In: Coastal Ecosystems
Editor: María-Teresa Sebastiá
ISBN: 978-1-63482-151-3

Chapter 3

STRATEGIES TO INCREASE THE IMPACT AND EFFECTIVENESS OF LONG-TERM MARINE MONITORING PROGRAMS

Christopher Krembs[1] and Brandon Sackmann[2]

[1]Marine Monitoring Program,
Washington State Department of Ecology,
Olympia WA, US
[2]Integral Consulting Inc, Olympia WA, US

ABSTRACT

Long-term marine monitoring data are indispensable for establishing baselines, trends, and for understanding the dynamics and variability of coastal marine systems in response to distant oceanic and climatic factors and ultimately to influences of man. Despite its undisputed value as a quantitative instrument, maintaining and committing to long-term monitoring programs remains challenging and the difficulties are often exacerbated by direct resource competition with short-term studies and modeling efforts. Specific challenges for long-term monitoring include an inconsistency in funding and staff, changes in sampling and analytical methods as technology evolves, lack of standardized procedures to assess and convey information about data quality, the wide range of temporal and spatial scales that need to be characterized, and trade-offs between measurements that provide overall representativeness versus those that are more sensitive to the detection of local human impacts and perturbations.

We report on recent efforts to re-imagine and restructure an existing long-term marine monitoring program to attain high public visibility and greater scientific impact. The improved design builds upon two strengths of the program.

(1) A combined presentation of present field conditions and 14 years of historical data.

(2) A spatial and temporal coverage that matches the scale of climatic and oceanic influences that permeate the monitoring network.

Strategically the restructured marine monitoring program, in lieu of competition, is contributing to and improving upon the quality of shorter-term, journal driven, research. We achieve this by (1) rapidly communicating present information to scientists in the region so that they can effectively respond to changing environmental conditions (2) providing extended spatial and temporal context through data products that provide quantitative assessments of longer-term, baseline conditions (3) challenging new and ongoing studies to collect representative data and interpret findings in context of larger scale variability and spatial structure, and (4) improving data quality and turnaround by QCing and analyzing data in an accelerated time frame.

Key to the success of this program is a highly visible web-disseminated report that educates the broader environmentally interested community about current conditions in Puget Sound and Washington's coastal estuaries. Eyes Over Puget Sound (EOPS) integrates disparate sources of information into an image-rich, story-driven, surface condition report published two days after visiting the field. The report leverages spatially and temporally nested information from aerial photographs, ferry-based monitoring, satellite remote sensing, moorings, traditional CTD profiles, and discrete water samples. EOPS is an environmental news story that accurately reflects region-wide conditions, and creates impact on a very tangible, human scale. EOPS is a growing source of educational material and serves as an access point for a wide range of long-term monitoring information products. Half a million downloads per year speak to the success of the program.

Keywords: Eyes Over Puget Sound, coastal environments, marine monitoring, information products, aerial photographs, remote sensing

INTRODUCTION

Long-term marine monitoring programs are indispensable for understanding complex coastal environments. They provide an objective temporal and spatial context that can both support and challenge our understanding of these systems. That said, one of their greatest shortcomings is that monitoring programs are often marginalized by scientists and the public due to low visibility and a limited or delayed throughput of information that highlights their importance. In this chapter we provide an example that illustrates how such challenges have been overcome using a simple and cost effective tool, the power of images.

By combining long-term monitoring and an image rich marine condition report, the Washington State Department of Ecology's (WA Ecology) Marine Monitoring Program brought together two concepts that greatly increased the program's performance, public and scientific recognition and value, and repositioned the program as an important information and data provider. Fundamental to the success of the program has been (1) team spirit amongst program personnel and management inspired by increased public visibility and (2) a well-crafted, mature workflow for creating a suite of standalone information products that comply with today's visually- and headline-driven public reporting style.

Combining environmental news with long-term monitoring data has become an essential tool for developing and maintaining WA Ecology's Marine Monitoring Program which detects and describes subtle environmental changes by interpreting the wealth of historical information that the program has collected. Information is provided by a succinct and straightforward narrative that leverages a variety of datasets to describe unexpected patterns and trends in marine conditions across many temporal and spatial scales. The narrative tells an 'environmental story' that resonates with both scientists and the environmentally-minded public. Effective information products that convey an important story can rejuvenate a program and push it towards increased quality, productivity, efficiency and effectiveness (Figure 1).

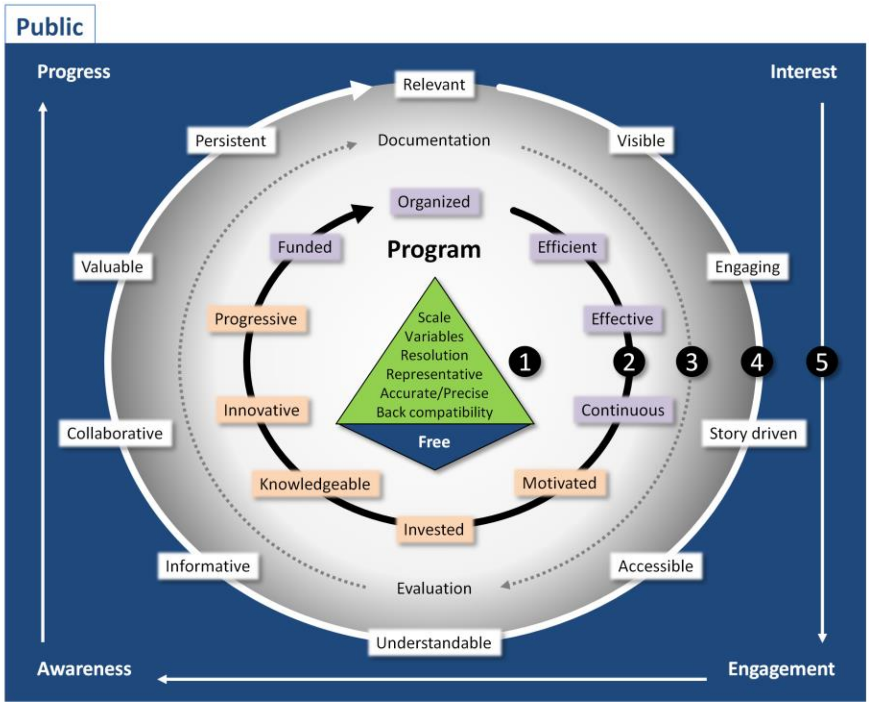

Figure 1. To be relevant for managing coastal environments marine monitoring programs need to find a constant balance between (1) the scientific integrity of the data that are collected, (2) the organization of the work flow, (3) the continuous documentation of activities and products, (4) effective engagement with the public, managers and scientific peers, (5) and a commitment to making environmental progress as well as a public and scientific impact. Public visibility and interest helps guide the choice of information that is offered and shapes the overall workflow. The program's iterative design, as illustrated here, leverages historical information and a rapid reporting schedule to create a monthly report that is visually engaging. (1) The scientific design matches the scale of processes to characterize variability and trends throughout the system in a way that can stand up to peer review and scientific scrutiny. (2) The organization of the workflow focuses on developing and delivering a suite of novel information products. Monthly reports reach the public, generate increased visibility for the program, and encourage team members to combine information across multiple scales; it is important that each month's 'environmental story' be put into a larger temporal and spatial context. Teamwork and constant review helps optimize the workflow, data quality, and overall transparency of the process. New data analysis methods, presentation techniques, and communication styles are used to meet evolving expectations for how people prefer to receive environmental news. (3) To ensure backward compatibility all analytical sampling methods, instrument calibration information, and routine sensor performance checks are documented and reviewed monthly; all activities are documented in transparent, Internet-accessible formats. Transparency allows for public and scientific scrutiny and encourages overall acceptance and confidence in the program's performance. (4) A visually attractive, succinct, factual, and timely reporting style engages the public and supports other monitoring programs working in Puget Sound. Scientific value, integrity, and environmental representativeness combined with the appropriate communication strategy fosters (5) public and academic engagement, awareness, and ultimately progress towards understanding and improving the quality of Puget Sound's marine waters.

Challenges for marine monitoring programs range from problems with internal organization and performance, to difficulty developing and sustaining an effective product-oriented workflow, to an inability to maintain scientific integrity and a favorable external perception. These challenges are particularly difficult to address as scientific interests evolve, data volumes increase, staffing levels fluctuate, and programs grow in overall complexity. Monitoring programs may also be burdened with additional sampling activities to increase their perceived value in the short term, adding to the challenges and resource constraints already present. These struggles can result in high staff turnover and loss of institutional memory which encourages a downward spiral in performance and may lead to the ultimate demise of the program.

With this in mind, it is important that the value of long-term monitoring be communicated and that programs start with a well crafted scientific design to account for variability in space and time at the appropriate scales. Equally important are data and method backward compatibility, the diligent documentation of modifications, and the continuous scrutiny of data quality and resources to maintain program integrity.

It is crucial that long-term monitoring efforts focus on the merits of their programs and frequently evaluate and revise their long-term goals. Critical self-evaluation helps programs stay relevant in the eyes of the scientific community and allows new ideas and interests to be incorporated. It also ensures that program staff are working at the 'cutting edge' and are critically engaged. With increased relevance the team is self-motivated, more interested in the results, and consequently more knowledgeable and invested.

External perception is a powerful motivator that can either highlight or cast doubt on the integrity of a monitoring program. Constant adaptation to prevailing public communication styles is of paramount importance. It no longer suffices to find real-time data on the Internet and present it without the context of a larger story. Information must engage and capture an audience's attention, be easily understood, and summarize information about present conditions in the context of historical insights. Since monitoring programs are evaluated by scientists, managers, and the public, information must presented intuitively to users with different educational backgrounds. Here we show how the marriage between science and the art of photography can capture the beauty and complexity of the marine environment in ways that written narrative simply cannot achieve. This marriage is an angle that monitoring programs can exploit to attain greater visibility and ensure that their efforts are valued.

Environmental Setting and Components of the Marine Water Monitoring Program of the Washington State Department of Ecology, USA

Puget Sound is a large and commercially utilized urban fjord situated in western Washington, USA. To understand and manage water quality in Puget Sound (whether its nutrient enrichment, low dissolved oxygen conditions, the transport of toxic chemicals, harmful algal blooms, or a host of other concerns [1]) it is imperative to understand water quality and patterns of circulation within the system. This includes the movement and exchange of water that results from seasonal river inputs and the input and exchange of saltwater from the ocean within the context of climate variability [2].

Ocean water makes its way into Puget Sound via Admiralty Reach, a shallower area at the mouth of Puget Sound that separates it from the Strait of Juan de Fuca. The variable movement and transport of upwelled water from the Pacific Ocean affects water quality in Puget Sound and influences its nutrient, oxygen, CO_2 and acidity balance [2]. The perennial influence of the Pacific Ocean must be quantitatively understood to appreciate the relative impact that terrestrial, climatic, and anthropogenic processes have on Washington State's marine water quality. Understanding these large-scale climate fluctuations has important predictive benefits for aquaculture and ecosystem restoration activities throughout the region.

The influence of the Pacific Ocean on water quality has become a focus of marine monitoring in Puget Sound [3]. Data from 1999 to 2014 show a significant correlation between temperature, salinity and dissolved oxygen with ocean climate indices such as the Pacific Decadal Oscillation, North Pacific Gyre Oscillation and anomalies in coastal upwelling [4]. Pacific Ocean boundary conditions can either mitigate or amplify negative effects on water quality caused by other processes. For example, when deep water from the Pacific Ocean makes its way into Puget Sound the intrusions of upwelled water occasionally promote hypoxia and even fish kills in particularly sensitive sub-basins.

Nutrient concentrations and their respective ratios have been steadily changing in step with regional population trends and fluctuating boundary conditions [4]. Changes to the planktonic food web are manifesting at the surface of Puget Sound in the form of extensive *Noctiluca* blooms [5], jellyfish aggregations [6], an increased abundance of macroalgae, and an overall loss of fish abundance; symptoms that have been observed in many other eutrophied coastal environments [7]. Long term monitoring data are indispensable when it becomes necessary to objectively and quantitatively place observed changes in water quality into an extended spatial and temporal context. In addition, sustained monitoring allows us to question and re-evaluate our current understanding of the system.

The long-term marine monitoring program at WA Ecology started in 1973. Since then, it has been subjected to a number of external evaluations and has made continual improvements to keep pace with developing methods and technologies. The program consists of 5 permanent support staff, one lead oceanographer and one manager. Funding is secured through a combination of State General Funds (appropriated through the Washington State legislature) and a variety of federal funding sources.

WA Ecology currently employs a multi-pronged strategy to monitor marine waters of Puget Sound over long time scales, relying on monthly samples collected by seaplane across a network of long-established sampling stations throughout the Sound (Figure 2). A CTD package is lowered through an opening in the floor of a Beaver Haviland seaplane (Figure 3A) using electrical winches to full water column depth in sheltered water bodies [8]. Routine sampling from ships is performed in the more open waters of the Strait of Juan de Fuca. Long-term monitoring data are complemented by process oriented monitoring that relies on moorings (both surface- and bottom-mounted) [9] and collaborative en route ferry monitoring systems [10].

Conditions in Puget Sound are inherently variable and require a comprehensive monitoring effort to capture and describe the dynamic characteristics of the system. The data that are collected provide insight across a wide range of spatial and temporal scales and facilitate a deeper understanding of past, present, and likely future of water quality in the context of the North Pacific's oceanic influence, changing land use patterns, and human pressures. Quantifying large-scale influences over decades is an important focus as is the programs efforts to understand and characterize human from natural influences on water quality in Puget Sound [4].

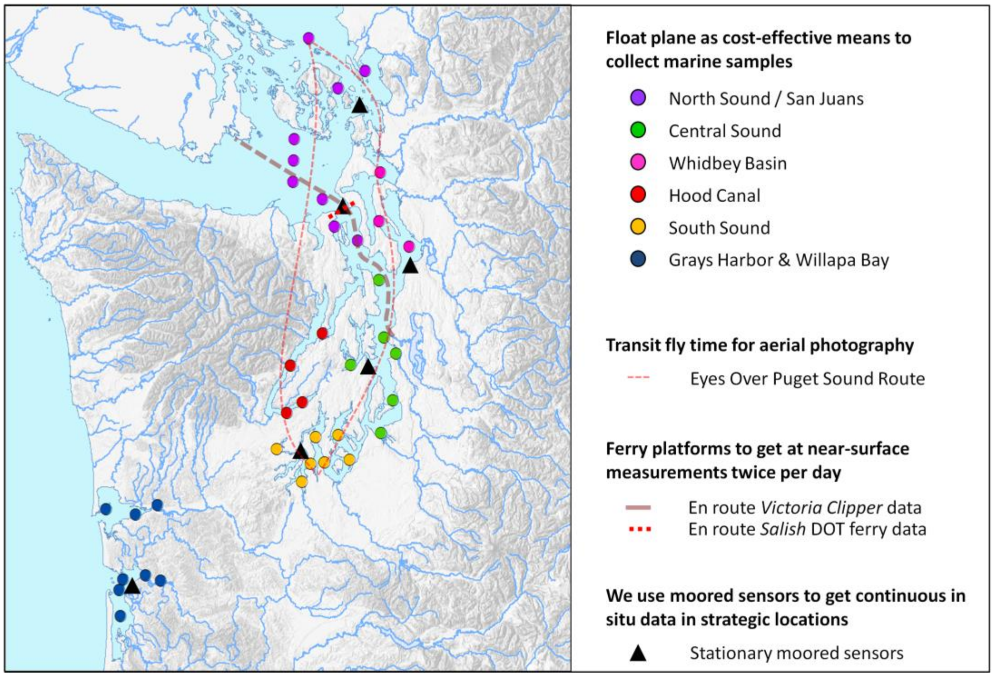

Figure 2. Marine monitoring stations of the Washington State Department of Ecology are visited monthly by seaplane and cover the greater Puget Sound region from the Canadian border to Olympia, WA, USA, including two coastal Bays. The scale of the monitoring network requires four flights per month, each with separate destinations. During transit to and from each set of sampling locations aerial photographs are taken from 2500 ft to document near surface conditions. The addition of aerial photography to the flights is a cost-effective way to leverage existing sampling infrastructure. Two en route ferry systems have also been implemented to monitor surface conditions throughout Puget Sound and to measure the exchange of water across Admiralty Reach, a point of water exchange between Puget Sound and the Strait of Juan de Fuca. Moorings have been strategically located to report on the water and solute exchange within the Puget Sound basin.

A new data communication strategy was developed and implemented in 2009 and has gained great traction and public resonance. Monitoring programs need to share information and it is important that data are reported in a format that is interchangeable amongst different teams. Standardized methods, routine sensor performance tests, an accessible and transparent data structure, and a monthly forum to discuss recent observations are indispensable foundation blocks of the program [8].

Data volume and variability can be overwhelming to audiences. The strength of Ecology's long term monitoring program is its focus on conditions and trends that fall outside of expected ranges (i.e., anomalies). The program leverages the well-characterized conditions of its monitoring network to help put new observations into a statistical context. WA Ecology relies on a team of knowledgeable individuals to review conditions on a monthly basis. A larger temporal and spatial perspective helps the team assess the quality of new observations and develop an up-to-date understanding of present conditions that can be shared with scientists and the public in a standardized online format.

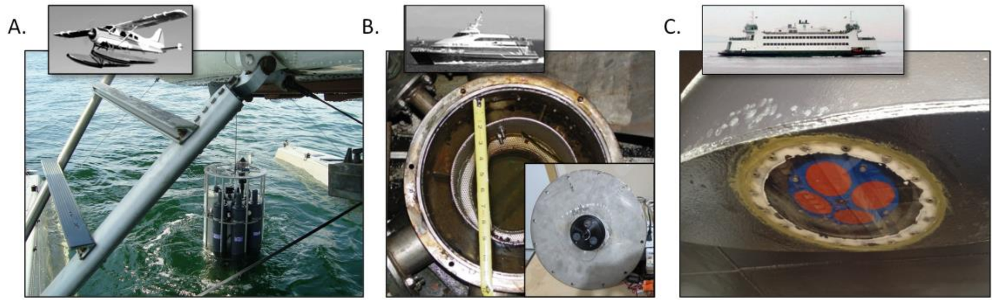

Figure 3. The marine monitoring program relies on three important platforms to take routine in situ measurements. A. A chartered seaplane deploys a CTD package to full depth carrying physical, chemical and bio-optical sensors and Niskin bottles that provide samples that are analyzed for 15 discrete chemical variables. B. A fast passenger ferry traveling between Seattle and Victoria provides a platform for a bio-optical sensor package and thermosalinograph to describe physical and optical gradients along an 80 kilometer transect. C. A ferry-based ADCP measures currents to full depth across a narrow constriction (Admiralty Reach) that is critical for characterizing day-to-day water exchange between Puget Sound and the Strait of Juan de Fuca.

Rapid data product development requires a high quality historial dataset. Well documented and reviewed quality assurance procedures, frequent sensor performance and analytical lab checks, and cross checks amongst different variables help ensure ongoing data quality. Additional elements of the monitoring network include (1) a pair of en route ferry systems (Figure 3B, C) that provide information to characterize surface variability and water exchange in Puget Sound [10] on a larger scale, and (2) a collaborative mooring program with the Applied Physics Laboratory of the University of Washington that uses bottom-mounted moorings in Admiralty Inlet to characterize the influence of the Pacific Ocean on Puget Sound's marine water quality. These efforts provide complementary datasets that are integrated with monthly monitoring data to develop an empirical model to predict intrusions of corrosive, low oxygen water into Puget Sound [2].

An Effective Communication Strategy Can Increase the Relevance of Marine Monitoring Programs

Increasing the perceived value and relevance of marine monitoring efforts with visually engaging information can have many positive benefits. Marine surface waters are in direct contact with people and are highly visible to the public (Figure 4). At the surface blooms, turbid river plumes, mats of macroalgae, large accumulations of jellyfish, and human-caused oil sheens provide a wide variety of features that can be documented to characterize surface water conditions in Puget Sound and generate immediate interest. Image-rich information and sparse text facilitate integration into social media and other types of electronic news reports. To extend scientific and public impact the program embraces web and social media as a way of ensuring that efforts remain highly relevant, visible, and accessible to environmental management and scientific endeavors in the region, (e.g. via monthly surface condition reports: Eyes Over Puget Sound (EOPS) [11, 12, 13], the Marine Water Conditions Index

[14] and contribution to reports of the Puget Sound Partnership [15] and the Canadian State of the Ocean Report [4]).

Figure 4. Examples of surface features that are documented from unique vantage points of A. aerial photographs, B. a sea plane and C. from satellite. A. Extensive Noctiluca blooms routinely adorn the surface of Puget Sound in June, B. Strong sediment-filled plumes carrying glacial flour outline freshwater inputs into the estuary in summer, C. Landsat 8 captures high-resolution thermal imagery showing mixing in narrow passages (cooler surface temperatures) and stratification (warmer surface temperatures) in bays and inlets.

Eyes Over Puget Sound (Figure 5) averages half a million downloads per year and highlights WA Ecology's success with web-based information products. The monthly web report combines high-resolution aerial photos, satellite images, en route ferry data between Seattle and Victoria BC, and measurements from moored instruments. Each EOPS report strives to generate an appreciation for the various temporal and spatial scales of variability that are important for understanding water quality in Puget Sound. The reports embrace a nested communication strategy to highlight different levels of detail and interests. Recent observations are placed into historical context (e.g., heat maps are frequently used to visually emphasize anomalies that are making their way through the monitoring network) to generate an awareness of temporal scale. Regionally calibrated satellite products that combine data from ocean color sensors with daily bio-optical sensor data from a ferry-based monitoring system on the ground help provide greater spatial context. Combined, these innovative satellite products document the location, size, and movement of large near-surface water quality features (e.g., harmful algal blooms) which are captured on a finer complementary scale with aerial photographs.

EOPS has achieved a resonance with a large, environmentally-focused user base. The timeliness of each EOPS report (2-day turnaround) and the larger spatial and temporal perspective allows WA Ecology's Marine Monitoring Program to occupy an important niche of public and scientific interest. Key to the success of EOPS is a succinct and objective reporting style that is engaging to the public, management and scientists alike. Each EOPS report consists of (Figure 5.1) a cover photo and a summary page (Figure 5.2), and headlines to pull together information from more detailed chapters (Figures 5.3 - 5.8) that include:

(5.3) a personal flight log provides a first-person perspective on fieldwork with occasional guest contributions,
(5.4) weather conditions capture regional-scale influences,
(5.5) anomalies in the water column are shown in historical context,
(5.6) aerial photographs document current conditions that are visible at the surface,
(5.7) ferry and satellite observations document conditions at progressively larger spatial and temporal scales,

(5.8) mooring pages focus on water mass characteristics and their interannual variation.

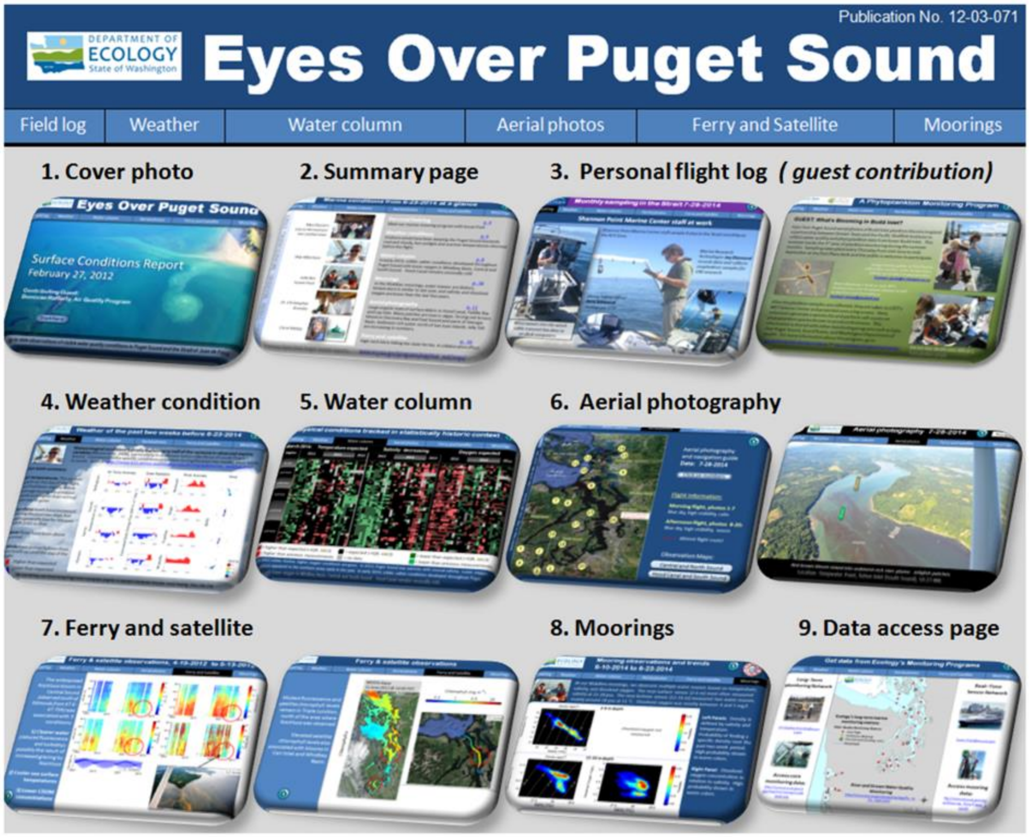

Figure 5. Outline and structure of Eyes Over Puget Sound. The report is structured to provide an overview and general information with increasing scientific detail going into the document. The largest section, aerial photography, provides an image-rich core (approx. 50 % of the report).

Data access pages advertise the location of data and provide links to additional data products (Figure 5.9). Sections are personalized by images and a short biography of individual chapter authors. An image-rich and clickable PDF format facilitates navigation within the document. EOPS reports are treated as WA Ecology publications and are citable sources for documenting observed conditions in Puget Sound. The EOPS surface condition report has motivated the program to be streamlined and focused to ensure that timely delivery of this key information product occurs monthly (EOPS, http://www.ecy.wa.gov/programs /eap/mar_wat/surface.html). The implementation of aerial photography and the publication of EOPS reports was achieved on a largely cost-neutral basis and gave the program an opportunity to re-imagine how to more effectively and creatively utilize many of its existing resources.

Important Elements to Ensure that EOPS Surface Condition Reports Resonate with the Audience

Modern society has access to a wealth of information and the increased dependence on web-based and social media outlets has shifted expectations towards more visually-oriented and headline-rich communication styles. Up-to-date news on the Internet has become the norm that monitoring programs must embrace to engage a wider audience with different educational backgrounds and interest in environmental issues. Information has to be relevant to the human scale in both space and time and be focused on reporting the unexpected and the novel to keep audiences engaged.

Many people experience Puget Sound from shore, ship, or piers and changes in surface water appearance quickly stir the interest of people spending time on or near the water. Puget Sound is used by a large community of recreational, tribal, commercial users; aesthetically it is a centerpiece that many associate with Washington’s quality of life. Aerial photographs provide a unique perspective that make patterns and processes easier to interpret by people on the ground. The impact of aerial photographs can be far greater than scientific figures and reports; they can be a powerful vector to reach peoples’ minds. Images that include boats, shorelines, streets and houses provide a level of intuition and personal scale to a spill or algal bloom that helps make these events more relevant and ‘tangible’ to the public and engages people to think about the marine environment from a larger perspective. Blooms of algae in red, green, brown and orange, floating algal mats washing ashore of oceanfront homes, patches of jellyfish the size of skyscrapers, oil sheens trailing ships, and dramatic sediment plumes photographed at the human scale resonate with the public; it generates awareness and complements scientific pursuits. Timeliness, the human dimension, visual appeal, and a story that captures the beauty and challenges of Puget Sound are keys to success of EOPS.

For scientific audiences, photographs, satellite-derived products, and maps can be used to reconstruct and visualize patterns of near-surface transport and mixing. Detailed snapshots and time-averaged maps intuitively characterize near-surface water quality and provide information about the distribution of gradients in water quality and hydrographic boundaries in Puget Sound. This unique bird’s eye view spatially organizes the visible symptoms of eutrophication and helps identify sources of solutes and particulate material as they move through the system. While imagery (whether it be aerial photographs or satellite images) can be a powerful communication tool, to use it effectively requires workflows that can quickly and efficiently generate products that are easy to understand.

En route ferry monitoring resonates with ferry riders and becomes personal. Ship time is cost neutral and monitoring programs can often benefit from the transects being occupied. Using bio-optical and physical sensors on ferries is one example of an effective, ‘high-tech’ sampling approach that appeals to the public and fills an intermediate temporal gap in our monthly data collection efforts.

Ferries (and other similar vessels of opportunity) provide a sustained source of all-weather environmental information to complement and extend our understanding of processes taking place within the long-term sampling network (e.g., ferry data have been used to describe the onset, geographic extent and disappearance of phytoplankton blooms in context of weather). Furthermore, ferry-based data have allowed investigation of the heterogeneous and patchy nature of surface waters at an even larger spatial scale and provide the daily ground truth information necessary to develop regionally-tuned satellite products. Ferry and satellite observations are brought together with data from WA Ecology's marine monitoring flight program which provides the foundational and long-term context to characterize interannual and interdecadal trends in regional water quality. This integration of diverse data showcases how the continuum of spatial and temporal scales can be studied in a cost-effective manner to document patterns of eutrophication within the context of estuarine circulation and climatic and oceanic variability.

The temporal window of interest for environmental news is short-lived. In addition, the volume of data can be overwhelming and people (public and scientific audiences alike) often have minimal interest in large-scale geographic or seasonal fluctuations; many of the most basic patterns of environmental variability are already known and appreciated (e.g., we know that summer will be warmer than winter). Most interest centers on whether current conditions are different and if this difference is a point of concern (Figure 6). The power of reporting data in the form of anomalies helps streamline the delivery of information and constitutes an effective strategy for presenting large quantities of information in a way that is engaging to a wide range of audiences. Converting information into 'anomaly space' reduces both the seasonal and geographic variability and volume of data for effective communication.

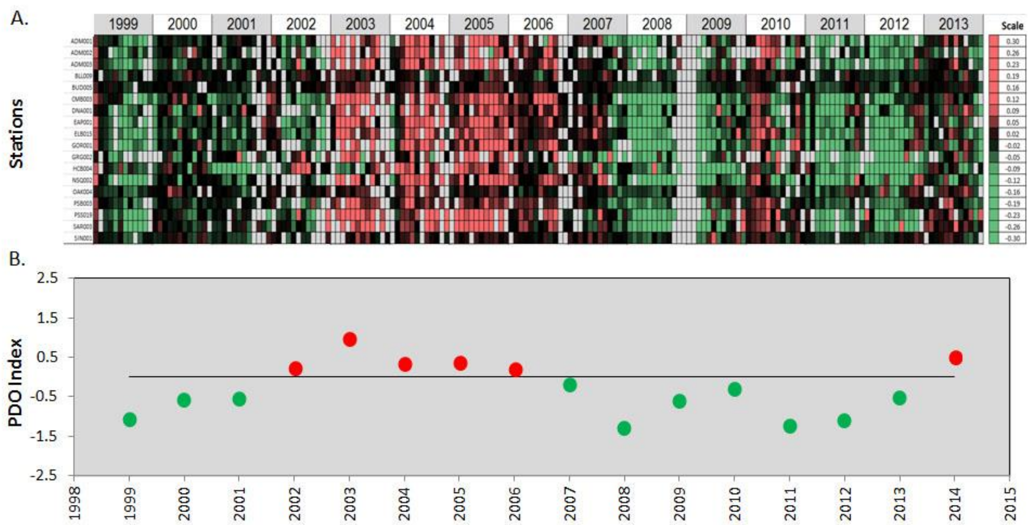

Figure 6. A. Monthly anomalies (in color) shown for individual monitoring stations (rows) in Puget Sound aligned along the axis of water transport (north to south). Colors highlight the inter-annual deviation from expected baseline conditions, for this example the thermal energy content in the upper water column 0-50m. Baselines were established for individual stations and times of the year to remove seasonal and spatial variability. B. The Pacific Decadal Oscillation is a strong driver of patterns in Puget Sound which can be seen in the heat map. Red and green highlight anomalies outside prescribes thresholds, black values fall near the median; and gray color illustrates missed sampling events and transparently shows the performance of data acquisition.

WA Ecology has used its long-term dataset of physical, chemical and bio-optical water quality variables to establish site-specific and seasonal expectations that are based on a 10 year time frame spanning 1999-2008. Anomalies are generated as the difference between new observations and the time averaged seasonal cycle that is specific to each location in the monitoring network. Working in anomaly space focuses the discussion on patterns and trends that permeate the system. Heat maps (Figure 6A) communicate anomalies in shades of green and red and indirectly advertise the volume and wealth of the dataset in a very intuitive way. By making datasets visually accessible their usage increases and it fosters the perceived value of the program.

Examples of Measures of Success

Guest Contributions to EOPS

EOPS quickly established itself as an outreach platform for the larger marine environmental community through its willingness to highlight other programs and activities. Since its inception, EOPS has showcased other community-oriented and/or environmentally-focused monitoring efforts, programs targeting education and outreach, and marine research projects. EOPS has become a recognized access point for information specific to Puget Sound.

EOPS Download Statistics

EOPS is posted on the Internet as a PDF document. Each month it is distributed through a subscriber-based e-mail listserv, Facebook, and Twitter. EOPS was quickly picked up by the blogging world and a variety of environmental news media outlets. It attains, on average, 0.5 million downloads per year. Its timeliness and visually compelling reporting style makes it attractive to media. Because of its large distribution, EOPS has been invited to present at aquariums, news events, radio broadcasts, numerous public meetings, and academic conferences.

CONCLUSION

With up-to date environmental information and documentation, WA Ecology's Marine Monitoring Program now fills a niche that complements and helps coordinate various science and monitoring efforts in the Puget Sound region. The program focuses its effort on creating visually engaging information products to stimulate public awareness and interest and empower people to become objective observers of their own backyard marine environment. Strengths of the program include: (1) data reporting and quality controls that are performed on time, (2) data that are interpreted in environmental context, (3) a monitoring staff that feels valued and engaged, and (4) a focus on consistent monitoring across many scales of variability. Collaborations with other programs form naturally due to the inherent interdisciplinary nature of the information products and a focused, multi-scale sampling approach. A short product development cycle and turn-around time is complemented by practical data formats that allow for rapid and effective comparisons of datasets across independent monitoring programs. The unique integration of data sources and historical insight provides the program with the information needed to understand, protect and manage the marine system in context of large-scale oceanic and climatic fluctuations and ultimately fosters a deeper and more thorough understanding of the Puget Sound marine system.

REFERENCES

[1] Feely R.A., S.R. Alin, J. Newton, C.L. Sabine, M. Warner, A. Devol, C. Krembs and C. Maloy, 2010. The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary. *Estuar Coast Shelf S* 88, p. 442-449.

[2] Deppe R.W., J. Thomson, B. Polagye and C. Krembs, 2013. *Hypoxic Intrusions to Puget Sound from the Ocean*. OCEANS' 13 MTS/IEEE San Diego – September 23-26, pp. 9 http://faculty.washington.edu/jmt3rd/Publications/Deppe_etal_Oceans2013.pdf

[3] Roberts M., T. Mohamedali, B. Sackmann, T. Khangaonkar and W. Long (PNNL), 2014. Puget Sound and the Straits Dissolved Oxygen Assessment: Impacts of Current and Future Human Nitrogen Sources and Climate Change through 2070. March 2014, Publication number 14-03-007, pp.151. https://fortress.wa.gov/ecy/publications /SummaryPages/1403007.html

[4] Krembs C., 2013. *Eutrophication in Puget Sound*, 2013. In: Irvine, J.R. and W.R. Crawford. State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2012. DFO *Can. Sci. Advis. Sec. Res.* Doc. 2013/032. pp. 106-112. http://www.dfo-mpo.gc.ca/Csas-sccs/publications/resdocs-docrech /2013/2013_032-eng.pdf

[5] Krembs C., M. Dutch, V. Partridge, S. Weakland, J. Bos, S. Albertson, B. Sackmann, M. Keyzers and C.F. Maloy, 2014. POSTER. Changes in nutrient ratios drive changes in pelagic and benthic assemblages, and benthic-pelagic coupling in Puget Sound: A compelling hypothesis linking water quality and the benthos. June 2014. Publication number 14-03-024. https://fortress.wa.gov/ecy/publications/SummaryPages/1403024.html

[6] Rice C.A., J.J. Duda, C.M. Greene and J. R. Karr, 2012. Geographic patterns of fishes and jellyfish in Puget Sound surface waters, Marine and Coastal Fisheries: *Dynamics, Management, and Ecosystem Science*, 4:1, p. 117-128.

[7] Vasas V., C. Lancelot, V. Rousseau and F. Jordán, 2007. Eutrophication and overfishing in temperate nearshore pelagic food webs: a network perspective. *Mar. Ecol. Prog. Ser.*, 336, p. 1-14.

[8] Boss J., 2014. Quality Assurance Monitoring Plan: Long-Term Marine Waters Monitoring, Water Column Program. (in press). https://fortress.wa.gov/ecy/publications/UIPages/PublicationList.aspx?IndexTypeName=Program&NameValue=Environmental+Assessment&DocumentTypeName=Publication

[9] Mora D., J. Bos and S. Pool, 2014. Quality Assurance Monitoring Plan: Long-Term Marine Waters Monitoring Mooring Program. January 2014, Publication number 14-03-103, pp.78 https://fortress.wa.gov/ecy/publications/SummaryPages/1403103.html

[10] Thomson J., 2014. Quality Assurance Project Plan: Ferry-Based Monitoring of Puget Sound Currents. June 2014, Publication number 14-03-110, pp. 38. https://fortress.wa.gov/ecy/publications/SummaryPages/1403110.html

[11] Sackmann B., C. Krembs, S. Pool, J. Bos, M. Keyzers and T. Khangaonkar, 2014. POSTER. Eyes Over Puget Sound: Producing Validated Satellite Products to Support Rapid Water Quality Assessments in Puget Sound. Ocean Sciences Meeting, Honolulu,

23-28 February 2014. http://www.eposters.net/pdfs/eyes-over-puget-sound-producing-validated-satellite-products-to-support-rapid-water-quality.pdf

[12] Krembs C., 2012. POSTER: Eyes Over Puget Sound: Integrating Multiple Observations to Report Current Conditions of Water Quality in Puget Sound and the Strait of Juan de Fuca. https://fortress.wa.gov/ecy/publications/summarypages/1203034.html

[13] Eyes Over Puget Sound: Surface Conditions Report – June 17, 2013. June 2013, Publication number 13-03-075, pp.43. https://fortress.wa.gov/ecy/publications/SummaryPages/1303075.html

[14] Krembs C., 2012. Marine Water Condition Index: Washington State Department of Ecology. May 2012. Publication number 12-03-013, pp.127 https://fortress.wa.gov/ecy/publications/summarypages/1203013.html

[15] PSEMP Marine Waters Workgroup. 2013. Puget Sound marine waters: 2012 overview. S.K. Moore, K. Stark, J. Bos, P. Williams, J. Newton and K. Dzinbal (Eds), pp. 56. http://www.psp.wa.gov/downloads/psemp/PSmarinewaters_2012_overview.pdf