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

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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 observe climate-based 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 $a$).

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.
- 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

Table: Current Herring Stock Status

<table>
<thead>
<tr>
<th>Station</th>
<th>Herring Stock</th>
<th>Stock Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dabob Bay</td>
<td>Quilcene Bay</td>
<td>Increasing</td>
</tr>
<tr>
<td>South Hood Canal</td>
<td>South Hood Canal</td>
<td>Healthy</td>
</tr>
<tr>
<td>Port Townsend Bay</td>
<td>Kilsut Harbor</td>
<td>Critical</td>
</tr>
<tr>
<td>Skagit Bay</td>
<td>Skagit Bay</td>
<td>Depressed</td>
</tr>
<tr>
<td>Bellingham Bay</td>
<td>Samish/Portage Bay</td>
<td>Increasing</td>
</tr>
</tbody>
</table>

Current condition of herring stocks based on recent (most recent 4–5 year mean) abundance compared to long-term (recent 20-year mean) abundance (Sundell 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 (Sundell et al., 2018).

Month of Larval First-Feeding

<table>
<thead>
<tr>
<th>Station</th>
<th>Growth Optimum (12 °C) of Atlantic herring larvae (Paukku et al., 2016).</th>
</tr>
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<td>South Hood Canal</td>
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</table>

Growth Optimum temperature (12 °C) of Atlantic herring larvae (Paukku 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

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

- High chlorophyll $a$ match:
  - 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.

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).

Temporal and Regional Anomalies

Temperature Anomalies (1999–2018 baseline)

- Station Year
- Dabob Bay 2014
- Skagit Bay 2015

Chlorophyll $a$ Anomalies (1999–2018 baseline)

- Station Year
- Bellingham Bay 2015

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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