Ocean Acidification: The Other CO₂ Problem

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What we know about the ocean chemistry of ...saturation state

\[ CO_2 + CO_3^{2-} + H_2O \Leftrightarrow 2HCO_3^- \]

**Saturation State**

\[ \Omega_{\text{phase}} = \frac{[Ca^{2+}][CO_3^{2-}]}{K_{sp,\text{phase}}} \]

\[ Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3 \]

calcium carbonate  calcium carbonate

\( \Omega > 1 = \text{precipitation} \)
\( \Omega = 1 = \text{equilibrium} \)
\( \Omega < 1 = \text{dissolution} \)
What we know about ocean CO$_2$ chemistry ... from field observations

WOCE/JGOFS/OACES Global CO$_2$ Survey

~72,000 sample locations collected in the 1990s
DIC ± 2 µmol kg$^{-1}$
TA ± 4 µmol kg$^{-1}$

What we know about ocean CO$_2$ chemistry... from observed shoaling saturation horizons

The aragonite and calcite saturation horizons have shoaled towards the surface of the oceans due to the penetration of anthropogenic CO$_2$ into the oceans.

Feely et al. (2004)
What we know about ocean CO$_2$ chemistry...from observed aragonite and calcite saturation depths
Natural processes that could accelerate the ocean acidification of coastal waters

- Coastal Upwelling
NACP West Coast Survey Cruise: 11 May - 14 June 2007
and mooring locations
The ‘ocean acidified’ corrosive water was upwelled from depths of 150-200 m onto the shelf and outcropped at the surface near the coast.

Vertical sections from Line 5 (Pt. St. George, California)  

Feely et al. (2008)
Mesocosm experiment, Bergen
Pelagic Ecosystem CO₂ Enrichment Study

Three pCO₂ treatments representing:
Glacial, Present, and Year 2100

Large Scale Mesocosm Facility, University of Bergen, Norway

from U. Riebesell & B. Rost
Coccolithophore (single-celled algae)

Manipulation of CO$_2$ system by addition of HCl or NaOH

*Emiliania huxleyi*

$pCO_2$ 280-380 ppmv

$pCO_2$ 780-850 ppmv

Calcification decreased
- 9 to 18%
- 45%

Malformed liths at high CO$_2$

*Riebesell et al.(2000); Zondervan et al.(2001)*

*Gephyrocapsa oceanica*
Shelled Pteropods
(planktonic snails)

Respiratory $\text{CO}_2$ forced $\Omega_A < 1$
Shells of live animals start to dissolve within 48 hours

- Whole shell: $\textit{Clio pyramidata}$
- Arag. rods exposed
- Prismatic layer (1 $\mu$m) peels back

Aperture (~7 $\mu$m): advanced dissolution
Normal shell: no dissolution

Orr et al. (2005)
Response of mussels & oysters to elevated CO\textsubscript{2} 

Decrease in calcification rates for the 2 species: 

\textit{Mytilus edulis} 
\textit{Crassostrea gigas} 

\begin{itemize}
  \item Significant with $pCO_2$ increase and $[CO_3^{2-}]$ decrease
  \item At $pCO_2$ 740 ppmv:
    \begin{itemize}
      \item 25% decrease in calcification for mussels
      \item 10% decrease in calcification for oysters
    \end{itemize}
\end{itemize}

Gazeau et al., 2007
Ecologically and economically important organisms with planktonic larval stages

- **Bivalves**: clams, scallops, mussels, oysters
  - Valuable commercial fisheries
  - Mussels & oysters: ecosystem engineers

- **Echinoderms**: sea urchins, sea stars, sea cucumbers
  - Commercial fisheries: sea urchins & sea cukes
  - Sea stars: keystone species

- **Crustaceans**: shrimp, crabs, lobsters, copepods
  - Valuable commercial fisheries
  - Copepods: central role in marine food webs

Annual $2 Billion Dollar Industry
Potential Effects on Open Ocean Food Webs

Coccolithophores → Copepods → Pacific Salmon

Copepods

Pteropods

Vicki Fabry

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What we know about the biological impacts of ocean acidification on marine fish

Research on Impacts of OA on Pacific Salmon

Predicted effect of climate change on pink salmon growth:

- 10% increase in water temperature leads to 3% drop in mature salmon body weight (physiological effect).
- 10% decrease in pteropod production leads to 20% drop in mature salmon body weight (prey limitation).

(Aydin et al. 2005)
## Scorecard of Biological Impacts

<table>
<thead>
<tr>
<th>Physiological process</th>
<th>Major group</th>
<th># species studied</th>
<th>Response to increasing CO₂</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td><strong>Calcification</strong></td>
<td></td>
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<tr>
<td></td>
<td>Coccolithophores</td>
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<td>2</td>
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<tr>
<td></td>
<td>Planktonic Foraminifera</td>
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<tr>
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<td>Molluscs</td>
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<tr>
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<td>Echinoderms</td>
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<td>Tropical Corals</td>
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<td>Coralline Red Algae</td>
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<td><strong>Photosynthesis</strong></td>
<td>Coccolithophores²</td>
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<td></td>
<td>Prokaryotes</td>
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<td>Seagrasses</td>
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<td><strong>Nitrogen Fixation</strong></td>
<td>Cyanobacteria</td>
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<tr>
<td><strong>Reproduction</strong></td>
<td>Molluscs</td>
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</tr>
<tr>
<td></td>
<td>Echinoderms</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

1) Strong interactive effects with nutrient and trace metals availability, light, and temperature
2) Under nutrient replete conditions

Figure from Doney et al. (2009)
Conclusions

- Impacts of ocean acidification on ecosystems are largely unknown.
- Calcification in many planktonic organisms is reduced at elevated CO$_2$, but the response is not uniform.
- Possible responses of ecosystems are speculative but could involve changes in species composition & abundances - could affect food webs, biogeochemical cycles.
- Baseline data with sufficient resolution are lacking in regions where CaCO$_3$ saturation states are expected to decrease <1 over in next 50-100 years.