be at risk due to the impact of development like wind energy on local fisheries. Quantifying this cultural significance is challenging; however, the presence of third- and fourth-generation commercial fishers underscores the importance of considering it. The fishing industry is integral to the community's identity and economic vitality.

Social value of commercial fisheries. Commercial fishing primarily serves as a means of income generation and is not commonly linked to the relaxation or enjoyment associated with recreational fishing. Nonetheless, commercial fishing holds other forms of social value. For example, employment data can inform more than economic value as it influences community size, vibrancy, and career opportunities in coastal WA communities, including fish processing and harvesting roles. The number of jobs is relevant to supporting the community, making sure it is large enough, vibrant, and supportive of individuals pursuing desired careers. The Department of Labor provides data on jobs in commercial fish processing, along with enhanced catch data for groundfish trawl fishery. It may also track harvesting vessel crew data and pay, possibly distinguishing WA-based crews. First receivers are also required to complete cost and earning surveys. Supporting industries like fishing gear and vessel maintenance also contribute to working waterfronts' literature. A working waterfront is distinct from economic value and reflects a community's social values. Social events also often revolve around commercial fishing activities. Events like seafood festivals serve as platforms for the commercial fishing industry to engage with the public, maintain social acceptance, and reinforce community connections.

NOAA's Social Indicators for Coastal Communities[139] may provide relevant information. This tool aggregates data to generate various indicators at the community level. These include measures like vulnerability and dependence on fisheries, which are utilized in regulatory processes to characterize communities and assess potential impacts. Some indicators are derived from the community census sample, which is updated every 5 to 6 years. Depending on the data source, others can be updated annually. Ongoing efforts are being made to address frequently asked questions.

Feedback on importance: Alongside its economic value, the social value of commercial fisheries also warrants consideration. It is important to take a broad view of the significance of fishing to communities.

> **WCMAC:** When considering the social value of commercial fisheries, the impact on schools and the families they serve is crucial. For example, reducing or eliminating commercial fishing and its associated infrastructure could negatively affect school populations. This trend is already evident, where the decline of the charter industry and sport fishing in Westport has contributed to a decrease in student enrollment in that area. It is likely that this decline will continue. While small schools can offer valuable education, they often struggle to provide the broad curriculum that larger schools can offer, making it more challenging for students to access a diverse range of subjects and opportunities.

Processing data. There are records on the number of fish processing or purchasing operations by location, but comprehensive information beyond that is lacking. This presents a challenge when attempting to assess the economic, social, and cultural values associated with these operations. For instance, in cases where a significant business impacts a community, it is essential to understand the flow of resources, costs, and benefits involved. This includes details such as the number of employees, the processing methods used (whether sold domestically or exported), and the types of fish processed. These data are often treated as sensitive and private information.

While landing records can identify where fish are sent, there is often limited knowledge of what occurs afterward. Despite the involvement of state and federal agencies in managing fish caught in public resource areas, once ownership transfers to a private company, regulatory bodies often lack the authority to collect further data. One recommendation is to examine receiver data, which provides insights into the products derived from the groundfish fishery. Beyond that, it is unclear what data or information the state has collected for monitoring, labor, or tax purposes. Key species of interest include Dungeness crab and salmon, as data on these,

[139] https://www.fisheries.noaa.gov/national/socioeconomics/social-indicators-coastal-communities

along with groundfish, can provide a broad overview. Additionally, information on shellfish farming would be valuable to complement existing datasets.

Feedback on importance: When considering the commercial fishery industry at large, this is a critical socioeconomic and environmental justice issue. Processors and processing workers significantly affect the outcome for fishers and local communities. However, there is little known about both.

> **WCMAC:** Regarding commercial processing data, there is a significant amount of information already available. Conducting an inventory of this data would be beneficial to identify any gaps that may exist in evaluating the impacts of potential activities like offshore wind energy on the commercial seafood processing industry.

Offshore wind data gaps

- Effect of offshore wind on the economic value of recreational fisheries
- Effect of restrictions to fishing grounds and spatial competition due to offshore wind

Effect of offshore wind on the economic value of commercial fisheries. This is less of a data gap because there is information about landings and revenue. There is a direct economic effect on people who incur costs. There is an increased cost associated with spatial conflict which takes three forms. First, fishing activities may be displaced from areas where turbines are located, potentially disrupting established paths such as historic trawling trails. Second, fisheries like the albacore tuna fishery, which follow fast-swimming fish, may face challenges if fish enter closed areas during pursuit, resulting in lost catch and additional costs to pursue the fish. Displacement includes the displacement of fishing that passes through that area. Third, as the scale of wind farms expands, competition for port and vessel services may arise, potentially affecting fishing operations. It remains uncertain whether fishing platforms could be repurposed for the energy industry or if fishing vessels could be used to maintain wind platforms. There are concerns about this competition.

Fishers may seek to offset these costs by, for example, relocating to areas with better access to fishing grounds. Fishing in waters belonging to other countries is an example of displacement. Alternatively, some individuals may opt to cease fishing altogether. There is ongoing debate regarding the potential shift of fishing activities to land-based fish farms. If rising costs make land-based aquaculture more economically viable, entire fishing industries may disappear. This scenario would lead to reduced functionality of marinas, boats, and related infrastructure.

Feedback on importance: The economic effect of offshore wind on commercial fisheries is an area with gaps in knowledge. Key questions include how offshore wind developments will affect fishing practices, where fishers will choose to fish, and the implications for landing their catch, all of which can influence local communities.

This effect remains the least understood even though offshore wind has the potential for substantial economic consequences. The magnitude of these impacts could be considerable, especially given that the structures involved differ from those on the East Coast. Even small-scale wind farms could have a significant effect on fishing operations. For instance, there is a need to examine whether offshore wind developments create safe havens that influence fish populations, their effect on where fisheries choose to land their catch, and the overall volume of fish landed. Fishers typically land their catch where their boats are docked, which is often near fishing sites. Landing decisions can also be influenced by buyers, as a buyer at one port may offer higher prices, leading to a trade-off between potential profit and fishing costs, such as fuel. Understanding where buyers are located and what markets they serve is crucial.

This data gap may become more manageable as offshore wind projects are implemented.

> **WCMAC:** The effect of offshore wind on the economic value of commercial fisheries represents a significant data gap. Speculating on the economic effects is challenging without a clearer understanding of what these offshore wind developments will look like. Generally, the larger the area designated for wind energy, the greater the potential for conflicts with fisheries and the more pronounced the impact.
>
> While the ocean may appear vast, it becomes much smaller when considering the specific locations where fish are found. This is a substantial issue and a major unknown. Without clarity on the locations and sizes of proposed developments, it is not possible to accurately quantify the associated costs. Furthermore, the large volume of power required for economic viability will likely necessitate a larger footprint, which, if situated within 300 fathoms, could disrupt existing fishing activities.

Effect of restrictions to fishing grounds and spatial competition due to offshore wind. Restricting the space where fisheries can operate confines them to a smaller area, resulting in increased competition, heightened risks, and fishing under potentially hazardous conditions. The same number of fishers could be competing in a reduced space. Furthermore, limiting access eliminates opportunities for engaging in social and cultural practices associated with fishing. However, offshore wind structures may also provide benefits for fishing opportunities. If these structures create fish havens and if fish migrate from these havens, new fishing opportunities may be created. How this would affect the concentration of fishing activities is unclear.

Spatial conflict takes three forms. First, fishing activities may be displaced from areas with turbines, potentially disrupting established routes like historic trawling trails. Second, if fish enter closed areas during pursuit, fisheries such as the albacore tuna fishery could encounter difficulties, leading to lost catches and increased costs. This displacement also includes fishing that typically passes through those areas. Third, as wind farms grow in scale, competition for port and vessel services may increase, potentially impacting fishing operations. It remains uncertain whether fishing platforms could be repurposed for the energy industry or if fishing vessels could be used to maintain wind platforms. There are concerns about this spatial competition.

If there are spatial overlaps between offshore aquaculture and commercial fishery activities, the closure of one area may cause fishers to move to another nearby area. The likelihood of fishers engaging in this redistribution effort will require consideration of the need for additional resources such as any necessary fishing gear. Modeling can help predict how and where fisheries might redistribute to. If spatial overlap limits commercial fisheries, there may be effects to the communities that rely on them. For instance, if 5% of a community's revenue is displaced, there is a need to understand the implications of this loss.

Offshore wind will also necessitate sufficient infrastructure and depending on their location, these developments can either support or hinder fisheries. While substantial development, dredging, and port enhancements may spur fishery growth and provide benefits, there are potential drawbacks. If port facilities become inaccessible or overly expensive, limitations such as space constraints or cost factors might crowd out fishing activities. Additionally, vessel traffic during construction, operation, and decommissioning phases may conflict with fishery operations.

Feedback on importance: From the perspective of offshore wind development's impact on fisheries, this data gap encompasses numerous related issues. Many economic, social, and cultural effects on commercial fisheries will hinge on the restrictions and spatial competition generated by offshore wind projects.

WCMAC: It is unclear how offshore wind will affect the fisheries' ability to conduct annual stock assessments in a manner that retains the efficacy of those assessment. While salmon and albacore are less likely to be affected, for example, many groundfish species rely on the stock assessment trawl surveys. Additionally, there is an ongoing project to use the same survey methods for Pacific whiting, sardines, and anchovies, applying the same transects for these coastal pelagic species. Offshore wind could greatly hinder the ability to assess these forage fish populations as well.

Ports like Westport, Ilwaco, and Warrington could easily be overwhelmed by the demands of offshore wind activities, with Astoria potentially experiencing a lesser impact. Westport currently has a three-year waiting list for slips and only one fuel dock available. These limitations raise concerns about the capacity of ports to accommodate additional vessels, particularly given the uncertain servicing needs for wind platforms. There is a prevailing belief that those involved in the offshore wind industry may have more financial resources than fishers, which will allow them to outbid fishermen for available space. This situation will create an uneven playing field for local fisheries.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Status and trend of commercial fishing
- Commercial fisheries data collection method
- Economic value of commercial fisheries
- Effect of external factors on the behavior of fishers
- Food and nutrition

Status and trend of commercial fishing. Data availability varies depending on the inquiry.

For economic status and trends in federal fisheries, data is primarily accessible through program reviews specific to each fishery. For instance, the data collection and reporting program of the Pacific Groundfish Trawl Fishery yields robust economic data. Much of this initiative is overseen by the NWFSC, which conducts a comprehensive 5-year review of the program, offering detailed insights into changes within the fishery, including shifts in the processing sector. However, community-level participation data may not consistently be available.

Relevant data can also be retrieved through PacFIN[140], a data selection tool that offers aggregated metrics like trip numbers and landings. Landing amounts can be aggregated by species, fisheries, and months and the platform allows analysis of revenue-to-landings for specific locations. PacFIN compiles reports based on this data and can provide species-specific summaries for Washington State. Metrics such as trip numbers or average catch sizes may necessitate supplementary data from other fisheries sources, which may not be universally mandated. Drawing data from the US Census Bureau[141] and PacFIN, the WA Coast Economist online dashboard offers access to locally relevant information encompassing all WA coastal counties. This includes population demographics, income levels, housing statistics, gross regional product, employment figures, and data on recreational boating and sales. The dashboard also provides output and value data pertaining to shellfish aquaculture and access to relevant economic studies conducted along the coast.

For ecological and biological trends, there are various sources of data from NOAA. First, there is the California Current Integrated Ecosystem Status Report which provides insights into the joint social and ecological system within the California Current Ecosystem, encompassing information on fishing activities. Second, there are a lot of data from stock assessments. Most fisheries have comprehensive data on landings through fish tickets. While metrics like the quantity of fish landed are available to shed light on status and trends, data regarding location and intensity are more nuanced and detailed information like cost is typically not provided. Third, there is the West Coast Limited Entry Groundfish Trawl Cost Earnings Survey, conducted by the NWFSC. A voluntary survey that receives periodic funding, this survey has been conducted every 4-6 years over its two-decade history. The RAM Legacy Stock Assessment Database[142] contains comprehensive data on fish catches at the stock level for various regions around the word. It may not distinguish Washington-specific data. Upon identifying key stocks, users can extract data to analyze catch, biomass, and other relevant metrics based on the latest stock assessment available.

Commercial fisheries data collection method. Commercial fisheries data are collected through various methods. These data are integral to fisheries management efforts, facilitating regulatory interventions to address any identified issues.

There are data collection methods that are tailored to individual fisheries and their regulatory requirements such as using logbooks, onboard observers, or VMS (Vessel Monitoring Systems).

[140] https://pacfin.psmfc.org/
[141] https://www.census.gov/data.html
[142] https://www.ramlegacy.org

For fisheries mandated to use AIS tracking, the Coast Guard oversees enforcement. Compliance and enforcement of AIS tracking regulations on the West Coast is as effective as anywhere globally. Data is also collected through fish tickets which are mandatory for every catch landed, requiring comprehensive information about the catch and its landing location. This ensures thorough documentation of all aspects related to landings and revenue. Another data source is the West Coast Fisheries Participation Survey Tool, conducted every three years and distributed to all fish permit holders. The survey includes inquiries about catch composition, community engagement, climate-induced changes in fisheries, and infrastructure considerations.

Data gaps primarily stem from a reluctance to impose administrative burdens on smaller vessels and industry resistance to sharing data deemed proprietary.

Economic value of commercial fisheries. Economic value refers to the financial returns generated. While there are some data gaps, this aspect is adequately addressed. NOAA is tasked with maintaining the economic viability of fisheries. Each year, NOAA produces the "Fisheries Economics of the United States"[143] report. It examines the economic performance of commercial and recreational fisheries and other marine sectors at state, regional, and national basis. For commercial fisheries, statistics on landings, revenue, and price trends are provided. The report also covers recreational fisheries, fishing-related industries, and the economic impact. Funding is not consistently available for this effort and there is an issue with lag. Once data is gathered, there's a subsequent period required for review, analysis, and report preparation. The most recent version is the 2022 edition[144].

There is also a tool to assess the economic value of fisheries. States and NMFS jointly developed an economic value modeling framework called Input Output Pacific[145] (I-OPAC). This framework utilizes fisheries data to parameterize input and output and measure a fishery's economic value. Additionally, for regulatory analyses requiring the evaluation of alternatives, the I-OPAC model may be used to assess economic impacts. The model can be tailored to specific geographical areas, fisheries, and factors and, depending on the inquiry, draws upon various data sources. For example, it can evaluate landings in Westport.

Effect of external factors on the behavior of fishers. The effect of external factors on fishers' behavior represents a significant data gap and has been the focus of substantial research in fisheries economics over the past decade and a half. There's been extensive critique and analysis, exploring various dimensions of this issue. On the East Coast, the primary effect is the necessity for spatial relocation of fishing efforts. Numerous published studies have developed and critiqued methods to understand spatial relocation. These studies often analyze data from vessel monitoring systems to examine where fishers choose to fish and the resulting catch in different areas. They investigate how fishers adjust their efforts when certain areas are closed and assess the potential impacts of such closures. Spatial relocation serves as a mechanism for

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[143] https://www.fisheries.noaa.gov/national/sustainable-fisheries/fisheries-economics-united-states

[144] https://www.fisheries.noaa.gov/resource/document/fisheries-economics-united-states-report

[145] https://www.webapps.nwfsc.noaa.gov/assets/25/1620_08012011_142237_InputOutputModelTM111WebFinal.pdf

controlling catch composition, given the spatial variation in species mix. For instance, if fishers aim to catch a significant number of Pacific cod while avoiding halibut, they may move to areas where the ratio is more favorable. The costs associated with such relocation efforts must also be considered. There are several lessons learned through these studies including:

- Research methods are predominantly focused on the shift of spatial effort rather than the overall fishing effort. There's a notable gap in studying the decision-making process of fishers to decrease or cease fishing altogether.
- Fishers move, persistently seeking fish and typically succeeding in their catch. However, this movement incurs costs, resulting in higher expenses to capture the same quantity of fish. Estimates of these costs diverge significantly, with a general consensus on a positive cost but no agreement on specific figures.
- There are various strategies fishers use to respond to challenges, strategies beyond adjusting fishing locations. One significant criticism of existing models is the need for a more substantial margin on changes in fishing time and depth. Data on these aspects are lacking. While it is easy to determine the location of fishing activities, the ability to track when and how deep fishers fish remains elusive due to insufficient data collection methods. Without these data, it is challenging to fully understand the range of flexibility fishers have. This gap arises partly because there is no opportunity to observe how fishers respond. It is worth mentioning that there has never been a demand to understand this response, nor is there any attempt to conceal this information. There is a need to better comprehend when individuals decide to fish.
- Due to the lack of comprehensive data collection on fishers before program implementation, there is no baseline for comparing the impacts of the programs, particularly on those who exit the industry. There is no regulatory entity responsible for gathering such information. Without historical data collection, understanding how behaviors are influenced becomes challenging.

Some relevant information may be attained by for example, examining how many groundfish permit holders also have another permit.

Another data gap is why fishers exit the industry. It is challenging to pinpoint causal factors. Central concerns often revolve around the potential loss of the entire fishing industry. To better understand fishers' vulnerability and their decisions to remain or exit the industry, further investigation is required.

When conducting regulatory or policy analysis, it is crucial to assess potential impacts and unintended impacts. While reports on specific cases could provide some insight, there is no universal answer or indicator that will provide information in a comparable way to understand the effect of external factors on the behavior of fishers.

Food and nutrition. It is essential to determine people's dietary preferences and the sources of their food. Seafood obtained through commercial, recreational, and subsistence fishing plays a crucial role in the diets of various communities in Washington. It serves as a nutritious source of protein and essential micronutrients like Omega-3 fatty acids. The US Department of

Agriculture (USDA) gathers food diaries from individuals across different regions, documenting the origins of consumed food. One notable finding is that economically disadvantaged communities often rely more heavily on locally caught seafood, while in wealthier regions, seafood contributes to balanced and healthy diets. However, parsing data from USDA Food Diaries by geographic location presents challenges. To accurately assess the reliance of Washington residents on locally sourced seafood, it is necessary to isolate and analyze consumption patterns specific to the state. For example, analyzing seafood consumption at the county level can provide insights into local food systems. This analysis would include factors such as the proportion of Omega-3s sourced from seafood, as well as metrics like total pounds consumed and caloric intake. Additionally, it would be valuable to explore whether residents of the Olympic Coast obtain a significant portion of their vitamins from Washington seafood.

Offshore wind data gaps

- Effect of offshore wind on the social and cultural values of commercial fisheries
- Effect of offshore wind on managed species and the management of species
- Effect of compensatory payments from offshore wind on commercial fisheries

Effect of offshore wind on the social and cultural values of commercial fisheries. Direct social or cultural impacts to commercial fisheries from offshore wind development may not be immediately apparent. However, there is an evident connection between the economic factors of commercial fisheries and their social and cultural values. Commercial fisheries are closely linked to livelihoods and can have broader impacts on entire communities. For example, limiting access to certain fishing areas can reduce opportunities for engaging in traditional social and cultural practices. One way to explore the potential connection between offshore wind, commercial fishing, and onshore communities, as well as the impacts, is to examine the overlap between offshore wind projects and fisheries, including the locations where fish are landed. If spatial overlaps occur between offshore wind projects and commercial fishing activities, the closure of one area could force fishers to relocate to nearby regions. The likelihood of this redistribution will depend on factors such as the availability of additional resources, including fishing gear. Modeling can help predict how and where fisheries may relocate. If spatial overlaps limit commercial fisheries, there could be significant effects on the communities that depend on them. For example, if 5% of a community's revenue is displaced, it is crucial to understand the broader implications of this loss. This assessment should consider the community’s demographics, the effects on competition, and how changes will alter the overall community landscape. This analysis would provide the basis to understand potential economic, social, and cultural impacts.

The potential effect of offshore wind on communities through commercial fisheries is also tied to changes in port infrastructure. Developments related to offshore wind, depending on their location, can either support or hinder fishing operations. Substantial development, including dredging and port enhancements, may facilitate growth in the fishing industry and offer benefits. However, vessels necessary for construction, operation, and decommissioning phases of offshore wind farms will necessitate sufficient infrastructure. If port facilities become inaccessible or prohibitively expensive, factors such as space constraints or rising costs could displace fishing activities. These changes may disrupt commercial fisheries and, in turn, impact the communities that depend on them.

Effect of offshore wind on managed species and the management of species. Offshore wind projects may affect species management if they limit survey data collection. Fisheries surveys typically revisit the same sites annually; if access to these sites is restricted, data loss occurs. There is a significant concern on how to adapt fisheries surveys if offshore wind development excludes them from certain areas. These surveys provide standardized data crucial for stock assessment models, which estimate species abundance and inform allowable catch limits. Reduced data quality due to restricted access may increase uncertainty in abundance estimates, potentially affecting total allowable catches (TACs) set by the National Marine Fisheries Service (NMFS). There is currently work to understand the relationship between exclusions from historical survey locations, stock assessments, and setting TACs.

The scientific understanding of the effects of offshore wind on marine species is still developing, and the impact is likely to vary depending on the species involved. Contrary to common assumptions, these structures may not necessarily have negative effects. Observations from the East Coast suggest that fish are aggregating around the platforms, which can act as refuges for certain species. However, there are concerns regarding bycatch.

Effect of compensatory payments from offshore wind on commercial fisheries. On the East Coast, cash payments are provided to fishers as compensation. However, there is limited understanding regarding how recipients use this money. It is plausible that individuals benefit from receiving such payments, enhancing their resilience to climate change driven fluctuations and impacts on fish stocks. While this approach offers appealing aspects and potential benefits, there are important considerations to take into account. For example, the impact of payments to individuals who were already planning to retire is not well understood. Additionally, the potential effects on their children, who will be unable to continue the family's commercial fishing business, remain unclear.

Offshore aquaculture data gaps

- Effect of offshore aquaculture on the social and cultural values of commercial fisheries
- Effect of offshore aquaculture on the economic value of commercial fisheries
- Effect of restrictions from offshore aquaculture on fishing grounds and spatial competition
- Effect of offshore aquaculture on managed commercial fishery species
- Effect of disease transmission and escapees from offshore aquaculture on commercial fisheries

Effect of offshore aquaculture on the social and cultural values of commercial fisheries. The direct effect of offshore aquaculture on the social or cultural values of commercial fisheries may not be immediately apparent. However, there is an evident connection between economics to the social and cultural values of commercial fisheries. Depending on what is farmed and the location of the facility, offshore aquaculture can support or hinder commercial fisheries. Different species have different values to different communities, including species like salmon and shellfish that have cultural importance. The social and cultural values of commercial fisheries may be affected if offshore aquaculture affects the harvest of certain species.

If there are spatial overlaps between offshore aquaculture and commercial fishery activities, the closure of one area may cause fishers to move to another nearby area. The likelihood of this redistribution will depend on factors such as the availability of additional resources, including fishing gear. Modeling can help predict how and where fisheries may relocate. If spatial overlaps limit commercial fisheries, there could be significant effects on the communities that depend on them. For example, if 5% of a community's revenue is displaced, it is crucial to understand the broader implications of this loss. This assessment should consider the community’s demographics, the effects on competition, and how changes will alter the overall community landscape. This analysis would provide the basis to understand potential economic, social, and cultural impacts.

Changes to port infrastructure to accommodate offshore aquaculture activities may also be crucial. Substantial development, dredging, and port enhancements may spur fishery growth. However, there are potential drawbacks. For instance, vessels necessary for construction, operation, and decommissioning phases of offshore aquaculture farms will necessitate sufficient infrastructure. If port facilities become inaccessible or prohibitively expensive, space constraints or cost factors may limit fishing activities. These changes may disrupt commercial fisheries and, in turn, impact the communities that depend on them.

Effect of offshore aquaculture on the economic value of commercial fisheries. Offshore aquaculture will have a direct economic effect on commercial fisheries. There is an increased cost associated with spatial conflict which takes three forms. First, fishing activity may be displaced from areas where offshore aquaculture facilities are located, potentially disrupting established paths such as historic trawling trails. Second, fisheries such as the albacore tuna fishery, which pursue fast-swimming species, may encounter challenges when fish enter closed areas during their chase. This can lead to lost catches and increased costs to continue the pursuit. Displacement can occur when these closed areas block the fishery's access to the fish. Third, as the scale of an aquaculture farm expands, competition for port and vessel services may arise, potentially affecting fishing operations.

Fishers may seek to offset these costs by, for example, relocating to areas with better access to fishing grounds. Fishing in waters belonging to other countries is an example of displacement. To consider redistribution efforts and its likelihood, necessary fishing gear must be taken into account. The type of gear and vessel mobility will dictate the ease of fishing in alternative locations. If spatial overlap limits commercial fisheries, there may be effects to the communities that rely on them. For example, if 5% of a community's revenue is displaced, it is crucial to understand the broader implications of this loss. This assessment should consider the community’s demographics, the effects on competition, and how changes will alter the overall community landscape. This analysis would provide the basis to understand potential economic, social, and cultural impacts.

Alternatively, some individuals may opt to cease fishing altogether. There is an ongoing debate regarding the potential shift of fishing activities to land-based fish farms. Offshore aquaculture can supplement natural stocks to meet demand without destroying populations. This factor will determine which species transition to aquaculture. While energy costs remain a primary concern, if other expenses make land-based aquaculture more economically viable, entire fishing industries may disappear. This scenario would render marinas, boats, and related infrastructure obsolete.

Changes to port infrastructure to accommodate offshore aquaculture activities may also be crucial. Substantial development, dredging, and port enhancements may spur fishery growth. However, there are potential drawbacks. For instance, vessels necessary for construction, operation, and decommissioning phases of offshore aquaculture farms will necessitate sufficient infrastructure. If port facilities become inaccessible or prohibitively expensive, space constraints or cost factors may limit fishing activities. These changes may disrupt commercial fisheries and, in turn, impact the communities that depend on them.

Effect of restrictions from offshore aquaculture on fishing grounds and spatial competition. The primary effect of offshore aquaculture would be spatial competition. Spatial conflict takes three forms. First, fishing activity may be displaced from areas where offshore aquaculture facilities are located, potentially disrupting established paths such as historic trawling trails. Second, fisheries such as the albacore tuna fishery, which pursue fast-swimming species, may encounter challenges when fish enter closed areas during their chase. This can lead to lost catches and increased costs to continue the pursuit. Displacement can occur when these closed areas block the fishery's access to the fish. Third, as the scale of an aquaculture farm expands, competition for port and vessel services may arise, potentially affecting fishing operations. The extent to which fishing platforms could be repurposed for the offshore aquaculture industry or if fishing vessels could assist in maintaining offshore aquaculture platforms remains uncertain.

Restricting the space where fisheries can operate may confine them to a smaller area, resulting in increased competition, heightened risks, and fishing under potentially hazardous conditions. Limiting access may also eliminate opportunities for engaging in social and cultural practices associated with fishing. To consider redistribution efforts and its likelihood, necessary fishing gear must be taken into account. The type of gear and vessel mobility will dictate the ease of fishing in alternative locations.

The effects of spatial competition on commercial fisheries may be offset by potential benefits from offshore aquaculture. For example, these structures could serve as fish havens, attracting fish to the area. If fish migrate from these havens, it could open up new fishing opportunities. This shift may influence the concentration of fishing activities in different regions.

Effect of offshore aquaculture on managed commercial fishery species. This is a data gap. Considering the prevalence of both hatchery-raised and wild salmon stocks, for salmon in particular, the widespread existence of hatcheries suggests an overall benefit in terms of salmon availability.

Effect of disease transmission and escapees from offshore aquaculture on commercial fisheries. Offshore aquaculture has the potential to affect the interactions of commercially valuable species, particularly through the transmission of disease. Disease outbreaks can hinder the commercial harvesting of these species by threatening population health, disrupting ecological dynamics, and impacting food chains, including people's ability to consume affected species. As for escapees from aquaculture facilities, they could displace or outcompete native species.

Resources

Table 41. Resources relevant to commercial fisheries.

NAME	ACCESS	TYPE	DESCRIPTION
Global Fishing Watch	https://globalfishingwatch.org/map/index?start=2024-10-24T00%3A00%3A00.000Z&end=2025-01-24T00%3A00%3A00.000Z&longitude=26&latitude=19&zoom=1.49	Database	Displays fishing activity and other vessel data to monitor global fishing patterns.
NOAA: Description of the Input-Output Model for Pacific Coast Fisheries	https://www.webapps.nwfsc.noaa.gov/assets/25/1620_08012011_142237_InputOutputModelTM111WebFinal.pdf	Report	Provides information on the input-output model used to estimate economic changes and impacts from factors affecting fishery harvests.
NOAA: Fisheries Economics of the United States	https://www.fisheries.noaa.gov/national/sustainable-fisheries/fisheries-economics-united-states	Website	Provides information on the reports NOAA prepares to assess the status of US marine fisheries.
NOAA: Social Indicators for Coastal Communities	https://www.fisheries.noaa.gov/national/socioeconomics/social-indicators-coastal-communities	Website	Provides information on social indicator web tools developed by NOAA Fisheries to assess coastal fishing community well-being and resilience to change.
Pacific Fisheries Information Network (PacFIN)	https://pacfin.psmfc.org/	Database	Contains data supplied from fisheries off the coasts of Washington, Oregon, California, Alaska, and British Columbia.

NAME	ACCESS	TYPE	DESCRIPTION
RAM Legacy Stock Assessment Database	https://www.ramlegacy.org/	Database	Compiles stock assessment results for commercially exploited marine species from around the world.
The Washington Coast Economist	https://sites.google.com/uw.edu/wacoasteconomist/dashboards/commercial-fishing	Dashboard	Provides economic research and information. The "Commercial Fishing" dashboard organizes Washington data by landed pounds, historically landed pounds, ex-vessel value, and price per pound.
US Census Bureau: Data	https://www.census.gov/data.html	Database	Offers data on various topics and geographies.
West Coast Fisheries Participation Survey Result Tool	https://www.fisheries.noaa.gov/data-tools/west-coast-fisheries-participation-survey-result-tool-2023	Database	Includes charts and tables that summarize survey responses collected from West Coast fishermen.

Recreational Fisheries

Key Data Gaps

General Data Gaps

- Location and intensity of recreational fisheries
- Recreational fisheries data collection method
- Effect of external factors on the behavior of fishers

Offshore Wind Data Gaps

- Effect of offshore wind on the economic value of recreational fisheries

Offshore Wind and Offshore Aquaculture Data Gaps

- Effect of restrictions to fishing grounds and spatial competition due to offshore wind or offshore aquaculture development

Other Data Gaps

General Data Gaps

- Status and trend of recreational fishing
- Social and cultural value of recreational fisheries
- Economic value of recreational fisheries
- Characteristics of recreational fishing vessels

Offshore Wind Data Gaps

- Effect of offshore wind on the social and cultural values of recreational fisheries
- Effect of offshore wind on managed species and the management of species for recreational fisheries

Offshore Aquaculture Data Gaps

- Efect of offshore aquaculture on the social and cultural values of recreational fisheries
- Effect of offshore aquaculture on the economic value of recreational fisheries
- Effect of offshore aquaculture on managed species of recreational fisheries
- Effect of disease transmission and escapees from offshore aquaculture on recreational fisheries

Background

A fishing license authorizes anglers to participate in all recreational fisheries within the MSP Study Area. Major categories include salmon, groundfish, Pacific halibut, albacore tuna, and razor clams. Anglers may partake in various fisheries during one trip. Some trips extend beyond the MSP Study Area into adjacent regions like the Strait of Juan de Fuca or Columbia River Estuary. Regulations are detailed in the Sport Fishing Regulation Pamphlet[146] by the Washington Department of Fish and Wildlife (WDFW).

WDFW's Ocean Sampling Program (OSP) collects data on recreational fisheries in the MSP Study Area, estimating the total fishing effort and catch every month by counting active vessels and randomly sampling catch. The estimates are available on the Pacific States Marine Fisheries Commission's (PSMFC) Pacific Coast Recreational Fisheries Information Network[147] (RecFIN) database[148]. OSP primarily focuses on boat-based fishing, but also collects data from anglers fishing at certain jetties. Boat-based recreational fishing has two components: a charter or "for-hire" fleet which caters to paying customers, and a "private boat" fleet where anglers fish aboard vessels they either rent or own. Approximately 32% of anglers use charter boats and 66% fish from private vessels, varying by species and port.

The Washington charter boat industry has been a significant part of coastal communities for decades. A survey found that all charter boat crew, owners, and guides in the Washington coast area were residents. Charter trips out of Westport had clients that were largely Washington residents (85%-95%), while those from Ilwaco were generally a mix between Washinton and Oregon residents (45% Oregon residents, 50% Washington residents, and 5% from other areas). Over half of charter trips targeted salmon, followed by bottomfish. From 2004-2008 to 2009-2013, charter trips decreased annually by 8% and the number of trips targeting Pacific halibut, salmon, and bottomfish declined while trips for albacore tuna increased.

Private vessel anglers predominantly launch from Neah Bay (30%), Ilwaco (27%), and Westport (20%). Smaller ports like La Push and Chinook also accommodate private boats and boat launches. There is no data available that specifies the residence of private boat anglers. Private boat trips increased by 11% from 2004-2008 to 2009-2013, with notable increases observed in salmon, albacore, and bottomfish trips. Over 74% of trips targeted salmon. Shore and jetty anglers favor the Columbia River Jetty near Ilwaco, recording 3,467 trips in 2013, well above the 2004-2013 average of 1,783 trips. About 87% of the catch consisted of salmon, with rockfish comprising the rest.

Recreational fishing trip expenditures provide a direct economic input to coastal and state economies. Expenses include fuel, gear, lodging, and charter fees. Anglers are barred from selling their catch. Visitors provide new money into coastal areas, while locals support their home economies. The charter boat sector, with owners and crew residing in coastal counties, contributes significantly to the local economy. Spending location influences where these

[146] https://wdfw.wa.gov/fishing/regulations
[147] https://www.recfin.org/
[148] https://reports.psmfc.org/recfin/f?p=601:1000::::::

benefits are felt. In 2014, recreational anglers spent approximately $30.4 million in trip related expenditures in the coastal area and $40.9 million statewide, translated to supporting 325 coastal jobs and 596 jobs statewide. These estimates exclude purchases of equipment like boats, trailers, and vehicles.

The MSP describes several recreational fisheries which are summarized below:

Salmon: The recreational salmon fishery occurs in Willapa Bay, the Chehalis Basin, and the Pacific Ocean. Ocean salmon are the primary target, with catch varying yearly. The species of salmon caught differ by area, with Chinook dominant in Westport and pink salmon in Neah Bay. Grays Harbor sees significant coastal estuary recreational salmon fishery catches. In the 2011/12 season, half of all salmon caught in the Study Area occurred off Westport, 25% near Ilwaco, and 12% near Cape Flattery. Managed by WDFW and the Tribes, regulations include daily limits, release rules, and season dates and are tailored to Marine Catch Areas.

Bottomfish: The recreational bottomfish fishery is the largest recreational finfish fishery by average annual catch and the second most popular in terms of fishing trips for charter boat and private boat fishing. Primary targets are black rockfish and lingcod. The season is open year-round, but with weather constraints, typically runs from March to October. Westport, Neah Bay, and La Push are the primary ports. Westport records the most catches, mostly black rockfish, while Neah Bay sees more rockfish diversity. The fishery has remained stable over time.

Pacific halibut: The recreational Pacific halibut fishery, open from May to September, is quota-limited, lasting only a few days annually at the most popular areas on the coast. The fishery has been stable since 2003, with about 7,613 fish caught yearly from 2007/08 to 2011/12. Neah Bay and La Push recorded the majority of recreational halibut harvest over the past decade. Because it occurs far offshore, the fishery favors larger vessels and private vessels. Charter vessels are outnumbered. WDFW subdivides management into the North coast, South coast, and Columbia River areas, and adjusts quotas and seasons accordingly.

Albacore tuna: This fishery is popular in summer and early fall when the fish migrate to the Washington coast, typically found 20 to 100 nautical miles offshore. They are caught using trolled jigs and live bait. Both charter boats and private vessels target them. Westport and Ilwaco serve as the primary ports for this fishery. From 2004-2013, there was an average of 4,328 trips. There was a notable increase in private vessel activity in 2013, reaching 7,056 trips.

Razor clams: The coastal razor clam fishery is a popular recreational activity in Washington, deeply rooted in local culture. Razor clamming spans the southern Washington coast, from Quinault Indian Reservation to the Columbia River mouth, including Kalaloch. Long Beach and Twin Harbors account for 70% of harvests.

Coastal Tribes have co-managed shellfish since 1993. Clamming seasons and daily bag limits have been adapted based on population assessments. The state recreational daily bag limit is 15 clams per person and the state season starts in October, with monthly openings based on clam abundance, and ends in May. Tribal fishery openings are coordinated with state recreational seasons. Occasionally, long-term closures result from population declines or health concerns, particularly from harmful algae blooms causing an increase in biotoxin.

Dungeness crab: The Dungeness crab recreational fishery is popular in Puget Sound, but mainly occurs within the Study Area. Coastal activity is greatest at Willapa Bay, Grays Harbor, and the Columbia River. More anglers are hiring charter boats to participate in the fishery before the commercial fishery opens. The fishery is managed by WDFW; however, WDFW does not have data on landings or the number of harvest trips because recreational harvests are not required to be reported.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to recreational fisheries:

General data gaps

- Location and intensity of recreational fisheries
- Recreational fisheries data collection method
- Effect of external factors on the behavior of fishers

Location and intensity of recreational fisheries. WDFW oversees fishing licenses and maintains numerical records, but it lacks a system for tracking spatial data. Available location information primarily indicates where trips start and end, without specifying in-water locations. This data is collected for both the charter boat sector and private anglers. Trips are sampled as they occur, and the collected data are then expanded to represent the total number of trips.

The marine environment is divided into 13 marine areas[149] by WDFW, each with its own fishing regulations. During angler interviews, a marine area is assigned to each trip based on the reported fishing location. As a result, marine areas can be identified for catch efforts; however, the data do not distinguish between offshore or inshore locations or provide additional details about fishing spots.

Various catch record cards are used to track species such as salmon, steelhead, sturgeon, halibut, and Puget Sound Dungeness crab. For albacore fishing, commercial vessel passenger fishing logbooks are required, though compliance rates are uncertain. These logbooks provide valuable data, including latitude, longitude, and general fishing area. However, there have been historical concerns about missing information from albacore trips, likely due to samplers being absent when boats depart or return.

Data from charter and private recreational fishing vessels (CPFVs) is limited, while more comprehensive information is available on private angler efforts. However, boat anglers are only required to report their catch for species covered by catch record cards. Additionally, catch data for shore anglers in marine areas remains unclear.

The broad spatial scale of the data is the primary challenge, a concern widely acknowledged within the community. It is challenging to get anglers to identify their fishing locations unless

[149] https://wdfw.wa.gov/fishing/locations/marine-areas

they use a phone app that tracks their trips. Even when they have the information, they may be reluctant to share it for fear of revealing prized fishing spots.

The intensity of fishing efforts is generally well captured, but there are minor gaps. Data on the quantity of trips and port landing are available for both charter boats and private anglers. Intensity data is captured via a state-led sampling program that is partially funded by RecFIN. Because federal funds are used for the sampling program, there is a greater focus on sampling efforts from boats than from shore. While some information is collected from shore trips, it may not be of the same quality or quantity as data collected from boat trips.

The National Oceanic and Atmospheric Administration (NOAA) holds information on recreational fishing in federal waters. State-collected data is consolidated into a single clearinghouse, facilitating access for agencies like the National Marine Fisheries Service (NMFS). RecFIN serves as a significant data source, managing a considerable portion of the data. WDFW's Ocean Sampling Program and RecFIN house the bulk of data used by NMFS, providing insights into catch quantities and port-specific fishing trends.

States maintain a closer relationship than the federal government in recreational fishing management. It would be beneficial if states enhanced their capacity to collect data that better represents location and intensity of recreational fishing efforts and catches.

Feedback on importance: Despite its economic importance, this information remains insufficient. Accurate data on the location and intensity of fishing activities, including detailed spatial information, are essential for assessing the potential effects of changes in fisheries and for developing effective management plans, particularly for spatial planning.

Fisheries data collection method. Data are collected from various sources, including charter boats and businesses, which are required to share information. In some areas, logbook submissions are mandated, detailing data such as fishing locations and the number of fishermen. Catch record cards for species like salmon, lingcod, and halibut also require annual reporting. Additionally, fishing for highly migratory species, which necessitate a federal permit, may require participants to provide specific information. Efforts are also underway to collect data on communities' dependence on recreational fishing. One method to measure this dependence is examining businesses tied to recreational fishing. A forthcoming publication from NOAA will detail the findings, highlighting the extent of a community's dependence on fishing.

There is an ongoing effort to enhance data collection on recreational fisheries. For instance, often constrained by funding limitations, there's interest in increasing the number of samplers during side months. There is also a lack of spatial data, as anglers may not always be aware of their fishing locations, and regulations do not require them to know precise details. However, location data has become more accessible due to the widespread use of phones and apps. There are also limitations regarding depth data. Understanding the depth at which fish are caught is crucial for assessing their survival upon release. However, only one depth measurement is recorded per fishing trip, and participation in the survey is voluntary. Anglers may target species at different depths during a single trip—for example, recording the depth for salmon, but catching rockfish at a different depth. There have been discussions about using descending devices. Collecting more detailed data on these practices could be beneficial. If using descending devices proves effective in reducing fish mortality at certain depths, it could support longer fishing seasons. However, past efforts to improve data collection have encountered resistance, making it challenging to implement changes.

There is also limited information regarding participants of recreational fisheries, namely anglers who purchase licenses directly from charter operators. Typically, when purchasing a license, all personal information is entered into a WDFW database. However, a person can purchase a Washington license to fish on a charter boat for a day and bypass this process. The data from these same-day sales aren't entered into the database.

Feedback on importance: There is potential for improvements in this field, especially if a clear purpose for the desired data is established. However, developing data collection methods, while important, is not essential for spatial planning.

Effect of external factors on behavior of fishers. Existing data on this topic is limited, often scattered or outdated, with no consistent efforts in data collection. Studies tend to focus on short-term forecasts rather than long-term trends.

Addressing this data gap requires understanding fishers' preferences. When displaced, fishers typically have three options: continue fishing, stop fishing, or fish elsewhere. They are most likely to choose an alternative location, but there is often a fear of the unknown. By fishing somewhere new, they might discover a better spot or worsen their situation. Additionally, the effect of offshore activities on fishing trips and how these activities might influence fisher behavior remains a significant uncertainty.

The primary concern is the potential long-term decline of the fishing industry. Offering comparable alternatives is challenging, as replicating similar conditions can be difficult and costly. To better assess the vulnerability of fishers and their decisions to stay in or leave the industry, there is a need to understand the factors that drive them away. This is a complex issue that requires further investigation.

Understanding the effect of external factors on fishers' behavior is a research question that must be considered in regulatory and policy analyses on a case-by-case basis. It is essential to assess potential effects and unintended consequences. However, while reports on specific cases could provide some insight, there is no universal answer or indicator that will provide information in a comparable way to understand the effect of external factors on the behavior of fishers.

Feedback on importance: There is an interest in understanding how fishing effort might shift to different locations. While this is important, designing studies to address this data gap is challenging.

Offshore wind data gaps

- Effect of offshore wind development on the economic value of recreational fisheries

Effect of offshore wind development on the economic value of recreational fisheries. It is uncertain whether there are studies relevant to predicting general economic effects. Considering the offshore nature of offshore wind activities, the behavior of highly migratory fisheries are more likely to be affected than others. Spatial data is essential to initiate the assessment of potential effects.

Offshore wind may act as a fish aggregating device (FAD) or cause fisheries to seek out other fishing grounds. How fishing trips may be altered and the effect of this change on people's behavior are unknown. Offshore wind will directly affect people who incur costs. If one area closes, fishers may move to another nearby. There will also be costs linked to these efforts, such as spending more time on the water and burning more fuel. To consider redistribution efforts and their likelihood, necessary fishing gear must also be taken into account. Additionally, there may be a need to better time fishing operations with favorable weather conditions to optimize opportunities. If fishing activities are diminished, communities will suffer from the loss of associated benefits. For instance, the expenditures typically associated with fishing would be redirected elsewhere, affecting where fishing gear is purchased, where time is spent, accommodations, dining, and fuel purchases. These analyses provide the basis to understand potential economic, social, and cultural impacts.

Changes to port infrastructure to accommodate offshore wind activities may also be crucial. Substantial development, dredging, and port enhancements may spur fishery growth. However, there are potential drawbacks. For instance, vessels necessary for construction, operation, and decommissioning phases of offshore wind farms will necessitate sufficient infrastructure. If port facilities become inaccessible or prohibitively expensive, space constraints or cost factors may limit fishing activities.

Feedback on importance: This is an area with the most significant data gap and considerable uncertainty, such the potential effect on fisheries, fishing and landing locations, and subsequent effects on the community. This is an area that remains the least understood yet profoundly influences economics. Offshore wind involves the introduction of new structures that differ from those on the East Coast, where even small-scale wind farms could have a substantial impact. These installations may create safe havens that could alter fisheries, and they may also affect landing locations. Typically, fishers land where their boat is kept, often near the fishing site, though landing decisions may also hinge on the buyer. Factors such as a buyer's location and the market they serve introduce trade-offs, such as costs (e.g., fuel) versus profits. Understanding the origin of buyers and their target market is imperative for assessing these dynamics.

Offshore wind and offshore aquaculture data gaps

- Effect of restrictions to fishing grounds and spatial competition due to offshore wind or offshore aquaculture development

Effect of restrictions to fishing grounds and spatial competition due to offshore wind or offshore aquaculture development. For both offshore wind and offshore aquaculture, there is a need to understand where people are people fishing, the installation location and the scale of these offshore facilities, and the fishing restrictions that will be put in place.

There is insufficient data to assess which fishing trips will be affected by offshore developments and how those fishing trips will change. Spatial data is crucial for this assessment, including knowledge of current fishing locations and predictions about fishers' relocation due to placement of potential offshore facilities. Notably, recreational fisheries are predominantly nearshore in state waters, within depths shallower than 200 meters. Given the offshore nature of any proposed offshore activities, recreational tuna fishing would be more likely to be affected than other recreational fisheries.

If offshore structures limit fishing space, fishers may face heightened competition and safety risks within the confined areas. Conversely, if structures create new fish habitats, opportunities for fishing may arise as fish migrate and alter the concentration of fishing activities. Responses to fishing restrictions may vary, with some fishers switching to alternative fisheries or ceasing fishing altogether. The frequency of fishing trips may also change, or fishing efforts may shift to focus on a smaller number of species or stocks, potentially impacting species populations. Fishers may also have to spend more time on the water and consume more fuel or synchronize fishing operations with specific weather conditions. These factors could lead to fewer fishing opportunities. Assessing redistribution efforts and their likelihood will require considering fishing gear. Notably, recreational fisheries often offer more substitution options than commercial fisheries, including access to different fishing grounds or species.

Changes to port infrastructure to accommodate offshore activities may also be crucial. Substantial development, dredging, and port enhancements may spur fishery growth. However, there are potential drawbacks. For instance, vessels necessary for construction, operation, and decommissioning phases of these offshore activities will necessitate sufficient infrastructure. If port facilities become inaccessible or prohibitively expensive, space constraints or cost factors may limit fishing activities.

Any loss of fishing grounds is also likely to have cultural and social ramifications. If fishing activities are diminished, communities will suffer from the loss of associated benefits. For instance, the expenditures typically associated with fishing would be redirected elsewhere, affecting where fishing gear is purchased, where time is spent, accommodations, dining, and fuel purchases.

Feedback on importance: The data for this data gap are critical for marine spatial planning. Filling this data gap could also drive discussions on the effect of these offshore activities on fishers’ behavior, economic value, ports, and fisheries surveys, and help address most other data gaps related to these activities.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Status and trend of recreational fishing
- Social and cultural value of recreational fisheries
- Economic value of recreational fisheries
- Characteristics of recreational fishing vessels

Status and trend of recreational fishing. The terms "status" and "trend" primarily refer to the quantity of pounds landed. While fishery performance is closely monitored, predicting it remains challenging. Catch per angler/boat is consistently tracked over time, with some exceptions. A comprehensive, long-term dataset of effort and catch composition is available. Efforts are also underway to estimate trends through port sampling, though these estimates are currently at a basic aggregated level. WDFW's Ocean Sampling Program aims to cover all fisheries, using samplers to collect catch effort data. Historical catch data dates back to the 1960s when the National Marine Fisheries Service (NMFS) oversaw the program, which was later transferred to WDFW in the early 2000s. These data are accessible through RecFin. The program operates in waves, with no sampling conducted during the winter months due to budget constraints and low fishing activity. However, effort data is monitored throughout the rest of the year.

Additional data and information are accessible through other resources. For instance, there is the California Current Integrated Ecosystem Status Report which provides insights into the joint social and ecological system within the California Current Ecosystem, encompassing information on fishing activities. Data is also available on the Washington Coast Economist, an online dashboard. Presently, this dashboard offers information on recreational boat fleets[150] and sales[151].

Social and cultural value of recreational fisheries. These are significant data gaps. Assessing these values is challenging for several reasons. For instance, identifying participants in recreational fishing is more difficult than in commercial fisheries, the value of fish species can vary by location, and the motivations behind recreational fishing remain unclear. People engage in recreational fishing for various reasons, including spending time with family and friends or procuring food.

There are some sources to inform this data gap. The NWFSC's recreational angler surveys employ an input/output model to assess livelihood factors, such as income levels and jobs supported by recreational fishing. It also serves as a secondary application, linking data on fishing trips and revenues with other industries and local economies to estimate additional income levels and jobs generated by recreational fishing. These surveys typically include

[150] https://sites.google.com/uw.edu/wacoasteconomist/dashboards/recreational-boat-fleet
[151] https://sites.google.com/uw.edu/wacoasteconomist/dashboards/recreational-boat-sales

inquiries about motivations for fishing, such as obtaining food or enjoying nature and help assess the relative importance of these factors. For example, fishing to provide food for families can infer value to livelihood. Charter boat operators are reached through separate surveys. Charter boat surveys include questions about the proportion of household income derived from recreational trips. Both the economic valuation effort and charter boat surveys occur appropriately every 5 years. States also hold license data, but gathering detailed information is difficult due to resource constraints.

When considering cultural value, it is essential to recognize the networks that create and sustain a community. These communities typically emerge around specific economic pursuits which attract related industries and people, shaping the community's identity. For instance, the commercial fishing industry not only provides employment but also influences how individuals perceive their roles and value within the community. Additionally, gatherings and festivals that celebrate fishing further strengthen the sense of cultural belonging and connection. The concept of *sense of place* plays a crucial role in the growth of both communities and economies.

Changes within the industry or environment can have profound effects on these communities, driving a desire for greater resilience. Achieving this resilience often requires diversifying economic activities, which can enhance long-term sustainability. However, such diversification may also erode elements of the community's cultural identity. This presents a dilemma between maintaining a community's identity and building resilience. However, shifts in identity may also have the potential to create new opportunities.

For social value, there are some indicators available, but none that approach valuation. NOAA's [Social Indicators for Coastal Communities](https://www.fisheries.noaa.gov/national/socioeconomics/social-indicators-coastal-communities)[152] aggregates data to generate various indicators at the community level. These include measures like vulnerability and dependence on fisheries, which are utilized in regulatory processes to characterize communities and assess potential impacts. Some indicators are derived from the community census sample, which is updated every 5 to 6 years. Consequently, relevant data in the social indicators are also updated at that frequency. Depending on the data source, others can be updated annually. There are also academic publications which may serve as an additional resource. Ongoing efforts are being made to address frequently asked questions.

Economic value of recreational fisheries. Recreational fishing catches cannot be sold. They may be gifted, but cannot be traded, bartered, or exchanged for money.

There are two types of economic value. The first pertains to economic contributions and impacts. States and NMFS jointly developed an economic value modeling framework called Input Output Pacific (I-OPAC). This framework utilizes fisheries data to parameterize input and output and measure a fishery's economic value. Metrics include jobs created in local communities supported by fisheries, as well as income levels and revenues generated by charter boats. It is important to note that this value is gross, as it does not account for costs. The I-OPAC model can be customized for specific geographic areas, fisheries, and factors,

[152] https://www.fisheries.noaa.gov/national/socioeconomics/social-indicators-coastal-communities

drawing upon various data sources depending on the inquiry. Additionally, the model is useful for assessing economic impacts in regulatory analyses that require the evaluation of different alternatives. The second type involves the net measure of economic value and includes data such as consumer surplus for anglers or profits for charter businesses. Consumer surplus reflects the difference between what anglers would have paid and what they actually paid for a fishing trip. This measure is used to calculate economic losses, such as damage assessments. On the charter owner side, profits serve as an equivalent measure.

To assess the economic value, one can also consider the money individuals spend or are willing to spend. There is a data gap on expenditures and existing estimates may lack specificity regarding trip type or fishery. Fishing for different species can involve varying trip costs. Private renters incur expenses such as ice, gas, accommodation, fishing equipment, and insurance, while charter vessel users pay for guides, tips, and cleaning fees. In addition, businesses like gear shops, hotels, and tourist establishments contribute to the overall economic impact. While annual reports provide information on fishing participation and estimated trip expenditures, the available data on economic value remains general. More targeted data collection efforts, such as mail surveys sent to anglers as part of the Fisheries Economic United States (US) Report, could offer more detailed insights.

The economic value of closing an area also is unknown. While there may be data on the current number of trips in a specific area, quantifying how many would transition to a substitute area is challenging. The missing component lies in understanding whether individuals would fish elsewhere or engage in alternative activities. To address this gap, methods like choice experiments can survey where individuals are fishing and what substitute sites they would opt for. Charter captains could provide valuable insights into potential fishing locations if an area were to be closed. Frequent private anglers may also be able to offer similar information.

Characteristics of recreational fishing vessels. Data is needed on recreational fishing vessels, including their size, destinations, and passenger capacity.

Offshore wind data gaps

- Effect of offshore wind on the social and cultural values of recreational fisheries
- Effect of offshore wind on managed species and the management of species for recreational fisheries

Effect offshore wind on the social and cultural values of recreational fisheries. The effect of offshore wind on these values will be difficult to predict. This assessment will require considering several factors, including whether offshore wind structures will attract fish or reduce their presence, how fishing trips may change as a result, and how these changes may influence people's behavior.

Spatial data is essential to begin evaluating the potential effects. If a wind farm is to be sited in an area that disrupts fishing, examining its potential effects requires understanding the location and intensity of existing fishing activities. The loss of fishing grounds can have significant cultural and social impacts. Liming access removes the opportunity to participate and prevent catch of species with social and cultural significance. For example, the offshore nature of offshore wind projects may impact recreational tuna fishing. This could affect the ability to harvest albacore tuna, which is often canned and used year-round. However, in contrast to commercial fisheries, recreational fisheries often have more options for substitution, with access to other fishing grounds or species. Hence, if one area closes, fishers may move to another nearby. But to consider redistribution effort and its likelihood, necessary fishing gear must also be taken into account.

Changes to port infrastructure to accommodate offshore wind may also be crucial. While significant development, dredging, and port enhancements could stimulate fishery growth, if offshore wind causes port facilities to become inaccessible or prohibitively expensive, it could also hinder existing recreational fishing activities.

Effect of offshore wind on managed species and the management of species for recreational fisheries. Generally, less information is available on recreational fisheries compared to commercial fisheries because they are not as closely monitored.

Offshore wind may affect species management by inhibiting fisheries surveys. A significant unknown is how to adjust these surveys if offshore wind excludes them from certain areas. These surveys provide standardized data that are crucial for stock assessment models, which estimate species abundance and inform allowable catch limits. Reduced data quality due to restricted access may increase uncertainty in abundance estimates, potentially affecting total allowable catches (TACs) set by the National Marine Fisheries Service (NMFS). There is work to study the relationship between exclusions from historical survey locations, the stock assessment, and setting TACs. While TACs are commonly divided into recreational and commercial quotas, this approach doesn't apply to all fisheries.

Another uncertainty is how managed species will respond to offshore wind facilities. Offshore wind structures could function a FADs, cause species to avoid the area, or affect their migration patterns. If offshore wind affects the mortality rates of recreationally important species, it could, in turn, influence recreational fishing.

Offshore aquaculture data gaps

- Effect of offshore aquaculture on the social and cultural values of recreational fisheries
- Effect of offshore aquaculture on the economic value of recreational fisheries
- Effect of offshore aquaculture on managed species of recreational fisheries
- Effect of disease transmission and escapees from offshore aquaculture on recreational fisheries

Effect of offshore aquaculture on the social and cultural values of recreational fisheries. Aquaculture efforts in nearshore areas are more likely to affect recreational fishing than those offshore. Many of these farms are anchored to sandy or muddy bottoms, which could have implications for Pacific halibut fishing. To assess the effects of offshore aquaculture on recreational fisheries, it is crucial to understand current fishing locations, potential areas where fishers may relocate due to aquaculture facilities, and how to quantify any substitution effects. Spatial data is essential to initiate this assessment. Unfortunately, even if the locations of offshore aquaculture facilities were known, they could not be overlaid with current recreational fishing data due to the lack of spatial information.

Offshore aquaculture may also affect recreational fisheries through its impact on port infrastructure. While significant development, dredging, and port enhancements could stimulate fishery growth, they could also hinder existing recreational fishing activities if port facilities become inaccessible or prohibitively expensive.

The effect of offshore aquaculture will also depend on what is farmed. Different species hold different values for different communities. Additionally, finfish aquaculture often faces resistance due to concerns about escapees and issues related to fish feed, particularly when wild-harvested fish feed is used.

Depending on how offshore aquaculture affects an individual's ability to recreationally fish and catch certain species, it may influence the social and cultural values associated with recreational fishing.

Effect of offshore aquaculture on the economic value of recreational fisheries. It is uncertain if there are studies relevant to predicting the economic effect of offshore aquaculture. The primary focus will likely be on how offshore aquaculture may restrict recreational opportunities. For example, fishers may need to spend more time on the water and use more fuel to reach fishing spots. The type of fishing gear and the mobility of fishers will influence how easily they can relocate to other fishing areas. Understanding how this redistribution of fishing effort will occur is essential for economic analysis. Additionally, shifts in fishery participation or fish distribution, could affect when and where people fish. For instance, there may be a need to adjust fishing operations to better align with favorable weather conditions. These factors may reduce overall fishing opportunities or lead fishers to seek alternative fishing grounds.

To assess the potential economic effects of offshore aquaculture, spatial data is essential, particularly to evaluate spatial competition. Understanding current fishing locations, potential areas where fishers may relocate due to offshore aquaculture, and quantifying potential substitution effects will be crucial. However, even if the locations of offshore aquaculture facilities were known, they could not currently be overlaid with recreational fishing data due to the lack of spatial information.

Effects of offshore aquaculture on managed species of recreational fisheries. This is a data gap. The effect on managed species depends on how offshore aquaculture affects species, such as changes in mortality rates. If those species are recreationally important, recreational fishing would be affected. Spatial conflict may also have an effect. If fishing is required to move to alternative areas due to restrictions, this can potentially result in a localized or a more targeted depletion. Offshore aquaculture facility could shift fishing efforts.

Effect of disease transmission and escapees from offshore aquaculture on recreational fisheries. Escapees and disease outbreaks have the potential to alter species interactions. Escapees may displace native species or outcompete them. Disease outbreaks pose risks to species health, population dynamics, the food chain, and their suitability for consumption.

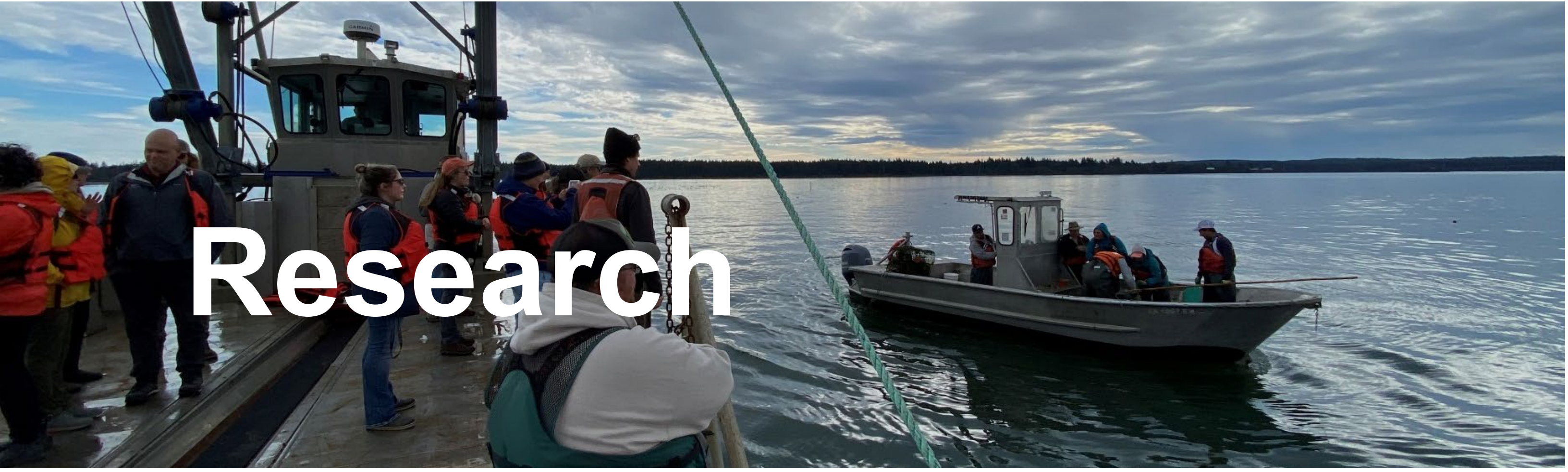
Consequently, affected species may need to be removed from both recreational and commercial fisheries. Recreational fishers are concerned about disease transmission to wild stocks and escapees. Quantifying these impacts could provide insights into the effects of offshore aquaculture on recreational fishing.

Resources

Table 42. Resources relevant to recreational fishing.

NAME	ACCESS	TYPE	DESCRIPTION
Community Social Vulnerability Indicators Tool	https://www.st.nmfs.noaa.gov/data-and-tools/social-indicators/	Database	Contains a set of 14 statistically robust indicators related to social, economic, and climate change factors. These indicators provide a distinctive assessment of a community's vulnerability and resilience to various disturbances.
Conceptualizing and operationalizing human wellbeing for ecosystem assessment and management	https://swinomish-nsn.gov/media/56269/breslow_et_al_2016__conceptualizing_and_operationalizing_hwb.pdf	Published article	Offers a framework for human well-being intended to guide the development of indicators and a complementary research agenda in social sciences for ecosystem-based management.
NOAA: Social Indicators for Coastal Communities	https://www.fisheries.noaa.gov/national/socioeconomics/social-indicators-coastal-communities	Website	Provides information on social indicator web tools developed by NOAA Fisheries to assess coastal fishing community well-being and resilience to change.

NAME	ACCESS	TYPE	DESCRIPTION
Recreational Fisheries Information Network	https://www.recfin.org/	Database	Integrates state and federal marine recreational fishery sampling efforts into a unified database to gather critical biological, social, and economic data.
Washington Coast Economist	https://sites.google.com/uw.edu/wacoasteconomist/	Database	Provides information on population, employment, income, housing trends, economic performance, recreational boats, commercial fishing, and shellfish aquaculture.
Washington Department of Fish & Wildlife (WDFW): Marine Areas	https://wdfw.wa.gov/fishing/locations/marine-areas	Website	Provides information on shoreline and water access points along Washington's coast for fishing.
WDFW: Puget Sound Creel Reports	https://wdfw.wa.gov/fishing/reports/creel/puget	Reports	Provides reports summarizing the results from angler interviews which were conducted on a random sampling schedule.
WDFW: Southwest Washington fishing reports	https://wdfw.wa.gov/fishing/reports/creel/southwest#2024	Reports	Contains fishing reports and other information for southwest Washington, including the Columbia River and its tributaries, are available.
Willapa Bay Recreational Salmon Reports	https://wdfw.wa.gov/fishing/reports/creel/willapa-bay	Website	Provides data from 2018 onwards on recreational salmon fishery monitoring at Willapa Bay Marine Area.



Research

Key Data Gaps

General Data Gaps

- Geographic extent of current research activities
- Status of current research activities
- Effective allocation of resources for research
- Inventory of ongoing research activities

Offshore Wind Data Gaps

- Potential risk of offshore wind displacing research activities

Offshore Aquaculture Data Gaps

- Potential risk of offshore aquaculture displacing research activities

Other Data Gaps

No other data gaps identified.

Background

Numerous institutions, including academic, governmental, and tribal entities, conduct multidisciplinary research in Washington's marine waters. Research covers diverse topics such as fisheries, ocean health, and habitat conservation, facilitated by collaborative initiatives like the Northwest Association of Networked Ocean Observing Systems (NANOOS), the Ocean Observatories Initiative, and the Oregon Health Sciences University's Center for Coastal Margin Observation & Prediction. Research partners include the University of Washington, Oregon State University, Washington state agencies, NOAA, United States Fish and Wildlife Service, Olympic National Park, and tribal governments.

One focus of research in the MSP Study Area is the collection of baseline data to understand oceanographic conditions, marine habitats and populations, and hazards. Data is gathered on various parameters, including temperature, salinity, carbon dioxide levels, tides, water currents, oxygen levels, and plankton blooms. Population assessments of fishery resources, seabirds, and marine mammals for conservation purposes are also routinely conducted. Other research includes studies on the intertidal, pelagic, and deep-sea habitats, the Cascadia Subduction Zone, benthic substrate sampling, seafloor habitat mapping, and coastal geomorphology.

Research equipment includes moorings, hydrophones, vessels equipped with sampling and trawling gear, shore-based instruments, and gliders. Research vessels operated by state universities are based in Seattle and Newport, Oregon, while NOAA's research ships serve the entire West Coast. The Olympic Coast National Marine Sanctuary's research vessel, the R/V Tatoosh, operates seasonally from La Push, from April to October. State agencies use smaller research vessels, and private vessels can also be contracted for specific research needs. Research may follow transect routes or target particular locations, with fixed platforms deployed either seasonally or year-round. Long-term monitoring assets are also in place.

While there is limited infrastructure, including oceanographic buoys, moorings, and shoreside stations with sensors, they provide critical data on oceanographic parameters. Notable oceanographic buoys include NANOOS' Chá bă buoy and its accompanying NEMO sub-surface profiler off La Push, as well as the NOAA National Data Buoy Center's buoys at Cape Elizabeth and Neah Bay. The Olympic Coast National Marine Sanctuary also operates a nearshore seasonal mooring array. Additionally, the Navy funds long-term passive acoustic monitoring with bottom-deployed devices.

Research and monitoring are anticipated to persist, focusing on key processes like fisheries populations and practices, ocean circulation, climate change, water temperature, ocean acidification, hypoxia, and harmful algal blooms.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to research activities:

General data gaps

- Geographic extent of current research activities
- Status of current research activities
- Effective allocation of resources for research
- Inventory of ongoing research activities

Geographic extent of current research activities. Research tends to prioritize geographically accessible areas, with ease of access and hazard risks influencing study locations. Estuarine regions receive more attention than outer coastal areas, with Willapa Bay being a focal point over Grays Harbor. Considerable research is also conducted around the mouth of the Columbia River, particularly on physical environmental factors such as sediment transport and flooding. Across the coast, the Olympic Peninsula has the lowest level of research activity. Research efforts also vary by depth, with limited knowledge available on the pelagic life stage of organisms considered significant or critical. These studies employ diverse methods, including moored assets, gliders, sail drones, aerial drones, towing equipment, cabled arrays with seismometers on the seafloor, axial sea mounts, and tectonic activity monitors.

Identifying areas of interest in the ocean and observing ongoing activities is generally straightforward. To understand where research is occurring, it may be valuable to gather information on current studies and relevant contacts. Research efforts are extensive and consistent, with activities conducted regularly according to the schedules of various agencies or entities. For example, within NOAA, different services carry out surveys for hake, salmon, marine mammals, and seabirds, each operating on distinct timelines. Other organizations, such as the University of Washington, United States (US) Geological Survey, BOEM, University of Oregon, and NSF, also contribute to research efforts. Additionally, Canadian research efforts may be relevant to understanding the extent of current research activities in this region.

Feedback on importance: Given the geographic focus of current research activities in the ocean, there is a need to assess whether resources are being inequitably allocated, potentially prioritizing areas that are more accessible or convenient for researchers over regions that may have more pressing research needs.

Status of current research activities. The research field is highly competitive, and while collaboration is encouraged, a sense of competition often persists among researchers. Individuals are frequently hesitant to share the progress of their work because their success depends on being the first to achieve results, and they are focused on preparing for the next phase of their projects. This reluctance to share impedes the community's ability to stay informed about ongoing research. Furthermore, information is often withheld until projects are completed or reports are published, leading to a lack of awareness about current efforts, even among collaborating partners.

For Puget Sound, various projects are tracked through the Puget Sound Partnership and the Recreation and Conservation Office. However, for the outer coast, coordination of research efforts is limited. Organizations such as the National Fish and Wildlife Service, those in the Olympic Peninsula, and several groups in Grays Harbor and Willapa may hold some information, but there is no central coordination. Additionally, conservation districts, The Nature Conservancy, and Audubon have their own research networks, but these are limited to the specific projects and interests of their organizations.

Incorporating a status component into research assessments could be beneficial, categorizing projects as completed, ongoing, or planned. Some initiatives, such as long-term monitoring efforts, are intended to continue indefinitely, making it essential to track their progress over time.

Feedback on importance: This involves a fundamental, systemic issue. While this information is important, addressing this gap would require a complete change of ideology.

Effective allocation of resources for research. Research efforts can exhibit biases in terms of, geographic focus, target species, seasonal timing, and duration due to various constraints such as limited time, personnel, and resources. For example, data coverage is often uneven across regions and species, with priority given to more accessible areas and commercially important species. Additionally, research typically offers temporary snapshots rather than capturing long-term trends, and data are particularly sparse during the winter season due to the difficulties in maintaining equipment amidst storms. These issues raise the question of whether research resources are allocated effectively to ensure comprehensive coverage and minimize duplicated efforts. Funding plays a significant role in shaping the research conducted on the outer coast, as it often directs the focus toward specific interests. This funding-driven approach can lead to a lack of coordination and collaboration with other interested and affected parties, potentially causing the concerns and perspectives of various parties to be overlooked.

Enhancing data collection efforts is crucial in areas where the existing datasets fall short of meeting analytical needs. For example, it is important to assess whether current monitoring efforts are conducted at strategic locations that are essential for validating and improving the accuracy of existing models. Significant gaps also exist in social science research, particularly concerning socioeconomic, socioecological data, and indigenous knowledge. For instance, socioeconomic data is often collected infrequently, which impedes effective trend monitoring and can have detrimental impacts on communities. Allocating resources to enhance research efforts to address disparities in data coverage is essential to ensure that research is comprehensive and effective.

Feedback on importance: There is a strong interest in ensuring that funding is directed toward initiatives that align with top priorities. For instance, monitoring efforts are currently limited to specific locations and timeframes, with a significant gap in winter data. Effective resource allocation is essential to address these research needs.

Inventory of ongoing research activities. There is often a lack of awareness about projects until reports are published. Creating an inventory could help evaluate the full scope of potential activities and their effects.

Feedback on importance: Making an inventory of research activities can help understand the full scope of potential activities and their effects.

Offshore wind data gaps

- Potential risk of offshore wind displacing research activities

Potential risk of offshore wind displacing research activities. Offshore wind projects have the potential to displace existing research activities in several ways. This displacement risk will depend on the scale and scope of the offshore wind development. First, these projects may cause spatial displacement of research efforts, leading to an opportunity cost. For instance, ship-based and aerial surveys may need to avoid areas with offshore wind installations. Aerial surveys, such as those for sea otters, typically occur at altitudes of around 700 feet, which may overlap with the height of wind turbines. Researchers have already had to navigate around existing offshore facilities. Remotely operated vehicle (ROV) dives were not conducted within two miles of submarine cables to avoid entanglement risks. Although researchers can adjust their sampling locations, excluding a research area could impact the continuity and value of historical data. To mitigate these issues, monitoring instruments could be integrated into offshore wind structures, but the effectiveness of this approach would depend on the proximity of these structures to existing monitoring assets.

Existing research activities may also be displaced due to resource competition. The availability of marina space, maintenance facilities, and qualified personnel for vessel operation are limited. With the influx of a new industry, it is essential to assess whether there will be sufficient skilled individuals to support offshore wind, research, and other existing activities, such as commercial fishing. This may lead to a shift of personnel from one industry to another. Moreover, the allocation of ships for various purposes could affect their availability for research. While NOAA vessels are primarily used by researchers, they are also available for charter by other agencies and entities. Additionally, regional research vessels, such as those operated by the University of Washington (e.g., Robertson and Thompson), and large vessels capable of lifting heavy loads, may be needed for constructing new offshore wind facilities. Consideration should be given to whether these vessels will be repurposed for the offshore wind industry and how this shift might impact the availability of ships for ongoing research. Securing limited vessel time is already a challenge. It remains to be seen how this dynamic might change if vessels are repurposed for offshore wind projects or used to study their impacts.

Finally, offshore wind activities could potentially interfere with research studies in several other significant ways. The installation and operation of wind turbines may disrupt sonar research, including seafloor mapping and the tracking of sonar-tagged marine mammals. Moreover, the installation of cables associated with offshore wind farms could interfere with sediment research and pose risks to research vessels and instruments, potentially leading to entanglement or collisions. The introduction of new debris from these projects could also complicate existing research efforts. Additionally, offshore wind installations could impact the distribution and behavior of marine species through mechanisms such as a fish aggregating device (FAD) effect or by altering upwelling and surface water circulation patterns.

Feedback on importance: Addressing displacement and resolving conflicting uses are priority concerns. It is crucial to evaluate the potential effects of offshore wind developments on research efforts related to all life phases of fish, shellfish, and marine mammals, as well as on key areas such as sediment transport, bed morphology, and water quality. For example, before installing infrastructure on the shelf, it is essential to assess how offshore wind activities may influence the energy dynamics of the marine system, including potential changes to currents, upwelling, and core ecosystem processes.

Offshore aquaculture data gaps

- Potential risk of offshore aquaculture displacing research activities

Potential risk of offshore aquaculture displacing research activities. The risk of offshore aquaculture displacing research activities will depend on the scale and scope of the development. Offshore aquaculture projects have the potential to displace existing research activities in several ways. Offshore aquaculture activities could potentially interfere with research studies by affecting the collected data. Offshore aquaculture could alter local ecosystems by introducing additional nutrients, which may promote phytoplankton blooms and cause cascading effects on prey dynamics. Offshore aquaculture may also disrupt the spatial distribution of species, potentially attracting them to the facilities. This attraction could result in species congregating around the floating structures, which may draw in predators and lead to trophic effects that extend beyond the immediate area of the aquaculture facility. The presence of these facilities could also facilitate the transmission of diseases from farmed fish to wild populations or transport viruses and bacteria. Additionally, if the aquaculture operation uses non-native species, these species could influence surveys that collect environmental DNA (eDNA) data.

New offshore aquaculture facilities may also affect existing nearshore and offshore surveys. Along the coast, the Washington monitors nutrient inputs, establishes caps for outflows, and conducts sampling for ocean acidification and pH levels. The Environmental Assessment Program (EAP) maintains a Marine Water & Sediment Monitoring Program with sites in Puget Sound, Willapa Bay, and Grays Harbor, where sampling has occurred monthly for years. Offshore, NOAA's fishery surveys which collect environmental data on nutrients, oxygen, and other variables may be affected.

Additionally, researchers may need to adjust their survey locations to accommodate these new facilities to ensure that long-term data records remain accurate and unbiased. Spatial displacement of research efforts is an existing issue. Researchers have already had to navigate around existing offshore facilities. Remotely operated vehicle (ROV) dives were not conducted within two miles of submarine cables to avoid entanglement risks. Although researchers can adjust their sampling locations, excluding a research area could impact the continuity and value of historical data. To mitigate these issues, monitoring instruments could be integrated into offshore wind structures, but the effectiveness of this approach would depend on the proximity of these structures to existing monitoring assets.

Existing research activities may also be displaced by offshore aquaculture due to resource competition. The availability of marina space, maintenance facilities, and qualified personnel for vessel operation are limited. With the influx of a new industry, it is essential to assess whether there will be sufficient skilled individuals to support offshore aquaculture, research, and other existing activities, such as commercial fishing. This may lead to a shift of personnel from one industry to another.

Feedback on importance: Addressing displacement and resolving conflicting uses are priority concerns. It is crucial to assess the effects of offshore aquaculture on research related to all life stages of fish, shellfish, and marine mammals, as well as on sediment transport, bed morphology, and water quality.

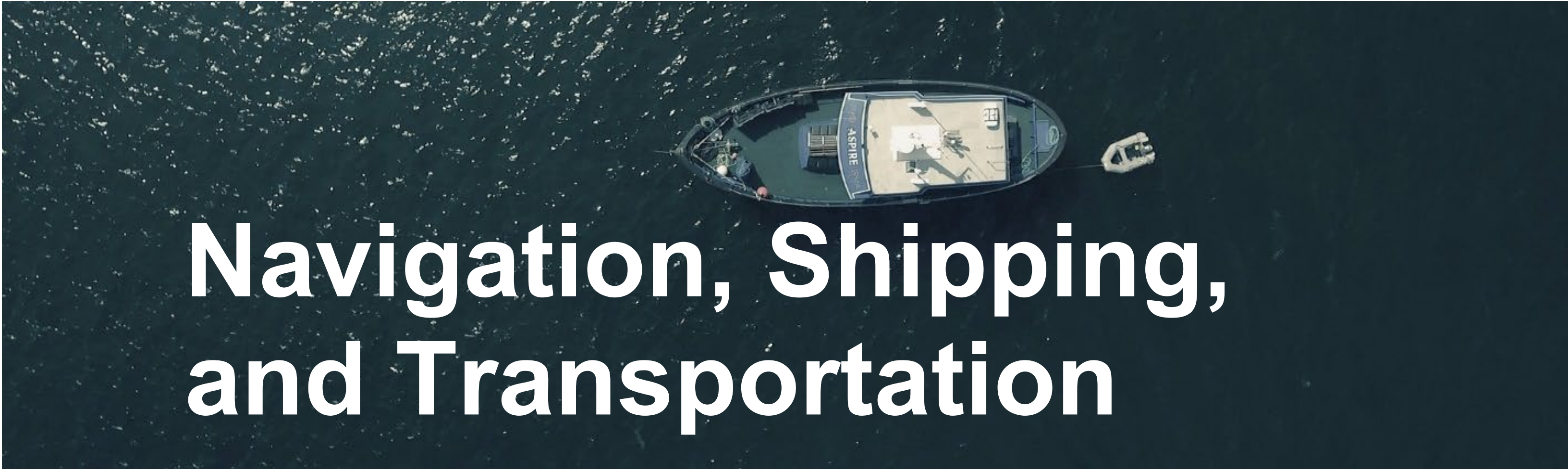
Other Data Gaps

No other data gaps were identified.

Resources

Table 43. Resources relevant to research activities.

NAME	ACCESS	TYPE	DESCRIPTION
West Coast Ocean Acidification and Hypoxia (OAH) Monitoring Inventory	https://geo.maps.arcgis.com/apps/webappviewer/index.html?id=a8b5c0ecfbe7451e950def767c55335e	Data portal	Aggregates and visualizes OAH monitoring assets along the West Coast.



Navigation, Shipping, and Transportation

Key Data Gaps

General Data Gaps

- Status, trends, and intensity of existing navigation, shipping, and transportation operations
- Cultural value of navigation, shipping, and transportation
- Social value of navigation, shipping, and transportation
- Economic value of navigation, shipping, and transportation
- Environmental effects of navigation, shipping, and transportation
- Effect of changing fuels for navigation, shipping, and transportation

Other Data Gaps

General Data Gaps

- Effect of navigation, shipping, and transportation on species

Offshore Wind Data Gaps

- Economic effect of offshore wind on navigation, shipping, and transportation
- Effect of vessel-based servicing for offshore wind on navigation, shipping, and transportation
- Effect of offshore wind on onshore transportation infrastructure
- Effect of offshore wind on routes and activities for navigation, shipping, and transportation
- Effect of potential failure of offshore wind structure on navigation, shipping, and transportation

Offshore Aquaculture Data Gaps

- Effect of offshore aquaculture on shipping patterns, routes, and activities of navigation, shipping, and transportation
- Economic effect of offshore aquaculture on navigation, shipping, and transportation
- Environmental effects of offshore aquaculture on navigation, shipping, and transportation

Background

Disclaimer: Input was not obtained from Tribal staff regarding the state of knowledge and data gaps related to shipping, transportation, and navigation. As such, this section focuses on activities as they pertain to non-Tribal communities. However, some experts provided insights into Tribal vessel activities, which have been included to highlight the scope of data gaps. These comments do not reflect the perspectives or knowledge of Tribal staff and community members. Meaningful engagement with Tribal communities is essential for a comprehensive and respectful understanding of these activities, and their input is critical to fully addressing these knowledge gaps.

a. Overview

Shipping**:** Trade in Washington began with Indigenous people and expanded with European explorers seeking natural resources. By the 18th and 19th centuries, competition intensified, and Washington became a major exporter of raw materials. The Port District Act of 1911 facilitated the establishment of ports like Grays Harbor, Seattle, and Tacoma. Grays Harbor is the sole deep-draft port adjacent to the MSP Study Area.

Various vessels travel through the MSP Study Area, including tank vessels carrying bulk liquids like oil and cargo vessels transporting dry goods such as grain and wood. Passenger vessels like cruise ships also transit occasionally. Integrated tug-barges (ITB) and articulated tug-barges (ATB) handle crude oil and petroleum products in the region. Vessels are defined by their carrying capacity or deadweight tonnage (dwt), indicating their cargo capacity. Tankers arriving to ports in the Pacific Northwest range from 12,000 to 190,000 dwt. In Puget Sound, tankers carrying crude oil and petroleum products are limited to 125,000 dwt. Grays Harbor and the Columbia River have no tonnage limit but are constrained by navigation channel depths. In particular, the Grays Harbor Navigation Channel allows deep-draft vessels to access Port of Grays Harbor facilities. All such vessels are restricted by this channel's depth.

From 2002 to 2011, the size of vessels calling at Pacific Northwest ports increased by 2-3% annually, based on the average weight of ships. As ships became larger, the total number of container ship calls decreased. This trend of using larger ships for efficiency is expected to continue or stabilize in the future. By 2035, the number of vessel calls is projected to drop to 3,336, down from a peak of 5,431 in 1996, reflecting an average annual decline of 1.9%. However, this projection doesn't consider potential projects in planning or permitting stages, which could increase dry bulk or liquid shipments through the region and lead to a rise in vessel traffic if approved.

Marine traffic in the MSP Study Area is shaped by global trade patterns, which affect the flow of traffic through the ports in Puget Sound, the Columbia River, and along the Pacific Coast. For example, container traffic in Tacoma, Seattle, and Portland grew until 2005, then declined due to the economic recession and increased competition from other ports. However, container volumes began to recover in 2011, remained steady through 2012-2013, and have been projected to grow at a modest rate of 2.2% annually from 2013 to 2035. Despite this increase in container volumes, overall vessel traffic slightly decreased, largely due to the use of larger container ships.

Navigation: The diverse and dense traffic of vessels in the MSP Study Area requires multiple schemes to guide their paths and prevent conflicts. The United States (US) Coast Guard (USCG) manages aids to navigation (ATON) in the MSP Study Area, including buoys, beacons, automated identification system (AIS), and lighthouses at Cape Flattery, North Head, Grays Harbor, and Cape Disappointment. The USCG's Puget Sound Vessel Traffic Service ensures orderly navigation in the Salish Sea by coordinating vessel movements through collection, verification, organization, and dissemination of information. Vessels equipped with AIS (required by 33 CFR 164.46) are tracked for informational purposes. The USCG collaborates with the Canadian Coast Guard's Marine Communications and Traffic Services to manage vessel traffic across the Salish Sea and offshore approaches. The Marine Exchange of Puget Sound monitors commercial vessels in Puget Sound and Grays Harbor, with tracking capabilities extending about 50 miles offshore. Similarly, the Merchants Exchange of Portland monitors commercial vessels in the Columbia River, with monitoring capabilities also extending about 50 miles off Washington and Oregon coasts.

Traffic separation schemes (TSS) create lanes to separate opposing streams of traffic. TSS are designated for the approaches to and within the Strait of Juan de Fuca and Puget Sound. There are also towboat lanes which are designed to limit interactions between fishing gear and towing vessels. Washington Sea Grant collaborated with towboaters and crab fishermen to establish towboat lanes along the Pacific Coast from San Francisco, CA to Cape Flattery, WA.

There are also navigation restrictions by the Olympic Coast National Marine Sanctuary (OCNMS). The International Maritime Organization (IMO) designated an Area to Be Avoided (ATBA) within OCNMS to reduce navigation hazards and potential casualties. Preventing spills in the OCNMS is a top priority due to the threat they pose to its resources. A voluntary program, the ATBA recommends that certain vessels carrying oil or hazardous materials stay outside this area. The voluntary compliance rates are high. Fishing and research vessels that are allowed in the sanctuary are exempted. Government vessels are also exempted but are encouraged to avoid the ATBA when solely transiting.

Where no management measures are in place, the West Coast Offshore Vessel Traffic Risk Management Project Workgroup suggests that large vessels (300 gross tons or more) transiting between Cook Inlet, AK and San Diego, CA should stay at least 25 nm offshore while laden tank ships should stay 50 nm offshore. Most vessels adhere to these recommendations based on AIS data, though exceptions include those entering Grays Harbor and Willapa Bay, and smaller vessels like tug and towboats.

United States Coast Guard: The USCG 13th District oversees Washington, Oregon, Idaho, Montana, and the Pacific Northwest coast, including the MSP Study Area. Operations at Sector Puget Sound and Sector Columbia River serve the MSP Study Area. Daily operations include search and rescue and patrolling the coast to enforce safety and fishing regulations.

- USCG Station Grays Harbor covers from Queets River to Long Beach Peninsula, managing four vessels for search and rescue. The US Coast Guard Captain of the Port of Sector Columbia River can close Grays Harbor bar during unsafe weather.

- USCG Station Cape Disappointment at Ilwaco is the region's largest search and rescue station. The station operates five search and rescue boats, aiding both commercial and recreational mariners within a 50-nautical-mile radius of the Columbia River entrance.
- USCG Station Quillayute River in La Push serves the Quileute Tribe's area with two lifeboats, supported by USCG Air Station/Sector Field Office Port Angeles.
- USCG Station Neah Bay, within the Makah Reservation near the MSP Study Area, operates two lifeboats for emergencies from Cape Alava northward.

b. Facilities

Ship and boat building, maintenance, and repair: The maritime industry's ship and boat building, maintenance, and repair sector encompasses constructing, maintaining, refurbishing, and modernizing commercial, recreational, and military vessels. Most of the activity associated with this industry occurs outside the MSP Study Area. Commercial companies in this sector are larger but fewer, while recreational companies are smaller, but more numerous.

Additionally, smaller facilities that support boat haul-out and repairs in ports and marinas within or near the MSP Study Area are crucial for supporting fishing, aquaculture, and other sectors alongside larger boat building operations.

Ports and marinas: Ports adjacent to the MSP Study Area, the Strait of Juan de Fuca, Columbia River, and Puget Sound support Washington's fishing industry with moorage, boat ramps, maintenance services, and fish processing facilities, crucial for both commercial and recreational fishing operations.

Emergency towing vessel: An emergency response towing vessel (ERTV) stationed at Neah Bay aids vessels in Washington waters and the Strait of Juan de Fuca. Any “covered” vessels (tankers, cargo, and passenger ships) must include the ERTV in their spill response plans. Industry-funded, it operates 24/7 to assist with maneuvering issues or for towing and escort.

c. Risks

Vessel discharges: Vessels discharge various types and amounts of wastewater like sewage, graywater, bilgewater, and ballast water, posing potential environmental and health risks due to pathogens, nutrients, and toxins. Within the state, OCNMS, and federal waters, there are regulatory and voluntary measures that address many types of vessel discharges.

Vessel discharges in Washington must adhere to state water quality standards. Some onboard treatment systems fall short, prompting vessels to use onshore pumpout facilities or delay discharges until outside state waters.

Vessel strikes: Vessel collisions with marine mammals, especially large whales, are a significant global concern where shipping routes intersect with whale habitats. Collisions can lead to injury or death of whales, often going unnoticed by vessel crews. The number of whale strikes may be greater than those documented. In Washington, blue whales, fin whales, and gray whales have been documented as ship strike victims. The West Coast Marine Mammal Stranding Network, authorized by National Oceanic and Atmospheric Administration (NOAA), collects data on stranded marine mammals along the West Coast, aiding research, public education, and implementation of NOAA Fisheries mandates under the Marine Mammal Protection Act and the Endangered Species Act.

Oil spill preparedness and response: Vessels navigating through the MSP Study Area pose a significant risk of oil spills, necessitating robust prevention, preparedness, and response measures. Oil spill risk is the likelihood of a spill incident occurring, influenced by factors such as spill source, volume, oil type, season, and location.

Different types of oil present varying spill risks. A state-conducted study determined that environmental risks from oil spills are greatest for heavy fuels, followed by crude oil, with lower risks associated with light oils and gasoline. This pattern reflects the prolonged persistence of heavier oils and their heightened threats to organisms and habitats.

Several state and federal laws and regulations govern the potential for oil spills in or near water, including preparedness and response planning and actions. USCG oversees federal oil spill prevention and response for vessels and facilities, while Ecology manages state-level responsibilities.

A coordinated response framework establishes roles and responsibilities, identifies resources and response procedures for oil spills or threat thereof. It encompasses national and regional contingency plans and geographic response plans (GRPs). A GRP aims to identify sensitive resources at risk of injury from oil spills and to describe and prioritize strategies to protect these sensitive resources at risk.

d. Economic value

Marine transportation and shipping significantly affect the economy of coastal counties adjacent to the MSP Study Area. However, isolating these effects exclusively to these counties is challenging because transiting vessels originate from and travel to various destinations, all contributing to the broader ocean economy of the state. The maritime impacts are summarized in the table below:

Table 44. Summary of economic effects from maritime subsectors in Washington State in 2012 (MSP Table 2.7-1).

MARITIME SUBSECTOR	EMPLOYER ESTABLISHMENTS	WAGES ($ MILLIONS)	JOBS	GROSS BUSINESS INCOME ($ MILLIONS)
Maritime logistics and shipping	800	1,156.0	16,700	3,722.4
Maritime support services	300	387.7	4,600	864.2
Boat and ship building, repair, and maintenance	150	1,163.8	16,500	1,489.7
Fishing and seafood processing	720	1,113.4	15,400	8,592.6

MARITIME SUBSECTOR	EMPLOYER ESTABLISHMENTS	WAGES ($ MILLIONS)	JOBS	GROSS BUSINESS INCOME ($ MILLIONS)
Passenger water transportation	130	262.8	4,500	544.5
Total	2,100	4,083.7	57,700	15,213.3

The NOAA Coastal Services Center analyzed the ocean economy at the county level using Economics: National Ocean Watch (ENOW) data (2005-2011), detailing sectors like living resources, marine construction, transportation, minerals, shipbuilding, and tourism. Pacific coastal counties (Clallam, Jefferson, Grays Harbor, Pacific, Wahkiakum) contributed 6% of employment and 3.9% of Washington's ocean economy GDP.

Table 45. Marine transportation contribution to the ocean economy of the five Pacific coastal counties and statewide (MSP Table 2.7-2).

MARINE TRANSPORTATION	PACIFIC COASTAL COUNTIES	STATEWIDE
Establishments	6	409
Employment	63	19,105
Wages (thousands of dollars)	4,523	1,279,000
Average wages	71,794	66,961
GDP (thousands of dollars)	7,976	2,594,000
Self-employed workers	40	523

Ports and marinas near the MSP Study Area offer moorage, access for fishing vessels, fish processing, shipping, storage, and vessel maintenance. The Port of Grays Harbor and other ports beyond the MSP Study Area compete not only among themselves but also with West Coast, East Coast, and Gulf Coast ports. Changes in trade patterns could significantly affect the economies of areas near the MSP Study Area.

The MSP provides information on several ports and marina, all providing critical services for important uses within the Study Area and contributing to the coastal economy. The following are discussed in the MSP: Clallam County ports (Neah Bay and Quileute Harbor Marina), Jefferson County ports, Grays Harbor County ports (Port of Grays Harbor, Westport Marina, and Quinault Marina); and Pacific County ports (Port of Peninsula, Willapa Bay, Ilwaco and Chinook)

e. Future Trends

Waterborne cargo volumes in Washington and Oregon are expected to grow 1.3% annually from 2013 to 2035. However, with a shift towards larger vessels, overall fleet numbers are predicted to decrease. These predictions are not specific to the coast of Washington, but also include Puget Sound, Columbia River, and Oregon ports. Changes in global trade patterns, influenced by economic shifts, may also affect trade flow through the Pacific Northwest. To date, there has been a modest alteration in trade routes; however, the future trajectory of these changes remains uncertain. Additionally, rail rates, port rates and ocean accessibility influence port competition. How these factors will affect ports in the future is unknown.

The energy sector will also affect future movements of cargo to and from the Pacific Northwest. Changes in US and Canadian oil supplies are likely to shape crude oil movements in Washington State to refineries in Puget Sound and Vancouver, BC. With decreasing supply of Alaskan crude oil transported by tankers and pipelines, and an increasing supply from North Dakota by train, there are proposals for refinery upgrades and new storage facilities in Grays Harbor and along the Columbia River. Additionally, existing and proposed pipeline facilities in Washington may transport tar sands crude oil from Canada. These proposed facilities could alter vessel traffic in the MSP Study Area by increasing both the number and variety of vessels passing through, as well as the volume of crude oil transported in the region.

f. Climate Change

Ports and marinas are facing infrastructure and operational challenges due to sea level rise caused by climate change, requiring adjustments or reconstruction of piers and other structures. Sediment from upstream erosion may obstruct boat access, leading to higher dredging costs for ports and marinas to maintain functionality. Land-based facilities may also need to adapt to minimize operational disruptions. Additionally, surrounding transportation systems could experience infrastructure damage, further impacting port operations.

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to navigation, shipping, and transportation:

General data gaps

- Status, trends, and intensity of existing navigation, shipping, and transportation operations
- Cultural value of navigation, shipping, and transportation
- Social value of navigation, shipping, and transportation
- Economic value of navigation, shipping, and transportation
- Environmental effects of navigation, shipping, and transportation
- Effect of changing fuels for navigation, shipping, and transportation

Status, trends, and intensity of existing navigation, shipping, and transportation operations. Comprehensive data exists regarding ship movements. Information comes from the commercial shipping industry, ports of call, and Automated Identification System (AIS) data. AIS automatically transmits vessel information to equipped stations which includes the vessel's identity, type, position, course, speed, navigational status, and other safety-related information. Large commercial vessels are mandated to carry Class A AIS devices, while fishing industry vessel and those carrying less than 150 passengers may opt for Class B AIS devices. Not all vessel types are guaranteed to be visible via AIS. There are also Vessel Entries and Transits (VEAT) reports that provides information on commercial vessel traffic in WA waters and the Marine Exchange of Puget Sound which provides a report every year on vessel entries and different types of vessels. Large vessels are also tracked well through collaboration between the

Coast Guard, Ecology, Puget Sound Harbor Safety committee, and the Grays Harbor Safety Committee.

The challenge lies in obtaining information about smaller vessels exempt from AIS requirements, typically those below a certain size threshold. Many recreational boats also do not have AIS. However, vessel concerns focus on larger vessels due to their increased potential for spill risks. A voluntary measure is in place, urging vessels weighing 400 tons or more and transporting hazardous materials to avoid specific areas.

For widespread trends, AIS is also the go-to resource. One can submit an AIS historical data request through the Navigation Center, inquiring about the availability of historical AIS tracks and relevant information. The requirements for AIS were mandated to be in effect no later than March 1, 2016, with its development dating back to the early 2000s. Information on trend can also be obtained by engaging with local port facilities, the Marine Exchange, and the American Pilots Association. These data could offer valuable insights into the trends concerning the types of vessels that are entering ports in Washington. However, this resource does not provide information on recreational boaters. Obtaining data on recreational boating may require engagement with state agencies, but data would be limited to information like vessel registrations and may not match the coherence of commercial vessel data.

Feedback on importance: This is an important data gap. There is interest in obtaining information on status, trends, intensity, and how many vessels are transiting. These are constants. There are not very many variables involved. Collecting this data will provide a snapshot on the state's shipping activity.

Cultural value of navigation, shipping, and transportation. While the cultural value of marine resources is recognized, there is a lack of effort to evaluate and quantify it. The significance of this value can vary depending on the context, such as the cultural importance of shipping versus the waterway itself. Coastal communities like Westport, La Push, and Willapa Bay depend on ocean resources that hold deep cultural meaning. Some of this information is documented in the Geographic Response Plans (GRPs), and Ecology is prepared to protect these resources. However, there are concerns that increased shipping activity could negatively impact these resources through spills or operational changes. Grays Harbor, for instance, has seen a steady increase in vessel traffic over the past decade, raising concerns about the effects of this heightened activity. However, the increase in traffic also results in more resources brought to the area.

There is a cultural economic component of enhancing the shipping industries in some of these areas. Cities like Aberdeen and Hoquiam are actively working to bolster their shipping industries, aiming to generate additional revenue and improve local resources. Additionally, the Pacific Northwest has a rich maritime culture, marked by historic wrecks and industries. A wealth of information is available, depending on the specific cultural, social, or economic aspects being explored.

Quantifying the cultural value of resources, such as for damage assessments, poses challenges. The conventional approach of using a 1:1 replacement cost or monetary value may not always be suitable. While efforts exist to understand the connections between culture and these resources, such as locating and studying shipwrecks, there's limited insight into how much people value them.

The coastal region holds significant cultural values, particularly for Tribal communities, whose strong ties to their land and traditions would be impacted by environmental hazards like spills. With numerous Indigenous populations, each with distinct cultural landmarks and locations, ensuring that shipping activities don't interfere with these sites is crucial. Changes in shipping patterns or an increase in the number of vessels could impede their exercise of treaty rights. Identifying culturally significant resources for Tribes necessitates direct engagement. Traditional navigation practices, including canoe journeys, are also vital, with concerns arising from safety issues at traditional launching and landing sites due to environmental changes such as loss of kelp, shoreline changes, and intensification of ocean conditions or storms. There are also concerns about visual impacts. Quantifying values such as viewscape, access to traditional places, and sovereignty over marine spaces presents challenges, as these are deeply ingrained in Tribal identity and difficult to measure monetarily. While Tribes understand these values intrinsically, they are harder to gauge from a Western perspective, highlighting the need for more comprehensive data and understanding in this area.

Feedback on importance: Information on the cultural value of navigation, shipping, and transportation could provide baseline data.

Social value of navigation, shipping, and transportation. There is a need to quantify and define what this value means as its significance depends on the inquiry. Cultural, social, and economic values overlap. Economic values are easier to obtain than social values, particularly regarding shipping and waterways. In this regard, social values are a data gap. However, information is available. The challenge lies in defining social value. Once the criteria are established, identifying relevant sources becomes feasible, rendering the perceived gap a matter of defining the parameters rather than a lack of data.

Examining shipping as a whole, society heavily relies on the transportation of various goods, ranging from automobiles to Amazon packages to oil and gas refinery products, all of which are transported via cargo vessels. The ability to access global products holds significant societal value. Furthermore, when considering Washington's maritime history, Indigenous Tribes historically maintained trade routes along the coast, spanning from Alaska to the Columbia River, facilitating the exchange of timber, fisheries, and furs. Post-contact, shipwrecks dating back to the colonization and settlement periods offer insights into evolving social values over time. However, quantifying maritime heritage presents a challenge. Attempting to assign a monetary value to these aspects has both advantages and disadvantages. There remains a limited understanding of how much individuals value them. Tribal communities may possess a nuanced understanding of these

Figure 14 A cruise ship on the water.

values, but from a Western perspective, assessing them presents considerable difficulty.

Feedback on importance: The extent of this data gap varies depending on the specific focus. Additionally, understanding how external factors, like a new ocean-based project, could influence the social value of navigation, shipping, and transportation requires more information. For example, such a project could increase social value by creating jobs and ensuring employment stability.

Economic value of navigation, shipping, and transportation. There would be a need to quantify and define what this value means. What a tow vessel values are different from that of a shipping yard. There is no uniform set of data. However, shipping is fundamentally commercial, making it easy to measure its economic value. Economic values can be assessed by examining the industries involved, including the jobs and salaries generated for the state and ports. Additionally, some ports and cargo industries track the values of what is going in and out, which can include different components such as ship building facilities and repair yards. Although it's unclear who would gather this data, data should be available as all involved in shipping, transportation, or navigation should be tracking their gains and losses.

Feedback on importance: There are aspects of this data gap that can be more foundational or provide the baseline data.

Environmental effects of navigation, shipping, and transportation. Understanding the environmental effects is crucial, particularly because many communities rely heavily on ocean and coastal resources. Unlike impacts to species, environmental effects can be more difficult to quantify due to their indirect nature. For example, assessing environmental impacts may involve evaluating the effects of noise pollution rather than directly measuring the death of fish. Additionally, different types of impacts may require different metrics. One metric cannot be universally applied to all scenarios. However, with foundational work already in place through risk models and vessel trend analyses, there are opportunities to address these questions in the future. This would require collaboration with agencies like Ecology, the EPA, and other federal agencies with environmental mandates. NOAA may also offer insights regarding environmentally sensitive areas.

Information on some environmental effects, such as those caused by oil spills, is available. Oil spills generally originate from vessels or oil tankers with large fuel reserves and lead to substantial environmental damage. Washington is unique in that it houses refineries, and while most products are consumed regionally, vessels bring in crude oil in and export refined products. When assessing the impacts of a spill, the focus is on the damage to species, nutrients, shorelines, and natural resources. Resources like the Environmental Sensitivity Index (ESI) map all resources at risk in the event of an oil spill. However, the ESI data for the outer coast of Washington was last updated in 2014, creating a significant data gap for effective planning. A spill would also require extensive restoration efforts to return the affected area to pre-spill conditions. However, assessing these pre-spill conditions is challenging due to the lack of accurate, long-term data, as much of it is ephemeral. Discussions have taken place with Tribes and resource trustees to explore how to capture pre-oil conditions and determine the appropriate frequency for data collection. Questions remain about the availability and accuracy of records regarding quantities, volumes, pre-oil conditions, and revenues, as well as how to effectively measure the impact of the spill.

Feedback on importance: This is an important data gap. Certain aspects can be foundational or fundamental in concept. Environmental considerations that establish a baseline will have greater utilitarian value for certain entities.

Effect of changing fuels for navigation, shipping, and transportation. There is interest in transitioning from petroleum to alternative fuel sources like hydrogen and ammonia. While there is no definitive authority on this matter, understanding the direction of this shift is crucial for assessing its impact on both local and long-distance traffic. This insight will help inform the associated risk profile.

Feedback on importance: This is critical information because it will inform the risk profile. Significant shifts in fuels may necessitate substantial restructuring of legislative structures and authorities.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Effect of navigation, shipping, and transportation on species

Effect of navigation, shipping, and transportation on species. This is not a data gap. While the information may not be readily available, numerous organizations track this data and could be engaged to gather the necessary information. This is simply a matter of identifying the appropriate contacts.

Offshore wind data gaps

- Economic effect of offshore wind on navigation, shipping, and transportation
- Effect of offshore wind on navigation, shipping, and transportation from vessel-based servicing
- Effect of offshore wind on onshore transportation infrastructure
- Effect of offshore wind on routes and activities from navigation, shipping, and transportation
- Effect of potential failure of offshore wind structure on navigation, shipping, and transportation

Economic effect of offshore wind on navigation, shipping, and transportation. There is already a fair amount of vessel traffic and populated areas in the ocean. Economic effects from offshore wind are expected due to existing cargo traffic and active fishing fleets. For instance, navigation, shipping, or transportation may be economically affected depending on whether offshore wind will cause obstructions, an issue that is likely to be discussed during facility siting conversations. This data isn’t currently available, but this is not due to a lack of access to resources. Data collection will take place at the appropriate time, ensuring accuracy and adherence to protocols.

There are many variables to consider in defining the economic effects, and it is important to identify what needs to be tracked. Determining the key factors—who, what, why, when, where, and how—is essential. For example, if an offshore wind facility is located near shipping lanes, it could increase fuel costs for vessels navigating around it. It will also be important to assess the broader effects of offshore wind on shipping throughout the entire state.

Effect of vessel-based servicing for offshore wind on navigation, shipping, and transportation. It is uncertain whether this information would be readily available. Depending on the volume and types of services required, there could be conflicts with existing fleets and port infrastructure, such as offloading and staff availability. Servicing often occurs at shipyards, raising questions on whether Grays Harbor or another location would have the capacity to meet those needs. There may also be conflicts with supply procurement which would involve industries like oil, gas, and equipment.

Servicing vessels used for offshore wind could introduce a new quadrant to the shipping industry. If there is limited commodity, expansion may be necessary, potentially leading to the creation of a new sector.

Effect of offshore wind on onshore transportation infrastructure. Offshore wind development may affect onshore infrastructure in various ways, including impacting a port's operational capacity by requiring new developments, such as fueling facilities; disrupting existing operations due to construction activities; and placing increasing demands on facilities and infrastructure by introducing a new industry. Infrastructure, such as roads, may also struggle to accommodate additional traffic driven by offshore wind development. It is unclear whether transported cargo can be identified as being intended for offshore wind development.

To effectively assess and manage potential impacts, baseline data are needed. There are some existing data on pier and shipyard usage, like the number of ships that frequent facilities and port calls. Obtaining additional information may require collaborating with private entities. Understanding the anticipated impacts on the industry also requires projections from the offshore wind industry. For instance, to gauge the effect on a facility already operating at 80% capacity, information on potential frequency of port calls resulting from offshore wind activities will be needed.

Effect of offshore wind on routes and activities for navigation, shipping, and transportation. Typically, vessel routes are determined by various factors including weather conditions; navigational considerations such as the most efficient route, starting point, and ending points; and vessel capabilities. Shipping lanes are not mandated routes; rather, they represent the paths commonly used by vessels to navigate from one point to another, often following the shortest and most efficient route.

Quantifying impacts from offshore wind requires data on the location of offshore wind turbines, required clearance, and associated impacts. The scale of the impact will vary greatly between installing one or a thousand wind farms and will determine the level of complexity involved. Additionally, the effect depends on the operational and technological limitations of offshore wind. For instance, if wind turbines are situated 150 miles off the coast of WA with a 50-mile buffer from the nearest shipping lane, transit and shipping impacts would likely be minimal. However, if offshore wind installations must be within a mile of the shore and at specific depths, selecting suitable locations becomes critical and could significantly impact shipping.

If offshore wind facilities are installed 20 to 30 miles offshore, authorities will ensure that the relevant channels are clear for vessels crossing the ocean, or smaller traffic may divert north or south along the coast. Monitoring shifts in traffic activity is possible, particularly for larger vessels with established routes. The Coast Guard could request several years of vessel traffic data from the Navigation Center to determine if and how shipping patterns change with the installation of offshore wind facilities. The Navigation Center could compile this information, prepare a heat map, and provide the necessary data.

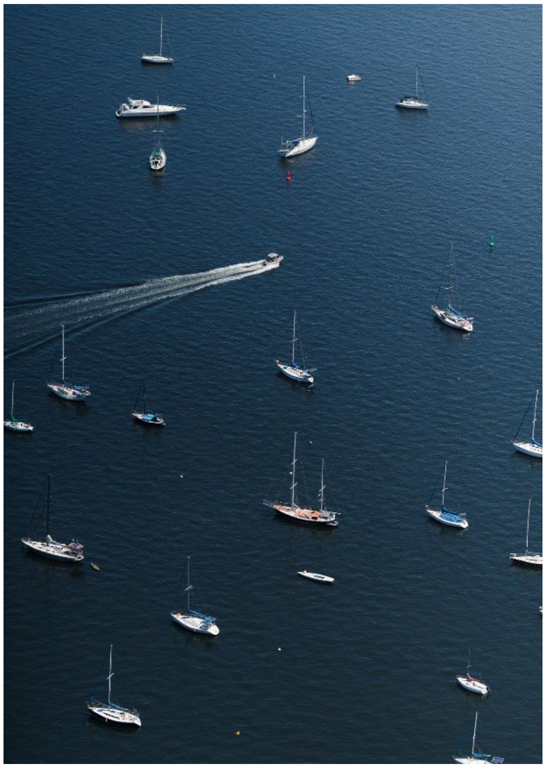


Figure 15. A group of boats in the water.

Offshore wind development could also impact vessel anchoring. When port facilities are unavailable for mooring, ships may be forced to drift offshore until space becomes available, divert to another port for refitting and restocking, or anchor at an alternative location. The specific choice depends on the vessel's needs. Vessels can anchor at federally designated anchorages or other locations. If an anchorage point is federally designated, it could affect the feasibility of offshore wind project siting. Anchoring in non-designated areas could potentially lead to conflicts over space.

Effect of potential failure of offshore wind structure on navigation, shipping, and transportation. The risk of collateral damage hinges on the severity of the failure. A turbine collapse near navigable channels or major seafaring routes could impede vessel passage. If floating, it could cause a marine casualty or a collision. The release of hazardous materials or pollution from offshore wind infrastructure, which may include significant lubricant material and oil, also poses additional risks to vessels and the marine environment. The potential risks of toxic spills from wind infrastructure and their impact on navigation remain unclear.

Assessing the likelihood of navigation being impacted by structural failure is challenging. While regulations require the reporting of obstructions to navigable waterways for safety purposes, established navigational channels do not exist offshore in open waters where potential offshore wind activities may take place.

Offshore aquaculture data gaps

- Effect of offshore aquaculture on shipping patterns, routes, and activities of navigation, shipping, and transportation
- Economic effect of offshore aquaculture on navigation, shipping, and transportation
- Environmental effects of offshore aquaculture on navigation, shipping, and transportation

Effect of offshore aquaculture on shipping patterns, routes, and activities of navigation, shipping, and transportation. Shipping patterns are tied to the type of operation transiting those routes. For instance, along shipping routes, there are seasonal variations. Container ships are prevalent during specific months and there is an influx of fishing vessels during fishing seasons. Routes refer to those that most people commonly use. Typically, vessel routes are determined by various factors including weather conditions; navigational considerations such as the most efficient route, starting point, and ending points; and vessel capabilities. If facilities are installed 20, 30 miles offshore, authorities will ensure the relevant channels are clear for vessels crossing the ocean, or smaller traffic may divert north or south along the coast. Monitoring shifts in traffic activity is possible, particularly for larger vessels with established routes.

Predicting the effect of offshore aquaculture may be difficult and requires data on facility locations, clearance requirements, and potential effects. The scale of these impacts varies greatly depending on the number of aquaculture farms installed, influencing the complexity involved. The effect will also depend on the type of aquaculture being conducted as aquaculture operations can exhibit different sensitivities to noise and releases from vessels. Additionally, the operational and technological constraints of offshore aquaculture will affect its impact. For example, if installations must be near shore and at specific depths, selecting suitable locations becomes crucial and could significantly affect shipping. The impact will also depend on the relative proximity of other industries. For instance, if offshore aquaculture is established near major fishing areas, fishing vessels could be more affected than other industries.

Economic effect of offshore aquaculture on navigation, shipping, and transportation. There is already a fair amount of vessel traffic and heavily used areas in the ocean. Economic effects are expected due to existing cargo traffic and active fishing fleets. The effect will depend on whether there are obstructions, a topic that is likely to be discussed during facility siting conversations.

It would be challenging to determine the impact of offshore aquaculture on various industries. The extent of impact would vary depending on the location, potentially affecting one industry more than another. For instance, if offshore aquaculture were established in an area with significant fishing activities, it would likely impact fishing vessels more than other industries.

Environmental effects of offshore aquaculture on navigation, shipping, and transportation. Offshore aquaculture activities can potentially affect shipping, and vice versa. Aquaculture operations may require vessels to adjust their routes, as different types of aquacultures may have varying sensitivities to noise and discharges from vessels. This could necessitate wider shipping lanes. Additionally, although there are restrictions on vessel discharges, it is unclear whether these regulations extend to the outer coast. There may be a need to consider, for example, extending the no discharge zone from Puget Sound.

Resources

Table 46. Resources relevant to navigation, shipping, and transportation.

NAME	ACCESS	TYPE	DESCRIPTION
Marine Traffic	https://www.marinetraffic.com/en/ais/home/centerx:-12.0/centery:25.0/zoom:4	Data portal	Provides near real-time information regarding vessel positions and movements as well as other related information such as port traffic and voyage details
NOAA: Environmental Sensitivity Index Maps and Data	https://response.restoration.noaa.gov/esi	Website	Summarizes coastal resources at risk if an oil or chemical spill occurs nearby.
Vessel Entries and Transits (VEAT) 2021 - VEAT 2021 - Vessel Entries and Transits for Washington Waters	https://apps.ecology.wa.gov/publications/documents/2208002.pdf	Publication	The VEAT reports list data by vessel destination and type, identifying vessels tracked by Ecology.

Culture

Marine recreation and tourism

Key Data Gaps

General Data Gaps

- Status, trends, and intensity of marine recreation and tourism
- Economic value of marine recreation and tourism
- Cost and effects of coastal threats on marine recreation and tourism

Offshore Wind Data Gaps

- Potential spatial conflict between offshore wind and marine recreation and tourism
- Effect of offshore wind on the economic value of marine recreation and tourism
- Effect of offshore wind on the social value of marine recreation and tourism

Other Data Gaps

General Data Gaps

- Geographic location of marine recreation and tourism
- Cultural and social value of marine recreation and tourism
- Public beach access locations

Offshore Wind Data Gaps

- Conflict of offshore wind with culturally important areas
- Potential for offshore wind to displace existing marine recreation and tourism, excluding spatial conflict
- Ecological effects of offshore wind and its subsequent effects on marine recreation and tourism
- Effect of offshore wind on existing onshore infrastructure associated with marine recreation and tourism

Offshore Aquaculture Data Gaps

- Potential spatial conflict between offshore aquaculture and marine recreation and tourism
- Potential for offshore aquaculture to displace existing marine recreation and tourism, excluding spatial conflict
- Effect of offshore aquaculture on the economic value of marine recreation and tourism
- Effect of offshore aquaculture on the social value of marine recreation and tourism
- Conflict of offshore aquaculture with culturally important areas
- Effect of offshore aquaculture on ecology and species important to marine recreation and tourism
- Effect of offshore aquaculture on onshore infrastructure associated with marine recreation and tourism

Background

The Marine Spatial Plan's (MSP) data and information on Washington's coastal recreation and tourism largely relies on the Surfrider Foundation's (Surfrider) Washington Coast Recreational Use Survey (Recreational Use Survey). In 2014, Washington residents were surveyed about their participation in recreational activities. Popular choices included beach going, sightseeing/scenic enjoyment, wildlife viewing, photography, hiking, and biking. Within the MSP Study Area, beach going, sightseeing/scenic enjoyment, and camping emerged as the three primary recreational activities. A comparison with an assessment[153] from the Washington State Recreation and Conservation Office, covering the years 2002 to 2012, revealed consistency in the most popular recreational pursuits. Notable changes included a heightened frequency of beach going and the emergence of paddleboarding and kiteboarding. The MSP offers detailed insights into wildlife viewing, waterfowl hunting, clamming, boating, surfing, and beach prospecting.

The availability of recreational and tourism experiences varies between the northern and southern coastal regions, depending on access to activities and the supporting amenities. According to the Recreation Use Survey, the largest proportion of recreational trips in 2014 took place in Pacific and Grays Harbor Counties, followed by Clallam and Jefferson Counties.

Historically, tourism and recreation played a minor role compared to other industries; however, resources published between 2011 and 2015 indicated tourism and recreation became the largest sector for coastal counties. Washington residents spent an estimated $481 million dollars on expenditures related to coastal trips and out-of-state visitors spent $160 million. Recreation-related spending was observed to support a significant number of jobs and labor income within the coastal economy and statewide. For communities at Pacific Beach, Copalis Beach, Ocean City, and Seaview Resident, employment in tourism-sensitive industries exceeded 50% of overall employment.

Table 47. Estimated recreation and tourism trip spending associated with Study Area coastal trips by Washington State residents and out-of-state visitors and total economic contribution to the Washington coast region and statewide (MSP Table 2.6-3).

	Trip spending by WA residents	Trip spending by out-of-state visitors	Total employment (from trip spending by WA residents)	Total labor income (from trip spending by WA residents)
WA Coast Region	$330.9 million	$160 million	4,725	$196.8 million
Statewide (total)	$481.2 million	$189.8 million	9,309	$413 million

Due to potential influence by various factors such as population growth, access limitations, and environmental issues, future trends of this industry were deemed difficult to predict.

[153] https://data.wa.gov/api/assets/F7F680E0-35D9-4575-88B9-74C0FE862CCD?download=true

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to marine recreation and tourism:

General data gaps

- Status, trends, and intensity of marine recreation and tourism
- Economic value of marine recreation and tourism
- Cost and effects of coastal threats on marine recreation and tourism

Status, trends, and intensity of marine recreation and tourism. Given changes in population dynamics and the impact of the COVID-19 pandemic (COVID), there is a recognized need for a new assessment, similar to Surfrider's Recreational Use Survey. Since the 2014 assessment, it's unclear whether there have been significant shifts in participation across recreational activities, though cold water swimming has notably increased. Similarly, coastal tourism has risen. The full extent of these trends is unknown.

Recreation data for the coast are held by state agencies. For example, Washington State Parks (Parks) has effectively monitored visitation to the properties under their management, the utilization of their facilities, and the range of activities that take place on their grounds. However, this level of data is not uniformly available across the different state agencies. To address this issue, Washington Department of Fish and Wildlife (WDFW), Washington State Department of Natural Resources (WDNR), Parks, and Washington State Recreation and Conservation Office (RCO) partnered with Earth Economics to assess visitation, consumer spending, and the economic contribution of outdoor recreation on state-managed lands[154]. Leveraging mobile device locational data, data collection spanned from 2019 to 2020. This data allowed agencies to gauge visitation trends throughout the year at individual sites and served as an internal management tool. Recreation data, specifically relating to trends in response to COVID, are also available through the Recreate Responsible Coalition[155]. Formed in May 2020, the coalition studied the surge in outdoor recreation after the pandemic, identifying issues such as increased pressure on beach access points. While some of this surge may have subsided, participation in recreation and tourism is expected to remain strong.

Figure 16. A surfer riding a wave.

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154 https://static1.squarespace.com/static/561dcdc6e4b039470e9afc00/t/62e43391a85a74075e952813/1659122600071/WDFW_FinalReport_small.pdf

155 https://www.recreateresponsibly.org/

Another source of data is [Washington State Recreation and Conservation Plan](https://wa-rco-scorp-2023-wa-rco.hub.arcgis.com/pages/final-plan)[156] (SCORP). Done every five years, this plan delineates the strategic direction for state investments in conserving public lands and developing outdoor recreation opportunities. A robust analysis of available outdoor recreation sites and public surveys are done to inform the plan's priorities and goals. While survey results can be segmented by region, there is interest in obtaining statistically significant data at a more granular level (e.g., county level). However, due to time and resource constraints, RCO has not been able to achieve this. Additionally, there is recognition that the five-year interval between surveys limits their usefulness for year-by-year investment planning. While valuable for long-term trend analysis, the SCORP data is insufficient for more immediate needs. As a result, there is a desire to conduct surveys every two or three years to ensure more consistent and reliable information. To complement SCORP, RCO is also exploring alternative data sources, such as assessments by Earth Economics.

Reason for priority: Understanding the current state and trends in recreation and tourism is important.

> **WCMAC:** Surfrider's Recreational Use Study served as a valuable baseline, offering insights into coastal recreation at that time. However, with COVID, the data from that study has become outdated. The pandemic had profound impacts on outdoor recreation but quantifying its effects – whether economically, socially, or in terms of user engagement – remains unknown. While there is a clear perception of increased recreational engagement along the coast, this can only be inferred from the Recreational Use Study and the reasons behind this surge are unknown. Currently there are no immediate plans to update this study due to the significant resources that would be required; however, there is an interest to do so, particularly to better understand the effect of inflation over the past decade on recreational costs.

Economic value of marine recreation and tourism. Efforts are underway to take advantage of the growing trend of outdoor recreation and shape communities around supporting this industry. In particular, there is a substantial focus on the economic benefits of introducing outdoor recreation to rural areas seeking economic and workplace diversity and shifting away from extraction-based economies. In 2015 and 2020, RCO prepared economic impact reports on outdoor recreation participation in Washington State. The 2020 edition of the Economic Analysis of Outdoor Recreation in Washington State report[157] likely offers the most comprehensive information on the economic value of recreation. This report details popular activities, their revenue generation, and associated costs such as gas expenses and spendings at convenience stores, restaurants, or hotels for a typical day of use. Data on recreation-related expenditures can be broken down by county and legislative district. With new funding, there is a plan to analyze the effect of recreation on the economies of underserved communities. There is also a notable data gap in evaluating the direct value versus the indirect benefits of marine

[156] https://wa-rco-scorp-2023-wa-rco.hub.arcgis.com/pages/final-plan

[157] https://static1.squarespace.com/static/561dcdc6e4b039470e9afc00/t/5f249326f05167773ab0774d/1596232557974/EconomicAnalysis-OutdoorRecreationWA_EarthEconomics_w0720-0.pdf

recreation and tourism. The Coastal Recreation Use survey provides valuable insights. However, in light of inflation, reassessing this survey is essential.

Reason for priority: As economic factors frequently have a more substantial influence on individuals' perceptions and decisions, understanding the economic value of marine recreation and tourism is essential.

> **WCMAC:** There is a decent understanding of the economic value of marine recreation and tourism. However, post-COVID, there likely are trends that have yet to emerge and be quantified. The pandemic sent shockwaves through the recreation community, leaving lasting effects that are still being studied. There is a need to examine, for example, whether formerly crowded destinations are now under capacity, whether new locations for recreation or tourism have surfaced, and the effects of recreation and tourism on rural communities.

Cost and effects of coastal threats on marine recreation and tourism.

Replacement and mitigation to address threats often requires costly acquisitions, space development, and careful planning. While cities may focus on these issues locally, it is unclear what efforts are being made along the coast. RCO has gained valuable insights through its partnerships with lead entities and regional organizations that analyze threats like climate change. However, RCO itself has not conducted studies in this area such as the effects of coastal threats on the economic value of outdoor recreation.

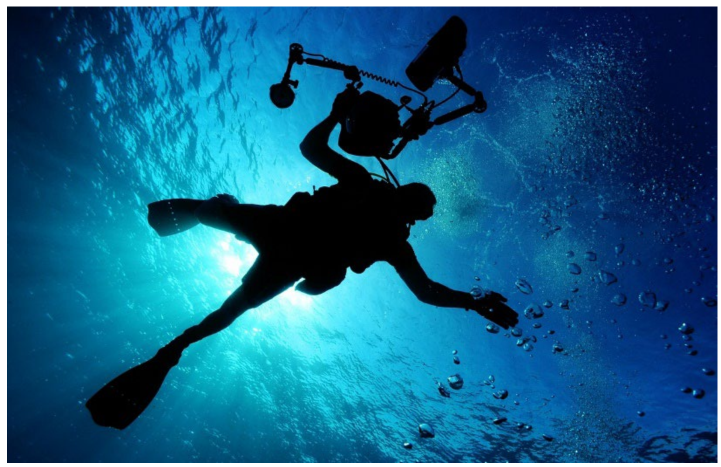

Figure 17. Underwater scuba diver with camera equipment.

Reason for priority: It is important to quantify the indirect costs and benefits associated with tourism and recreation to appropriately prioritize values and make well-informed decisions.

> **WCMAC:** With an increasing number of people visiting the outer coast, the threat of ecological disasters or damaging developments becomes even more significant. While unsure about the actions of local economic development councils, they generally do well with tracking these issues.

Offshore wind data gaps

- Potential spatial conflict between offshore wind and marine recreation and tourism
- Effect of offshore wind on the economic value of marine recreation and tourism
- Effect of offshore wind on the social value of marine recreation and tourism

Potential spatial conflict between offshore wind and marine recreation and tourism. Offshore wind activities raise concerns about potential conflicts across onshore, nearshore, and offshore areas.

Onshore, concerns focus on potential traffic impacts for recreational boaters and fishers accessing marinas and ports, as well as safety risks, reduced marina slips, and interference with vessel launches. However, some protections are in place to mitigate these issues. For example, any land or facilities funded by RCO on the coast have long-term obligations. If construction disrupts a funded site for more than 180 days, the responsible party must either restore public access to the space or provide a suitable replacement.

Nearshore, conflicts may arise from spatial competition, such as vessel route competition, and increased traffic to support offshore wind. Significant marine construction will also add a new layer of coastal conflict. These conflicts may result with potential displacement of recreational boating, effects to wildlife and fisheries, limitation of wildlife watching opportunities, visual effects to natural recreational experience, and boat and noise nuisance. Cumulative impacts of traffic from vessels and recreational activities must also be considered.

Offshore, little overlap with offshore wind activities is anticipated. Coastal recreation is primarily beach-oriented, and offshore recreational traffic is minimal. For example, surfers do not typically occupy the same areas as shipping lanes. While there may be more activity near the Columbia River, recreational activities like fishing are generally infrequent at offshore distances.

While data on recreational activities may exist, spatial data is likely currently unavailable. For example, while there may be information on the frequency and economic impact of surfing, specific data on surfing locations may not be readily accessible. However, state parks, counties, and local businesses, such as surf shops, may have information relevant information, such as popular surfing spots. The boundaries for recreational activities are already defined, which could help address some gaps. It is also important to note that data from state agencies may be limited, as RCO's data, for instance, does not include commercial activities like chartered fishing trips and whale watching.

Reason for priority: A comprehensive understanding of spatial conflicts between offshore wind development and marine recreation and tourism is essential for evaluating how proposed offshore wind projects may affect recreational opportunities, facilities, visitation patterns, and communities within the Study Area. This knowledge will help inform associated issues, such as the social and cultural impacts and displacement effects.

> **WCMAC:** The impact on recreation and tourism hinges on the location of transmission and landing lines. Areas with high-intensity usage are often near ports or infrastructure. Understanding the coastlines impacts, whether due to development or landing lines, is crucial. Activities prone to conflict should be identifiable. Considering certain activities are niche or seasonal, recognizing the variability in conditions and seasons necessary for recreation activities will be essential for an accurate assessment.

Effect of offshore wind on the economic value of marine recreation and tourism. Increased traffic associated with the construction, management, maintenance, and decommissioning of offshore wind facilities may bring economic benefits to certain areas, such as through increased port and slip rentals and use of other support services. Offshore wind activities may also support Washington's reputation as a pro-environmental state and attract more visitors. However, an influx of activities or conflicts with offshore wind development could also displace or diminish the appeal of recreation and tourism and thereby, negatively impact local economies. A decrease in visitors could translate into reduced revenue for businesses reliant on recreation and tourism. Data from the "Economic Analysis of Outdoor Recreation in Washington State: 2020 Update"[158] could be used for comparison.

Reason for priority: Offshore wind development could attract additional workers, potentially increasing local tax revenues and enabling greater investment in recreational amenities. Conversely, it might also deter tourists, leading to a reduction in local spending on recreational activities. The economic effect of offshore wind on recreation and tourism has the potential to significantly transform small coastal communities and warrants a thorough understanding.

> **WCMAC:** Shoreline effects or developments from activities like offshore wind projects can have significant economic consequences. In communities such as Ocean Shores and Westport, where tourism and recreation are key attractions, the presence of offshore wind developments may associate these areas with industrial activity. This could reduce the appeal of these communities, deterring both visitors and residents. A decline in tourism and recreation revenue could substantially impact the local economy. Additionally, disruptions to recreational activities may affect the types of skilled labor coastal communities attract. Recreation often plays a crucial role in drawing professionals who seek coastal living for leisure activities, and they may reconsider their relocation if offshore wind developments interfere with these pursuits.

Effect of offshore wind on the social value of marine recreation and tourism. It is uncertain whether offshore wind development could displace recreation participation enough to cause a decline in a specific area. Offshore wind structures are expected to be hardly visible from the coast, especially off a rural coastline. However, if this development makes something less appealing, people may avoid engaging in the affected recreational activity or visit the affected area unless they are residents or part of the community. More importantly, understanding people's reaction to this development is crucial. Discerning cultural perceptions towards offshore wind presents an obstacle to progress. Additionally, there is a limited availability of people. Offshore wind jobs, competing against what is already a small work force, may make it difficult for the recreation industry to hire staff and meet its needs.

Reason for priority: Offshore wind development could diminish the appeal of recreational activities and alter the character of a small community.

> **WCMAC:** Offshore wind can affect people's ability to engage in recreation for mental health purposes. For instance, surfers in the Westport jetty area may be unable to surf

158 https://static1.squarespace.com/static/561dcdc6e4b039470e9afc00/t/5f249326f05167773ab0774d/1596232557974/EconomicAnalysis-OutdoorRecreationWA_EarthEconomics_w0720-0.pdf

200 yards down the beach. Many recreational activities are restricted to specific locations due to environmental challenges.

Other Data Gaps

The following are the remaining data gaps:

General data gaps

- Geographic location of marine recreation and tourism
- Cultural and social value of marine recreation and tourism
- Public beach access location

Geographic location of marine recreation and tourism. There is a solid understanding of the geographic distribution of recreation and tourism. However, some minor gaps likely exist, particularly with smaller facilities in rural and remote areas. Efforts are actively underway to identify and document these facilities, such as RCO's collaboration with WA Tourism.

The Recreational Use Survey, conducted over a decade ago, is the most recent analysis of the geographic and spatial distribution of coastal tourism. Grays Harbor, Westport, Ocean Shores, and Long Beach were hotspots for recreation and tourism, with a significant focus on surfing. Based on past experiences, these hotspots are believed to remain the same. However, there is an interest to revisit and potentially update the survey given the changes in population dynamics and the impact of covid.

SCORP, developed in partnership with WA Hometown, offers a comprehensive analysis of recreational facilities and opportunities that exist across the Study Area. At a broad level, there is robust data on the types of activities occurring in various locations. However, complexities emerge with more in-depth analyses such as whether a land can be classified as a park.

Cultural and social value of marine recreation and tourism. There's a significant gap in understanding the cultural and social values related to marine recreation and tourism. However, RCO possesses various sources of data and information that could shed light on this gap. First, although not systematically analyzed, grant submissions often include letters highlighting the significance of certain activities to western culture and social values. Second, data from experience surveys used in preparing the 2023 SCORP offer insights into individuals' desired outdoor recreation experiences. Third, in 2019, RCO collaborated with the University of Washington on a report exploring the economic, social, and health benefits of nature connection, particularly through accessible green spaces in communities.

Other state agencies may have relevant information and data. Parks did a study a few years ago focusing on fostering and increasing participation in outdoor activities by communities of black, indigenous, and people of color (BIPOC). This study aimed to understand how Parks can alter or transform its planning, management, and operations to better cater to the needs of BIPOC communities. A dedicated program is in development. There are also ongoing discussions with state agencies such as Parks, DNR, DFW, RCO, and the Tribes around the impacts of recreation on Tribal interests, treaty rights, and Tribal spaces on public lands.

A significant body of academic research focuses on the public health benefits derived from green spaces and outdoor recreational opportunities. Access to green space is recognized as one of the social determinants of health. There are collaboration efforts by green spaces providers, public health agencies, and community planners to optimize community planning strategies that prioritize access to green spaces and outdoor recreation and promote physical and mental well-being. However, despite the academic work in this space, a gap remains in quantifying the social value of outdoor recreation and tourism. Anecdotally, individuals value having access to the coast and this access is understood to be one of the reasons why people choose to live in Washington.

Figure 18. Two people kayaking on the ocean.

The Coastal Economist also provides insights into cultural values associated with Washington's landscapes through an opportunistic survey. While this survey may introduce biases and potentially underrepresent Tribal perspectives, it offers a valuable insight into people's personal connections to the land and the reasons behind their affinity for Washington.

Public beach access locations. There is good data on public beach access locations, as analyzed in the 2023 Recreation and Conservation Plan[159] and provided in its Outdoor Recreation Inventory Dashboard[160]. Updates to this data rely on funding availability, typically occurring every five years. Recent updates uncovered records not previously found, a result of growing data availability rather than significant changes in access points. Nonetheless, public beach access remains vulnerable to threats. There is a need to assess whether access points are popular due to being hot spots or simply because they are the closest option available.

Offshore wind data gaps

- Conflict of offshore wind with culturally important areas
- Potential for offshore wind to displace existing marine recreation and tourism, excluding spatial conflict
- Ecological effects of offshore wind and its subsequent effects on marine recreation and tourism
- Effect of offshore wind on existing onshore infrastructure associated with marine recreation and tourism

[159] https://wa-rco-scorp-2023-wa-rco.hub.arcgis.com/documents/23587e5259f84294b040cf20b0838271/explore
[160] https://wa-rco-scorp-2023-wa-rco.hub.arcgis.com/apps/e4e1bcbee9d14a658c00e69f3988ff38/explore

Conflict of offshore wind with culturally important areas. The effect of offshore wind development on cultural assets is uncertain, and the availability of mapping data and identification of culturally significant areas along the coast is also unknown. Understanding culturally significant resources or wildlife is crucial. For instance, disruptions to fishing could have cultural implications for local communities. Nearshore, there are cultural landmarks like historical forts. Offshore, cultural assets primarily consist of shipwrecks, potentially catalogued by NOAA's heritage program. There are also spiritually significant islands offshore that could be affected by turbine visibility. The RCO maintains a cultural resources unit tasked with reviewing such resources, but their database is not publicly available. Other staff specializing in cultural resources may possess this information.

Potential for offshore wind to displace existing marine recreation and tourism, excluding spatial conflict. If offshore wind affects water or sediment movement, it could prompt changes in recreational activities. Shifts in currents and wave energy may displace surfing and other wave-dependent activities. Habitat impacts may affect species recreationally harvested and thereby affect activities like clamming and fishing. Additionally, people often seek pristine natural settings when spending time outdoors. If offshore wind structures impact aesthetics or the viewshed, it may drive users to other sites or halt activities altogether.

Offshore wind development may also affect onshore resources that existing recreational activities depend on. Staff shortages, greater demand for support services, and increased wear and tear of roads resulting from offshore wind projects could affect existing recreational activities. Competition over resources like boats, parking, and access points, as well as increased costs due to heightened demand, could also emerge and affect recreation. Access points are also constantly at risk. There is a need to determine whether access locations are popular because they are hot spots or simply because they are the closest option available.

Ecological effects of offshore wind and its subsequent effects on marine recreation and tourism. Offshore wind activities can harm habitat and species by increasing vessel traffic, noise, pollution, and potentially altering water movement. There is a lack of data on the effect of offshore wind infrastructure on coastal ecosystem functions and the subsequent effects on cultural, economic, and social values linked to a healthy functioning ecosystem. Areas with offshore wind infrastructure may also receive less direct sunlight which would affect species that photosynthesize and its predators. These effects can influence activities such as clamming and fishing, especially valued species like salmon. There would be a reliance on state agencies like Ecology to evaluate ecological effects and analyze how these effects cascade through existing recreational infrastructure, facilities, and opportunities.

Effect of offshore wind on existing onshore infrastructure associated with marine recreation and tourism. Building or improving recreation sites may be necessary to meet growing demand. If job opportunities rising in smaller coastal towns due to offshore wind development, it remains uncertain whether local communities and facilities can accommodate the influx of newcomers and provide adequate opportunities for them to pursue their recreational interests and hobbies.

Offshore aquaculture data gaps

- Potential spatial conflict between offshore aquaculture and marine recreation and tourism
- Potential for offshore aquaculture to displace existing marine recreation and tourism, excluding spatial conflict
- Effect of offshore aquaculture on the economic value of marine recreation and tourism
- Effect of offshore aquaculture on the social value of marine recreation and tourism
- Conflict of offshore aquaculture with culturally important areas
- Effect of offshore aquaculture on ecology and species important to marine recreation and tourism
- Effect of offshore aquaculture on onshore infrastructure associated with marine recreation and tourism

Potential spatial conflict between offshore aquaculture and marine recreation and tourism. What can be grown offshore is limited. Kelp and shellfish aquaculture facilities are typically situated closer to the shore. Offshore aquaculture is likely to focus on finfish. With offshore net pens, the closer they are to the shore, the greater the likelihood of conflict with coastal recreation.

Conflicts regarding offshore aquaculture activities and their impact on marine recreation and tourism span across onshore, nearshore, and offshore areas. Onshore, concerns focus on potential traffic impacts on recreational boaters and fishers accessing marinas and ports, as well as safety risks, reduced marina slips, and interference with vessel launches. However, some protections are in place to mitigate these issues. For example, any land or facilities funded by RCO on the coast have long-term obligations. If construction disrupts a funded site for more than 180 days, the responsible party must either restore public access to the space or provide a suitable replacement.

Nearshore, conflicts may arise from spatial competition, such as vessel route competition, and increased traffic to support offshore aquaculture. Significant marine construction will also add a new layer of coastal conflict. These conflicts may result with potential displacement of recreational boating, effects to wildlife and fisheries, limitation of wildlife watching opportunities, visual effects to natural recreational experience, and boat and noise nuisance. Cumulative impacts of traffic from vessels and recreational activities must also be considered.

Offshore, little overlap with offshore aquaculture activities is anticipated. Coastal recreation is primarily beach-oriented, and offshore recreational traffic is minimal. For example, surfers do not typically occupy the same areas as shipping lanes. While there may be more activity near the Columbia River, recreational activities like fishing are generally infrequent at offshore distances.

While data on recreational activities may exist, spatial data is likely currently unavailable. For example, while there may be information on the frequency and economic impact of surfing, specific data on surfing locations may not be readily accessible. However, state parks, counties, and local businesses, such as surf shops, may have information relevant information, such as popular surfing spots. The boundaries for recreational activities are already defined, which could help address some gaps. It is also important to note that data from state agencies may be limited, as RCO's data, for instance, does not include commercial activities like chartered fishing trips and whale watching.

Potential for offshore aquaculture to displace existing marine recreation and tourism, excluding spatial conflicts. If offshore aquaculture affects water or sediment movement, it could prompt changes in recreational activities. Shifts in currents and wave energy may displace surfing and other wave-dependent activities. Habitat impacts may affect species recreationally harvested and thereby affect activities like clamming and fishing. Additionally, people often seek pristine natural settings when spending time outdoors. If offshore aquaculture structures affect aesthetics or the viewshed, potentially by increasing debris, it may drive users to other sites or even halt activities altogether. The majority of current debris are fisheries-related by weight, with shellfish aquaculture being a significant contributor.

Offshore aquaculture may also affect onshore resources that existing recreational activities depend on. If staff shortages, greater demand for support services and resources, increased costs, and increased wear and tear of roads result from offshore aquaculture projects, existing recreational activities could be affected.

Effect of offshore aquaculture on the economic value of marine recreation and tourism. Aquaculture brings significant economic benefits, contributing substantially to the economy of Washington. With offshore aquaculture, increased traffic associated with the construction, management, maintenance, and decommissioning of offshore aquaculture facilities may bring economic benefits to certain areas, such as through increased port and slip rentals and use of other support services. However, an influx of activities or conflicts with offshore aquaculture development could also displace or diminish the appeal of recreation and tourism and negatively impact local economies. Offshore aquaculture may lead to increased beach litter, potentially driving up costs for visitors seeking cleaner beach environments. A decrease in visitors could translate into reduced revenue for businesses reliant on recreation and tourism. Data from the "Economic Analysis of Outdoor Recreation in Washington State: 2020 Update"[161] could be used for comparison. Evaluating the economic benefits of offshore aquaculture against the potential increase of debris and negative affects to recreational activities presents a significant challenge.

Effect of offshore aquaculture on the social value of marine recreation and tourism. The effect of offshore aquaculture on marine recreation and tourism will depend on the cultivated species. There may be an overall net benefit, but this hinges on what is grown. Certain types of

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161 https://static1.squarespace.com/static/561dcdc6e4b039470e9afc00/t/5f249326f05167773ab0774d/1596232557974/EconomicAnalysis-OutdoorRecreationWA_EarthEconomics_w0720-0.pdf

finfish aquaculture face social opposition, particularly those involving net pens due to concerns on its effect on native salmon populations and salmon recovery efforts. With potential to diminish the appeal of Pacific Northwest salmon for tourism promotion, charter fishing, and other water-based recreation activities, there are significant social, cultural, and economic repercussions. In contrast, shellfish aquaculture has the potential to enhance water quality.

If offshore aquaculture activities negatively impact recreation, it is uncertain whether they could substantially displace recreational participation enough to cause a decline in a specific area. However, if this development makes something less appealing, people may avoid engaging in the affected recreational activity or visit the affected area unless they are residents or part of the community. Understanding people's reaction to this development is crucial. Discerning cultural perceptions towards offshore aquaculture presents an obstacle to progress. Additionally, there is a limited availability of people. It is uncertain whether offshore aquaculture jobs, competing against what is already a small work force, would make it difficult for the recreation industry to hire staff and meet its needs.

Conflict of offshore aquaculture with culturally important areas. The effects of offshore aquaculture are uncertain. Restoring a healthy population of kelp or shellfish would greatly benefit cultures. However, if the wrong species are farmed or improper methods are used, it could introduce diseases and interfere with people's ability to recreate. It is crucial to understand resources or wildlife that hold cultural significance. Any disruption to fishing could culturally impact local communities. Potential impacts on native salmon, salmon recovery, and orca recovery carry significant tribal cultural relevance and historical connections.

Additionally, the availability of mapping data and identification of culturally significant areas along the coast remains unknown. Nearshore, there are cultural landmarks like historical forts. Offshore, cultural assets primarily consist of shipwrecks, potentially catalogued by NOAA's heritage program. There are also spiritually significant islands offshore that could be affected by turbine visibility. The RCO maintains a cultural resources unit tasked with reviewing such resources, but their database is not publicly available. Other staff specializing in cultural resources may possess this information.

Effect of offshore aquaculture on ecology and species important to marine recreation and tourism. Offshore aquaculture activities have the potential to alter the ocean's chemistry, the availability of different species, and ecosystem interactions. This could result in effects on fishing and clamming activities.

Effect of offshore aquaculture on onshore infrastructure associated with marine recreation and tourism. Building or improving recreation sites may be necessary to meet the growing demand associated with offshore aquaculture. If job opportunities rise in smaller coastal towns due to offshore aquaculture development, it remains uncertain whether local communities and facilities can accommodate the influx of newcomers and provide adequate opportunities for them to pursue their recreational interests and hobbies.

Resources

Table 48. Resources relevant to marine recreation and tourism.

NAME	ACCESS	TYPE	DESCRIPTION
Earth Economics: Economic Analysis of Outdoor Recreation in Washington State 2020 Update	https://static1.squarespace.com/static/561dcdc6e4b039470e9afc00/t/5f249326f05167773ab0774d/1596232557974/EconomicAnalysis-OutdoorRecreationWA_EarthEconomics_w0720-0.pdf	Report	Assesses the economic contribution of outdoor recreation in Washington.
Washington State Recreation and Conservation Office (RCO): 2023 Recreation and Conservation Plan	https://wa-rco-scorp-2023-wa-rco.hub.arcgis.com/documents/23587e5259f84294b040cf20b0838271/explore	Report	Outlines the plan for State investments in the conservation of public lands and development of outdoor recreation opportunities.
RCO: Economic Analysis of Outdoor Recreation in Washington State	https://rco.wa.gov/wp-content/uploads/2020/07/EconomicReportOutdoorRecreation2020.pdf	Report	This report estimates the economic contribution of outdoor recreation.
RCO: Economic, Environmental, & Social Benefits of Recreational Trails in Washington State	https://rco.wa.gov/wp-content/uploads/2020/01/HikingBikingStudy.pdf	Report	Evaluates the economic, environmental, and social benefits of outdoor recreation activities associated with trails and their nexus with the economy of Washington.
RCO: Health Benefits of Contact with Nature	https://rco.wa.gov/wp-content/uploads/2020/01/HealthBenefitsofNature.pdf	Report	This study is a literature review of the health benefits from nature contact.

NAME	ACCESS	TYPE	DESCRIPTION
RCO: Washington State Recreation and Conservation Plan	https://wa-rco-scorp-2023-wa-rco.hub.arcgis.com/	Website	Contains links to the Washington State Recreation and Conservation Plan, and the Outdoor Recreation Experience Survey and Provider Survey.
RCO: State of Washington 2022 Assessment of Outdoor Recreation Demand Report	https://wa-rco-scorp-2023-wa-rco.hub.arcgis.com/documents/3d212cbd61a6459ca5cba3a8feeba8c2/explore	Report	Discusses a survey that was conducted to assess the demand for outdoor recreation in preparation for the state comprehensive outdoor recreation plan.
RCO: Outdoor Recreation Inventory Dashboard	https://wa-rco-scorp-2023-wa-rco.hub.arcgis.com/apps/e4e1bcbee9d14a658c00e69f3988ff38/explore	GIS Dashboard	Includes data on the quantity and distribution of key outdoor recreation opportunities statewide. It also offers a service area analysis for outdoor recreation opportunities.
Recreate Responsibly Coalition	https://www.recreateresponsibly.org/	Website	Provides information on the Coalition's effort to advance responsible recreation.
Washington Department of Fish and Wildlife: Outdoor Recreation on State Lands in Washington	https://static1.squarespace.com/static/561dcdc6e4b039470e9afc00/t/62e43391a85a74075e952813/1659122600071/WDFW_FinalReport_small.pdf	Report	Estimates visitation to state-owned recreation lands in Washington and the effects of visitor spending on local and statewide economies.
Washington Hometown's Northwest Portal	https://www.northwestportal.com/	Website	Drawing from over 200 sources with over 20,000 records, provides interactive recreation maps.

NAME	ACCESS	TYPE	DESCRIPTION
Washington State Parks Visitation Reports	https://parks.wa.gov/about/strategic-planning-projects-public-input/reports-studies/visitation-reports	Website	Visitation data Washington State Parks collects for overnight and day-use visitors.

Culturally or historically significant sites

Key Data Gaps

General Data Gaps

- Location and spatial data of culturally or historically significant sites
- Status of culturally or historically significant sites
- Effect of climate change on culturally or historically significant sites
- Identification of traditional cultural properties

Offshore Wind Data Gaps

- Potential for offshore wind to disturb or damage culturally or historically significant sites
- Potential spatial conflict between offshore wind and culturally or historically significant sites

Other Data Gaps

Offshore Aquaculture Data Gaps

- Potential for spatial conflicts and disturbances or damage to culturally or historically significant sites from offshore aquaculture

Background

Disclaimer: Input was not obtained from Tribal staff regarding the state of knowledge and data gaps specific to culturally or historically significant sites. As a result, this section focuses on sites recognized by non-Tribal communities. While some information on Tribal culture, as provided in the MSP, is referenced for background purposes, it does not reflect the perspectives or knowledge of Tribal staff and community members. Meaningful engagement with Tribal communities is essential for a comprehensive and respectful understanding of these sites. Their insights, distinct from non-Tribal perspectives, are crucial for fully addressing these knowledge gaps.

The coastal regions of Washington are abundant with cultural resources, encompassing archaeological sites and traditional cultural properties linked to the cultural practices, traditions, beliefs, lifeways, arts, crafts, and social institutions of current and past, both western and Indigenous communities. Additionally, Washington's maritime history is deeply embedded along its coast, with numerous historic resources reflecting Euro-American maritime culture and shipwrecks.

For thousands of years, people have inhabited Washington's shoreline and used its marine environment. One of the earliest archaeological sites, located in the Ozette Reservation, indicates human presence in the area for at least the past 6,000 years, with possible settlement along the West Coast dating back to 14,500 BP (before present). The Indigenous Peoples of the lands now known as Washington have traditionally held deep relationships with the ocean and coastal lands, a dynamic that continues today. Archaeological findings, oral histories, and ethnographies document their marine-oriented activities, which served and continues to serve subsistence, cultural, ceremonial, and economic purposes. They historically harvested a wide range of marine species, including salmon, halibut, and shellfish, and continue to uphold aquatic species treaty rights for harvest today. Specialized gear for fishing, sealing, and whaling, such as seaworthy canoes and fishing hooks, were developed to support these activities.

Records of coastal and marine activities are documented across various types of archaeological sites and anthropological reports, including shell middens, villages, petroglyphs, burial grounds, fish weirs, canoe runs, and traditional cultural properties. The shoreline and uplands adjacent to the MSP Study Area contain numerous late prehistoric sites, spanning from the intertidal zone to several kilometers inland. Notable sites listed in the National Register of Historic Places include the Ozette Indian Village Archaeological Site, Tatoosh Island, and the Wedding Rock Petroglyphs. Large middens discovered in La Push further illustrate the extensive use of the ocean by Indigenous Peoples. There are likely undiscovered coastal archaeological sites in the area.

Due to historical sea level changes, it is likely that prehistoric Indigenous archaeological sites are now submerged beneath the ocean. Around 19,000 BP, the sea level was significantly lower, with the shoreline up to 30 miles offshore from the present-day coast. As sea levels rose over time, occupants were pushed inland. The Bureau of Ocean Energy Management (BOEM) modeled paleo shorelines from 19,000 BP to 1,000 BP to show historical shoreline shifts. Their analysis suggests that much of the Study Area has a moderate probability of containing preserved submerged prehistoric sites, with a slightly higher likelihood of preservation toward the southern regions.

The rich maritime history of Washington’s Pacific coast that began with its original inhabitants, the coastal Tribes, evolved with European colonization starting in 1579. Mapping efforts began in the late 1700s, and Euro-American settlement further established in the 1850s, leading to Washington's statehood in 1889. Maritime trade, commerce, processing, and resource extraction grew and prompted the construction of lighthouses, such as Cape Disappointment, and lifesaving stations. Additionally, as communities developed along the coast, the rise of industries such as canneries, mills, and shipyards, along with the growth of recreational boating and tourism, shaped the coastal economy, history, and culture. Today, industries like shipping, fishing, aquaculture, and tourism remain vital.

Historical resources along the coast, including lighthouses, historic districts, and unique buildings, connect the present with the past. Several sites are listed on the National Register of Historic Places and the Washington Historic Register, with many more recorded in the Washington Historic Property Inventory. In addition to land-based historical resources, there are underwater resources such as shipwrecks. The Washington coast is known for its treacherous waters, characterized by fog, strong currents, sand bars, and a rugged coastline, which historically made navigation difficult. Between 1808 and 1972, over 180 ships were reported wrecked or lost in or near the Olympic Coast National Marine Sanctuary, including clippers, steam freighters, fishing boats, and barges. The Columbia River bar, located at the southern end of the MSP Study Area, is considered the second most dangerous bar crossing globally, contributing to numerous shipwrecks. While some shipwrecks have been discovered, many remain uncharted, with only a fraction of the losses documented in the area.

Historical places, archaeological sites, and traditional cultural properties encompass locations of cultural identity, spiritual significance, historical origins, and aesthetic value. These sites may be at risk from new uses affecting the seafloor or from visual disturbances caused by offshore developments. Integrating cultural landscapes into marine management is crucial. The Department of Commerce and the Department of the Interior developed the Cultural Landscapes Approach[162] (CLA), a method to incorporate Tribal knowledge and cultural heritage into marine management decisions. This approach may be beneficial for Washington State when evaluating new ocean and coastal projects.

[162] https://marineprotectedareas.noaa.gov/toolkit/cultural-landscape-approach.html

Key data gaps

The following data gaps, listed without rank, were identified as having the highest interest among those related to culturally or historically significant sites:

General data gaps

- Location and spatial data of culturally or historically significant sites
- Status of culturally or historically significant sites
- Effect of climate change on culturally or historically significant sites
- Identification of traditional cultural properties

Location and spatial data of culturally or historically significant sites. Cultural or historical sites encompass a variety of locations, such as shipwrecks, naval planes, military installations, old forts, original lifesaving stations, World War II outlooks, canoe landing sites, and submerged cultural sites significant to Tribes. Some location or spatial data are available. For example, there is a general idea of the location of some shipwrecks; however, only 9 have been located thus far. Other historical shipwrecks predating 1972 are expected to exist. Submerged or underwater archaeology typically occurs at the university level or through NOAA surveys. As another example, there are three sites—Tatoosh, Wedding Rock, and Ozette—that are listed on the national historic register. The Ozette Tribal Village was buried by a landslide 500 years ago. Tens of thousands of artifacts, unearthed in the 1970s, are preserved and stored at the Makah Cultural & Research Center. [163]

Information about historic or culturally significant sites and specific locations is shared sparingly. There is a deliberate practice of protecting cultural and historical information from the public to prevent potential disturbance or harm to these sites. This approach aims to maintain control and safeguard these locations from unintended impacts. However, there are resources available. The Department of Archaeology & Historic Preservation (DAHP) manages the Washington Information System for Architectural and Archaeological Records Data (WISAARD)[164], a comprehensive database housing information on archaeological sites, historic properties, and cultural survey reports. The accuracy of the data depends on the quality of submissions, which are collected through a controlled, professional crowdsource approach. Additionally, the Washington State Archaeological Predictive Model that was integrated into WISAARD provides data on the likelihood of encountering archaeological sites.

WISAARD categorizes data into pre-contact and post-contact periods. Extensive onshore data is available from records of past projects and surveys. In comparison, offshore data is notably scarce, limited mostly to sporadic reports of shipwrecks. While DAHP requires archaeological surveys for land-based projects, surveys for oceanic and submerged areas are not typically mandated due to high costs and DAHP's lack of reliable predictive modeling for offshore sites.

[163] https://makahmuseum.com/about/ozette-archaeological-site/
[164] https://dahp.wa.gov/project-review/wisaard-washington-information-system-for-architectural-and-archeological-records-data

There is a significant unknown regarding undiscovered sites in deep waters, a consistent data gap from the northern to the southern shorelines of Washington. There is also a significant absence of information on precontact offshore sites. This disparity results in a notable imbalance in the types of sites documented by DAHP.

While some data is available, the full cultural landscape is not yet fully understood. For instance, numerous paleo shorelines and other cultural sites exist, yet their complete extent remains unclear. The geographic extent of cultural or historic submerged resources is also a significant data gap. The location of the different Tribal settlements that have existed at varying sea levels over time are also unknown. The Makah Tribe has conducted some studies along a portion of the coast. This data is primarily retained within the Tribe and select agencies. The Bureau of Ocean Energy Management (BOEM) is also collaborating with coastal treaty Tribes, particularly the Quinault Indian Nation, to understand this information in relation to potential ocean development.

Additionally, while this data gap primarily pertains to geographic sites, tangible and intangible heritage also holds significant value. This encompasses traditional knowledge related to fishing practices and Indigenous advancements in fishing technology over time. Some Tribes have utilized artifacts, such as contents from middens, to support their claims in legal proceedings. Although there is no dedicated, ongoing effort to document or interview individuals regarding this information, Washington Sea Grant periodically engages in such activities.

Feedback on importance: The most significant data gap is the lack of knowledge about the locations of cultural and historical sites offshore. Identifying these sites is the critical first step. Understanding the spatial distribution of sites enables assessment of potential impacts and informed decision-making. Developing a predictive model would be the next step. However, locating submerged sites is a substantial undertaking that will require collaboration with academics, federal agencies, Tribes, and interested or affected parties. It is promising that BOEM is actively working on this issue.

Status of culturally or historically significant sites. The availability of data on the status of a site depends on the definition of "status." There are many different types of status, such as site integrity, data review, and the review of status for records or sites. Site integrity includes assessing the structural condition, rate of degradation, and human impact on the site.

There have been limited opportunities to assess the status of submerged resources. In 2017, remotely operated vehicles (ROVs) were employed to examine the United States Ship (USS) Bugara, a sunken submarine located 735 feet off Cape Flattery, in collaboration with United States (US) Navy partners. Submerged cultural sites buried under sediment generally benefit from greater preservation.

DAHP collects data on the historic and archaeological resources they manage. Evaluations rely on individuals' opinions and observations. Site impacts are difficult to calculate because data collection is often ad hoc. Except for rivers under federal oversight, which are monitored annually for damage or looting, there is no systematic data collection for other sites. Site revisitation is typically driven by specific projects. Additionally, collected data are not tallied and there is no system to track metrics like the presence, absence, or continued existence of sites. There is also no formal scoring system for site integrity. Developing such a system would require a reevaluation of each site.

Feedback on importance: Establishing a baseline is essential; however, this type of information is not easily quantifiable.

Effect of climate change on culturally or historically significant sites. There is a need to understand how climate change affects the rate of degradation, considering factors such as material type, biogenic growth, and material composition. Efforts are underway to understand the impact of climate change on historical and cultural sites. Studies are being conducted on inundation patterns, site elevation, and site locations. Preliminary data has been analyzed on a few occasions.

The most significant impact is likely erosion which is complex to assess. Increased storm and wave energy may erode or compromise coastal locations containing petroglyphs and historical village sites. Increased storm activity can also impact nearshore shipwrecks by breaking them up and washing them ashore. Shipwrecks are sometimes discovered during storms, leading to subsequent searches offshore. For example, a shipwreck near Astoria was found following a storm. Additionally, particularly for wooden-hulled ships, changing ocean chemistry could affect degradation rates. Coastal islands and nearshore areas are also at risk from sea level rise, which threatens cultural sites and graves located in these regions.

In addition to direct effects from climate change, human responses to climate change, such as the construction of bulkheads and hardscaping, can also have significant impacts. The measures people take to protect their properties and public assets can profoundly affect the environment and surrounding areas.

Five years ago, available data was insufficient, but recent data collection has improved, allowing for more precise analyses and the collection of sufficiently detailed data to evaluate archaeological sites. Addressing this issue systematically is a priority but requires additional funding and staffing to effectively focus on and manage.

Feedback on importance: There is limited understanding of the effect of climate change on cultural and historical sites. The anticipated effects are expected to be most significant along the shoreline. Increased storm activity could expose previously protected sites, and heightened wave action may exacerbate erosion along the shoreline. Pre-contact sites that are fully submerged or buried, such as stone tools, are somewhat protected from climate change impacts. However, they may still be affected by changes in ocean salinity which could influence their preservation. To accurately gauge these impacts, more information is needed about how climate change affects shorelines. Although some relevant information is available through climate vulnerability assessments, it must be assessed against archaeological site predictive models, which are still lacking. Data from Europe, Asia, Australia, and the Pacific Islands could provide valuable insights.

Identification of traditional cultural properties.

NOTE: This data gap was identified by non-Tribal members. Their feedback is provided below. However, readers are encouraged to engage directly with Tribal governments for accurate and comprehensive understanding of their perspectives and concerns regarding this data gap.

Although there are efforts to gather relevant data and information, there is a need to identify traditional cultural properties. Traditional cultural properties are not limited to archaeological sites. They may include significant rock formations or locations tied to Tribal stories, which are not quantifiable or physically tangible. Natural resources are also integral cultural resources, including harvest and fishing areas. Viewsheds are also significant. Maintaining a landscape that visually aligns with descriptions from oral histories is essential. For example, locating open water resource harvest area may require unobstructed views of shoreline features. The overall feel of an area can also influence the success of a harvest.

Tribes are increasingly advocating for the protection of archaeological sites, their traditional harvesting grounds, and the resources they collect. Many of these areas continue to be used under the protection of treaty rights upheld by court decisions. Land managers and permit agencies may require direct consultation with Tribes to identify important resources areas.

Feedback on importance: Understanding traditional cultural properties is crucial. Experience with wind and solar projects on the East coast has shown that the most significant challenges often arise from culturally sacred areas, not from archaeological sites where mitigation strategies are available. Identifying these sacred areas and understanding their limitations is a critical first step. Spatial conflicts will vary depending on the type of offshore use—such as offshore wind, which may have a visual impact, versus kelp farming. Tribes will perceive these uses differently. It is essential to identify which uses are acceptable to Tribes and consult with them early and meaningfully to explore ways to minimize impacts. Mitigation may not be possible for certain cultural losses.

Offshore wind data gaps

- Potential for offshore wind to disturb or damage culturally or historically significant sites
- Potential spatial conflict between offshore wind and culturally or historically significant sites

Potential for offshore wind to disturb or damage culturally or historically significant sites.

While the harsh marine environment can lead to natural degradation of structures like shipwrecks over time, offshore wind projects may cause disturbance or damage to artifacts and sites associated with paleo shorelines, many of which have not yet been identified. There are approximately 100 underwater archaeologists, making it a relatively uncommon profession. This scarcity restricts the capacity to thoroughly assess potential impacts. As cultural and historical sites are non-renewable resources, any damage from such activities constitutes permanent harm.

Anchor points, cables, and connections associated with offshore wind projects have the potential to impact sites. The precise effects, such as cable installation, are difficult to predict due to the lack of available data of cultural and historical sites. However, there will be effects if offshore wind structures are located over ancient offshore landforms which provide insights into how an area was originally colonized. There are thousands of archaeological sites on the old shoreline that could be affected by the placement of cables or anchors. Typically involving academic studies, identifying and locating these sites will be challenging and will likely cost more than traditional land-based archaeological surveys. Although the technology to conduct such surveys is available, it is not commonly used in daily archaeological practice. Some ad hoc studies have been conducted in various areas. There is a need to for a coordinated effort to map this information and consider cumulative effects.

Onshore aspects of offshore wind may also affect culturally or historically significant sites. Port developments related to these projects—such as worker housing and port expansions—could lead to increased activity, which has the potential to damage nearby sites. Additionally, if offshore installations are visible from shore and disrupt the viewshed, the visual impacts could affect traditional and cultural properties.

More broadly, the entire coastal area may be impacted. Beyond 100 feet from the shoreline, data availability on shoreline conditions diminishes, except in cases where high points such as islands have been studied. For these unstudied areas, the potential impacts are unknown. There have been a few academic studies that identified archaeological sites offshore. In theory, it is possible to create predictive models to assist in identifying areas with high potential impacts on cultural and historic sites. To conduct a predictive data analysis, environmental factor datasets and accurate data on sea level changes over the past 1,000 years are necessary. Given that sea levels were lower with the first inhabitants, the original shoreline was significantly farther out. While feasible to estimate historical water levels, there is also a need to determine which areas were potentially habitable. Addressing this question requires extensive research, time, and financial resources. Oregon State University is currently collaborating with BOEM to model the shoreline and culturally significant sites of the entire west coast. There is interest in collecting remote sensing and geophysical data off Taholah, WA.

Feedback on importance: Understanding the potential to damage cultural and historical sites requires first identifying the locations of these sites and evaluating the risk to areas likely targeted by offshore wind projects. Key considerations include the buffer zones around turbines and facilities. As these areas are restricted from public use, access will become more limited, potentially concentrating and shifting activities such as fishing, research, and non-consumptive recreation into adjacent areas, including those within the Olympic Coast National Marine Sanctuary (OCNMS). Mapping and predictive modeling are essential tools for this task.

Potential spatial conflict between offshore wind and culturally or historically significant sites. The lack of information on cultural and historically significant sites complicates the assessment of spatial conflicts with offshore wind projects. Under the National Historic Preservation Act of 1966 (NHPA), BOEM is mandated to ensure that cultural and historic sites are not impacted. There is currently a project by the Quinault Indian Nation that aims to understand ancient coastlines and further explore Tribal cultural landscapes, both tangible and intangible. This work will hopefully identify potential submerged resources and better inform offshore development.

More specifically, structures such as cable routes and new power hubs may affect cultural and historically significant sites. Additionally, security buffers around installations may preclude research into paleo shorelines and historical research and surveys important to Tribes and OCNMS. Onshore conflicts are also a significant concern, potentially even more pressing than offshore issues. When projects extend ashore, smaller counties, which often have limited staff and resources, are tasked with managing them. This was a significant concern during solar energy developments. While large energy projects typically receive federal oversight, smaller counties lack the capacity to conduct thorough reviews. It would be advantageous if the State could provide guidance and conduct cultural resource reviews for these projects. Alternatively, the allocation of funds to agencies such as DAHP for a dedicated position could allow consistent and focused review of such projects. In the absence of this, reviews may be inconsistent and subject to varying processes.

Feedback on importance: The potential for offshore wind development to conflict with cultural and historical sites cannot be assessed until their locations are known. Currently, there is insufficient information to begin this assessment. Mapping and predictive modeling are essential tools for addressing this gap.

Other Data Gaps

The following are the remaining data gaps:

Offshore aquaculture data gaps

- Potential for spatial conflict with and disturbance or damage from offshore aquaculture to culturally or historically significant sites

Potential for spatial conflicts and disturbances or damage to culturally or historically sites from offshore aquaculture. Offshore aquaculture could potentially disturb artifacts and sites associated with paleo shorelines, many of which have not yet been identified. As these resources are non-renewable, any damage caused by such activities would result in permanent harm. The lack of information on cultural and historically significant sites complicates the assessment of spatial conflicts with offshore aquaculture projects. Additionally, potential security buffers around offshore aquaculture installations may preclude research into paleo shorelines and historical research and surveys important to Tribes and OCNMS.

The installation of large net pens could significantly impact traditional gathering practices. Even if the effects are not immediately visible, changes in nutrient levels could have substantial consequences. Additionally, if offshore aquaculture leads to acidification, wooden or metal shipwrecks may be affected, though the specific effects are not well understood. There is existing literature on this topic.

Any interaction with the sea bottom can also have significant effects. For example, geoduck harvesting involves the removal of large quantities of sediment, which can disturb archaeological sites. Geoduck aquaculture has led to the collection of shipwreck information.

NOAA maintains an underwater obstruction database and routinely informs aquaculture leaseholders, as reviewed through SEPA, of potential shipwreck obstructions. Generally, DAHP recommends that leaseholders avoid these areas to protect resources and ensure safety. However, there have been no subsequent evaluations to determine whether shipwrecks are being impacted or avoided. The management of shipwrecks is complex, with some classified as archaeological resources and others subject to salvage or removal. Additionally, anchor points which may be necessary for offshore kelp aquaculture, may affect culturally or historically significant sites.

Offshore aquaculture could also affect onshore areas, particularly impacting access points where boats come ashore. This presents a major concern, as changes to boat entry and exit points have a high potential to impact archaeological sites. It is essential to ensure that this information is provided for all related projects.

BOEM is mandated under the NHPA to ensure that cultural and historic sites are not affected. There is currently a project by the Quinault Indian Nation that aims to understand ancient coastlines and further explore Tribal cultural landscapes, both tangible and intangible. This work will hopefully identify potential submerged resources and better inform offshore development.

Resources

Table 49. Resources relevant to culturally or historically significant sites.

NAME	ACCESS	TYPE	DESCRIPTION
Department of Archaeology & Historic Preservation (DAHP): Washington Information System for Architectural and Archeological Records Data	https://wisaard.dahp.wa.gov/Map	GIS Map	State's digital repository for architectural and archaeological resources and reports.
Makah Cultural & Research Center: Ozette Archaeological Site	https://makahmuseum.com/about/ozette-archaeological-site/	Website	Provides information and photographs on the Ozette Archaeological Site

Conclusion

Addressing data gaps is essential for effective ocean resource management. The limitations and varying quality of existing datasets impede the ability to fully capture the ocean's dynamic nature and its resources. This complexity arises from the intricate relationship of numerous factors, including physical forces such as currents and tides, ecological interactions among various marine species, and the significant influence of human activities, including fishing, shipping, and pollution. Changes in one area can have far reaching effects on others. For example, alterations in environmental parameters can impact species migration patterns, which in turn can affect local fisheries and the communities that depend on them. Comprehensive and accurate data is vital to understand these complex interactions and to develop effective management strategies.

This project gathered valuable feedback from a diverse group of experts, resulting in the identification and assessment of a total of 533 distinct data gaps. These experts come from various fields, including marine biology, oceanography, and fisheries management, each contributing unique perspectives and insights based on their specialized knowledge and experience. It is important to note that this feedback reflects the professional opinions of these experts and has not undergone factual verification. Nevertheless, their expertise is instrumental in providing an overview of the current state of knowledge related to the ocean and its resources, highlighting specific areas that warrant further investigation.

It is also crucial to recognize that the identified data gaps do not represent a comprehensive list. The ocean is a vast and complex system, and as research advances and methodologies improve, new gaps in knowledge are likely to emerge. Additionally, the dynamic nature of marine environments, influenced by factors such as climate change, technological developments, and evolving human activities, can shift the status of existing data gaps.

This report on data gaps serves as a foundational tool for assessing the current landscape of existing knowledge. It aims to guide future research initiatives that promote sustainable ocean management practices and facilitate effective responses to ongoing and emerging challenges. The next step is to develop a comprehensive strategy to address the identified data gaps. This process will require collaboration among local, state, federal, and Tribal staff, as well as academic institutions, non-profit organizations, and various industries. Diverse perspectives and expertise should be brought together to ensure that a wide range of insights is integrated into this effort.