Winter as OA Refugia in Pacific Northwest Coastal Waters

Burke Hales

Wiley Evans, Katherine Harris, George Waldbusser

Also:

Miguel Goni, Angel White

too.
Ocean Acidification in Pacific Northwest Coastal Waters


2. Upwelled waters outcrop near shore, with high-CO$_2$ signal (Hales, Van Geen, Feely) and influence bay chemistry (Barton et al 2012)

3. Coastal waters are influenced by anthropogenic CO$_2$ such that $\Omega$ is reduced by 0.2 in deep waters (Feely, Harris) and 0.5 in surface waters (Harris)

\[
W = \frac{Ca^{2+}}{K_{sp,arag}} \left[ CO_3^{2-} \right]
\]
Background: Ocean Acidification in Pacific Northwest Coastal Waters

4. Early larval sensitivity to ambient-water shell-mineral stability under present-day conditions.

Shell content goes from 0 – 80% in two days

5. Mechanism is energetically-costly kinetic acceleration of aragonite precipitation within first hours after hatching.

Energy reserves fall by 80%

$\Omega_A$ in initial water

$$\frac{[Ca^{2+}][CO_3^{2-}]}{K_{sp,arag}}$$
In situ continuous T, S, pH data (YSI), corrected with discrete samples for pCO$_2$, TCO$_2$ (Hales lab).

Netarts Bay chemistry is strongly influenced by coastal chemistry and upwelling; pCO$_2$ and TCO$_2$ check samples combined with in situ monitoring confirm this.

6. Is it $\Omega$?

How do we isolate $\Omega$ from other effects?

Background: Ocean Acidification in Pacific Northwest Coastal Waters

$$W = Ca^{2+}[CO_3^{2-}] / K_{sp, arag}$$
6. Is it $\Omega$ (continued)?

Chemical Manipulations of Carbonate Chemistry (general approach):

Manipulate Alkalinity and total CO$_2$ simultaneously to hold individual parameters constant:

<table>
<thead>
<tr>
<th>pCO2 \ ΩAr:</th>
<th>4</th>
<th>2</th>
<th>1</th>
<th>0.5</th>
<th>pH$_{sws}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>8.33</td>
<td>8.18</td>
<td>8.03</td>
<td>7.88</td>
<td>pH$_{sws}$</td>
</tr>
<tr>
<td>400</td>
<td>8.18</td>
<td>8.03</td>
<td>7.88</td>
<td>7.73</td>
<td>pH$_{sws}$</td>
</tr>
<tr>
<td>800</td>
<td>8.03</td>
<td>7.88</td>
<td>7.73</td>
<td>7.58</td>
<td>pH$_{sws}$</td>
</tr>
<tr>
<td>1600</td>
<td>7.88</td>
<td>7.73</td>
<td>7.58</td>
<td>7.43</td>
<td>pH$_{sws}$</td>
</tr>
</tbody>
</table>

Turns out this is challenging, but...

Waldbusser, Hales et al. in prep.
6. Is it $\Omega$?

No pCO$_2$ effect!

Waldbusser, Hales et al. in prep.

No pH effect!

Clear $\Omega$ effect!

<table>
<thead>
<tr>
<th>PCO2/$\wedge$</th>
<th>~3</th>
<th>~1.5</th>
<th>~0.7</th>
<th>~0.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>~400</td>
<td>87.78</td>
<td>53.54</td>
<td>48.69</td>
<td>5.50</td>
</tr>
<tr>
<td>~700</td>
<td>87.00</td>
<td>74.20</td>
<td>10.39</td>
<td>1.42</td>
</tr>
<tr>
<td>~1600</td>
<td>94.22</td>
<td>76.49</td>
<td>0.74</td>
<td>0.00</td>
</tr>
<tr>
<td>~2800</td>
<td>89.50</td>
<td>85.71</td>
<td>22.13</td>
<td>0.00</td>
</tr>
</tbody>
</table>
6. Is it Ω?

PCO2 = 412
Omega = 0.77

PCO2 = 368
Omega = 3.02

PCO2 = 2876
Omega = 0.94

PCO2 = 2758
Omega = 3.81

Imaging courtesy E. Brunner, OSU

Waldbusser, Hales et al., in prep.

So, yes, it’s Ω
7. Does natural variability help or hurt?

Using $\text{pCO}_2$ as proxy, threshold for break-even is at $\text{pCO}_2 \sim 450 \mu\text{atm}$; threshold for no impact is at $\text{pCO}_2 \sim 280 \mu\text{atm}$

Daily variability during a typical upwelling season

Break-even spawning/growing conditions now $\sim 50\%$ of time;

No-impact conditions now $< 20\%$.

Invariant system would have fewer instances of harmful conditions (today).

Vance, 2012, MS Oregon State University
Winter conditions as OA refugia

So, upwelling season is tough going for shell producers in early larval stages. When is it better to spawn?

Evans et al. JGR 2011

Time series data show that winter pCO2 levels are (surprisingly?) low
Winter conditions as OA refugia

Combined pH/pCO$_2$/Salinity timeseries allow calculation of $\Omega$.

Waters mostly above the ‘no effect’ threshold Nov-Mar; almost entirely above ‘break-even’ threshold.

Harris et al. 2013
Wintertime low-\(\text{CO}_2\) conditions persist across the shelf and throughout the water column.

High-\(\text{CO}_2\) waters are present, but forced down and offshore by winter downwelling circulation.

‘Break-even’ threshold is forced down and offshore by downwelling forcing.

Surface waters reach values as low as \(~340\) \(\mu\text{atm}\).
But that water starts to encroach before local winds are upwelling favorable.

Likely caused by coastally-trapped internal waves propagating northward from persistently upwelling regions in northern California (sensu Hickey et al 2007)
Winter conditions as OA refugia

Signature of winter coastal river discharge:

\[ \text{Winter conditions as OA refugia} \]

\[ \text{Signature of winter coastal river discharge:} \]

\[ pCO_2 \] (and pH) seem inoffensive, but \( \Omega \) is low.
Coastal waters respond to winter flood events by blooming, lowering CO$_2$ and raising $\Omega$.
Conclusions:

1. Pacific Northwest coastal waters experience low-$\Omega$ conditions caused by the additive effects of natural variability and anthropogenic forcing.

2. Oysters and mussels (and clams...) show similar susceptibility in early larval stages to current conditions.

3. Anthropogenic factors have increased frequency, intensity, and duration of harmful events.

4. Winter observations show much more favorable conditions, with low-$\Omega$ events mostly absent.

5. Coastal rivers/estuaries deliver low-$\Omega$ water to the coastal ocean.

6. But these waters are high in nutrients (N, P, Si, Fe), and support coastal primary productivity, which drives coastal $\Omega$ back up.
Are there ecosystem adaptations threatened by changing carbon cycles?

- Native oysters and mussels seem to spawn outside of the upwelling periods. This may be for non-OA reasons (on-shelf retention of larvae, e.g.), but also has benefit of avoiding most extreme low-Ω events.

- Remote forcing brings high-CO$_2$ source waters far inshore of the shelf-break, well before local upwelling winds. Moderate weakening of winter downwelling forcing will result in rapid exposure of the inner shelf to high-CO$_2$ conditions.

- Is river input at an optimum? Anomalous southward, on-shore excursion of Columbia River waters led to low-Ω conditions in early Spring 2011.