Interactive effects of ocean acidification and ocean warming on Pacific herring (Clupea pallasi) early life stages

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We looked at the Pacific herring spawn stocks in Cherry Point which is in decline.
Are warmer and more acidic waters part of the reason?

As the ocean concentration of carbon dioxide increases, so does acidity (causing pH to decline).

Adult herring spawn in nearshore coastal waters
Responses to acidification are species-specific

Impairs olfactory senses

Orange Clownfish (Munday et al. 2008. *PNAS*).

Reduces growth and survival


No sperm motility effects

Atlantic Herring (*Clupea harengus*)

<table>
<thead>
<tr>
<th>Year</th>
<th>Effects under high CO$_2$</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>No embryonic or hatch rate effects, but some nutritional condition effects.</td>
<td>Franke</td>
</tr>
<tr>
<td>2012</td>
<td>Egg survival decreased</td>
<td>Bodenstein</td>
</tr>
<tr>
<td>2014</td>
<td>Larval growth decreased, organ damage</td>
<td>Frommel</td>
</tr>
<tr>
<td>2014 2015</td>
<td>Proteome and swimming not changed</td>
<td>Maneja</td>
</tr>
<tr>
<td>2018</td>
<td>Interactive effect of T and CO$_2$ on larvae, but T has greatest impacts.</td>
<td>Sswat</td>
</tr>
</tbody>
</table>
Atlantic herring larvae developed muscle fibers sooner under warmer conditions.

Accelerated growth can lead to physical deformities.
How are Pacific herring early life stages affected by elevated pCO$_2$ and temperature?
Pacific herring were collected from Cherry Point, WA

WDFW spawn survey: April 2017
N = 4 males

4 females

3 Basins per treatment
(N = 12 slides per treatment)
Fertilization Success

Hatching Success

Larval Weight, Length

Respiration
Warmer temperature resulted in lower hatching success.
Warmer temperature resulted in decreased larval lengths.
Embryo respiration was significantly elevated under ocean acidification and ocean warming conditions.
Concluding Points and Future Directions

- Embryos primarily affected by increased temperature – interaction effect with \( \text{CO}_2 \) on respiration

- Ability to adapt to high temperature over time? Or will future warming surpass Pacific herring embryo thresholds?

- Respiration effects point to an energy use story.
Atlantic herring may benefit from OA effects on food webs
High CO₂ mesocosms had greater food abundance (copepodite and nauplii)

Thank you

- Dr. Paul Dinnel
- Dr. Katherina Schoo
- Kelley Bright
- Intrepid Research Assistants
  - Jocelyn Wensloff
  - Max Miner
  - Katey Williams
  - Hillary Thalman
  - Darby Finnegan
  - Lynne Nowak
  - Tyler Tran
Interactive effects of ocean acidification (small) and ocean warming (large) on Pacific herring early life stages

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SSEC 2018
Table 2: Average in-situ seawater parameters (Orion Star™ A329 pH conductivity meter and discrete carbonate chemistry values (calculated using CO2SYS) during incubation. Treatments represented by control (600 μatm) or high (1200 μatm) pCO2 cross-factored with control (10°C) or high (16°C) temperature with mean ± 1 SD of (n) measurements.

<table>
<thead>
<tr>
<th>Treatment (μatm + °C)</th>
<th>In-Situ Measurements</th>
<th>Discrete Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pH (NBS Scale)</td>
<td>Temperature (°C)</td>
</tr>
<tr>
<td>600 +10</td>
<td>7.92 ± 0.03 (47)</td>
<td>10.4 ± 0.03 (47)</td>
</tr>
<tr>
<td>600 +16</td>
<td>7.87 ± 0.03 (42)</td>
<td>16.1 ± 1.5 (42)</td>
</tr>
<tr>
<td>1200 +10</td>
<td>7.60 ± 0.06 (48)</td>
<td>10.4 ± 0.03 (48)</td>
</tr>
<tr>
<td>1200 +16</td>
<td>7.58 ± 0.04 (42)</td>
<td>16.4 ± 1.0 (42)</td>
</tr>
</tbody>
</table>