Monitoring temperature and chlorophyll *a* to explore the survival potential of Pacific herring larvae in Puget Sound

Holly Young[1,2], Christopher Krembs[1], Adam Lindquist[3], Skip Albertson[1], Allison Brownlee[1], Julia Bos[1], Laura Hermanson[1], and Mya Keyzers[1]
[1] Washington State Department of Ecology [2] Washington Conservation Corps [3] Washington Department of Fish and Wildlife

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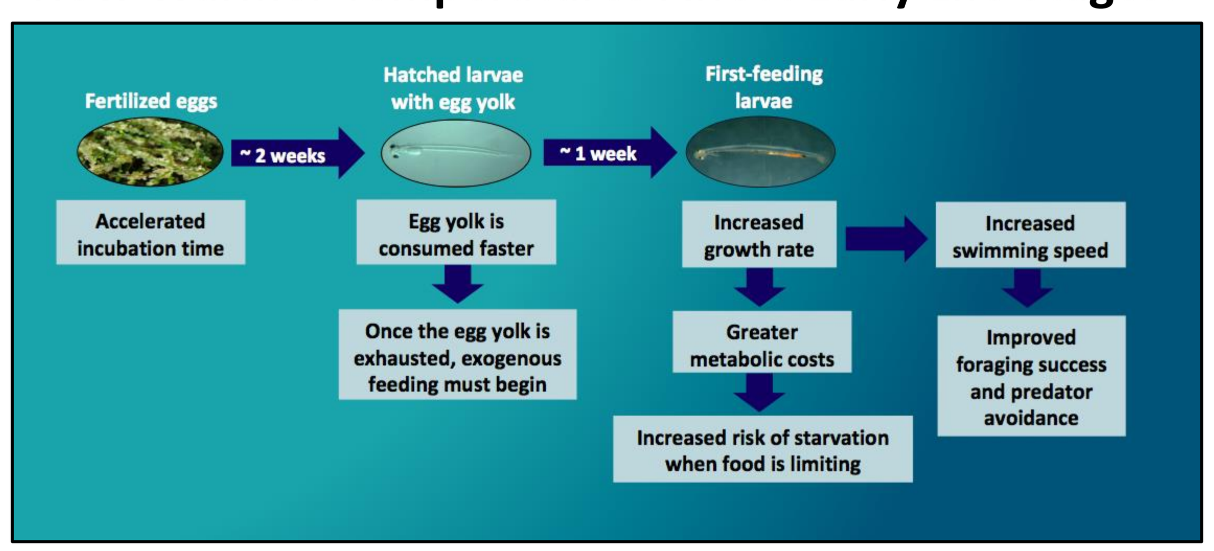
Background

How can long-term monitoring inform when optimal conditions occur for Pacific herring larvae?

In a changing climate, historical baselines of long-term monitoring data can provide valuable environmental context to observed biological patterns, including survival of Pacific herring larvae. Such data has been collected monthly by the Washington State Department of Ecology's Marine Waters Program throughout Puget Sound since 1973.

How Warmer Temperatures Affect Early Life Stages:

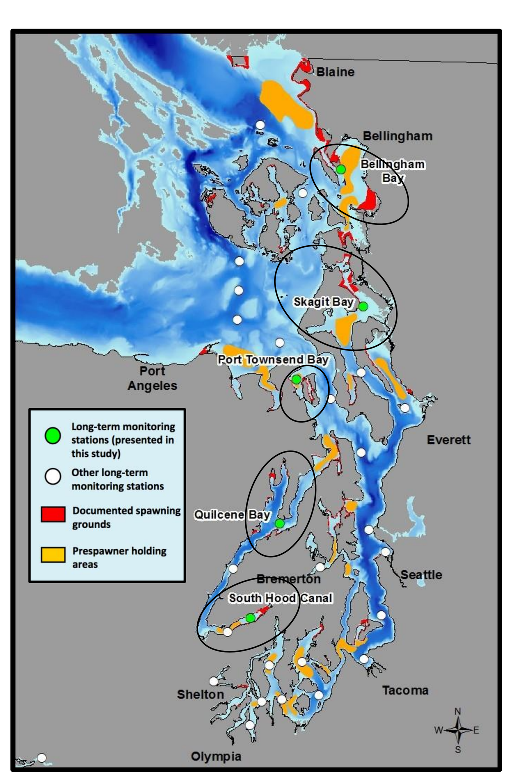


Temperature and Food Availability:
Ocean temperature is a critical factor affecting herring survival during early, sensitive life stages. Warmer temperatures accelerate larval growth and can increase survival potential if food availability is not limiting. Climatic variability may also indirectly affect herring via food-web interactions. Hjort (1914) proposed that catastrophic starvation of first-feeding larvae is primarily responsible for the observed fluctuations in recruit abundance. A timing mismatch with a plankton bloom may decrease larval survival as they begin exogenous feeding.

This study examines:
- The inter-annual and regional variability of Puget Sound temperatures in the context of early herring life stages.
- How frequently the larval first-feeding stage coincided with plankton blooms (high chlorophyll *a*).

Methods

- Long-term monitoring stations near spawning areas were selected to examine surface water quality (0–15 meters).
- Documented spawning dates from 2012–2018 were used to determine when larvae were in the first-feeding stage.
- A historical baseline (1999–2018) was used to show anomalies in temperature and chlorophyll *a* data.
- Chlorophyll *a* concentrations were used as a proxy for food availability (plankton biomass).



Long-term monitoring stations and areas associated with herring spawning in Puget Sound. Map by Sandy Weakland.

Key Points

- Long-term monitoring data is valuable for predicting larval herring survival based on observed water quality conditions.
- If food availability is not limiting, temperature can indirectly influence larval survival by optimizing growth rate.

Next Steps:

- Examine herring recruitment to confirm that healthy recruitment occurs when temperature and food availability was optimized during the cohort's first-feeding larval stage.
- If recruitment is not reflected by optimal conditions, this provides direction to explore other factors, such as habitat quality, that may be limiting herring survival.

Current Herring Stock Status

Station	Herring Stock	Stock Status
Dabob Bay	Quilcene Bay	Increasing
South Hood Canal	South Hood Canal	Healthy
Port Townsend Bay	Kilisut Harbor	Critical
Skagit Bay	Skagit Bay	Depressed
Bellingham Bay	Samish/Portage Bay	Increasing

Current condition of herring stocks based on recent (most recent 4-year mean) abundance compared to long-term (previous 25-year mean) abundance. (Sandell et al., 2018).

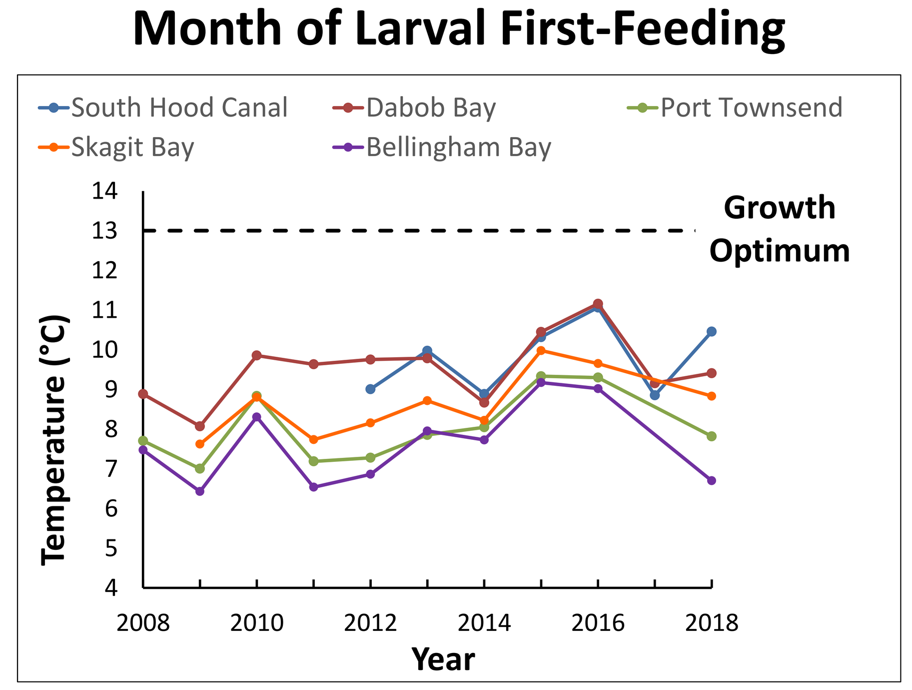
Increasing: recent mean abundance more than 20% above long-term mean
Healthy: recent mean abundance within 20% of long-term mean
Depressed: recent mean abundance 51–80% below long-term mean
Critical: recent mean abundance 81–99% below long-term mean

Temperature and Larval Growth

When do herring larvae begin the first-feeding stage?

- At 8–10 °C, the larvae enter the first-feeding stage 2–3 weeks post fertilization (McGurk, 1984).
- February, March, or April was selected for each station as the month of larval first-feeding. This was calculated by adding 2–3 weeks to peak spawning dates documented in February and March (Sandell et al., 2018).

Month of Larval First-Feeding

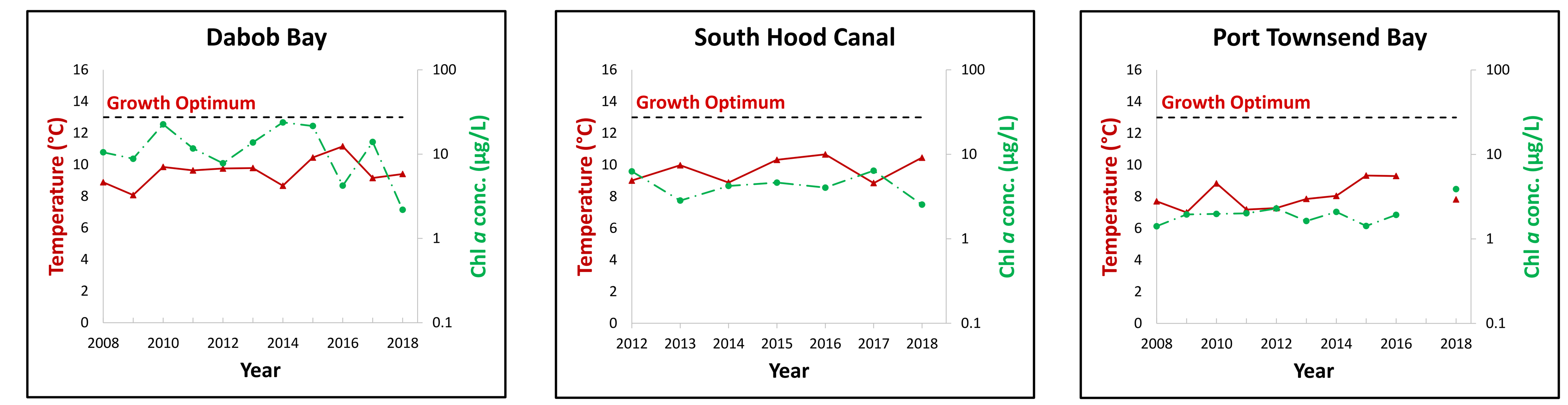


Station comparison of median temperatures during month of larval first-feeding relative to herring larvae growth optimum temperature (13 °C).

Growth Optimum temperature (13 °C) of Atlantic herring larvae (Paulsen et al., 2016).

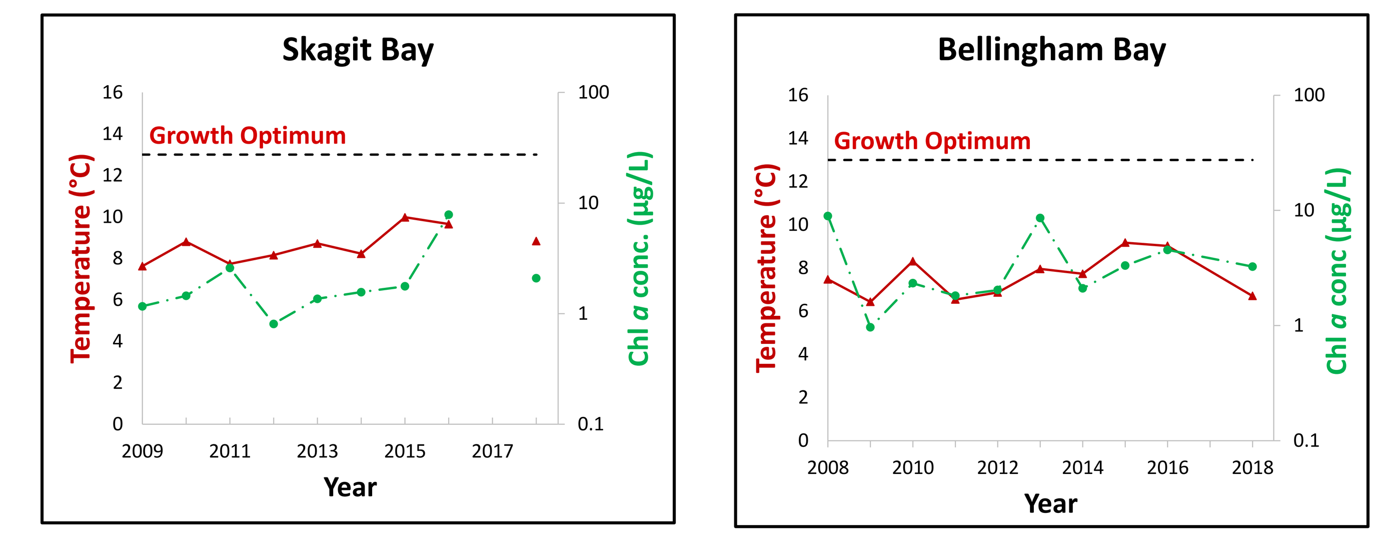
Warmer temperatures
↓
Larval growth rate increases
↓
Swimming speed increases: larvae better forage and avoid predators
↓
Larval survival increases (if food is not limiting)

Temperature and Chlorophyll *a* During Month of Larval First-Feeding



Optimal conditions: High temperatures and high chlorophyll *a* concentrations coincide
↓
increased survival of first-feeding larvae

Nonoptimal conditions: Low chlorophyll *a* concentrations
↓
decreased survival of first-feeding larvae



Median temperature and chlorophyll *a* concentrations by region during month of larval first-feeding relative to herring larvae growth optimum temperature (Paulsen et al., 2016).

Did first-feeding larvae match or mismatch with high chlorophyll *a*?

Legend: First-feeding larvae; Peak larval abundance; Max. Chlorophyll *a*

- Documented spawning dates (Sandell et al., 2018) determined timing and duration of the first-feeding stage and peak larval abundance.
- With the exception of Bellingham Bay, high chlorophyll *a* matched with the larval first-feeding window. About two mismatch years were observed over a ten-year period (2008–2018) for each station.
- With the exception of Dabob Bay, high chlorophyll *a* did not often match with peak larval abundance.

High chlorophyll *a* match:

Station	Year	February				March				April				May			
Dabob Bay	2014																
Skagit Bay	2015																

High chlorophyll *a* **mis**match:

Station	Year	February				March				April				May			
S. Hood Canal	2012																
Bellingham Bay	2016																

Temporal and Regional Anomalies

Temperature Anomalies (1999-2018 baseline)

Station	Month	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Dabob Bay	April											
South Hood Canal	February											
Port Townsend Bay	March											
Skagit Bay	March											
Bellingham Bay	March											

Legend: Lower; Expected; Higher; No Data

Chlorophyll *a* Anomalies (1999-2018 baseline)

Station	Month	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Dabob Bay	April											
South Hood Canal	February											
Port Townsend Bay	March											
Skagit Bay	March											
Bellingham Bay	March											

Legend: Lower; Expected; Higher; No Data

Temperature and chlorophyll *a* anomalies in February, March or April relative to 1999–2018 baseline levels.

How did conditions vary in the past 10 years?

- In 2015 and 2016, temperature was higher than baseline levels for all stations. High chlorophyll *a* anomalies coincided with these warmer months in Dabob and Skagit Bay, potentially increasing larval survival.
- In 2016, Dabob Bay experienced warmer temperatures in April, however chlorophyll *a* was lower than baseline levels. Poor food availability potentially decreased larval survival.

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Contact: Holly Young hollyrayeyoung@gmail.com
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