Ocean Acidification: The other CO$_2$ Problem

Carol Blanchette
Marine Science Institute
UC Santa Barbara
The CO$_2$ Problem

- Humans burn fuel
- The burning of fuel produces carbon dioxide
- Adds 6 GT of C to the atmosphere each year
- Atmospheric CO$_2$ has increased over 40%
- CO$_2$ is a greenhouse gas
- **Greenhouse effect** contributes to **global warming**
Human activity and CO$_2$
Anthropogenic CO$_2$

Antarctic Ice Core Record

“It is very likely that [man-made] greenhouse gas increases caused most of the average temperature increase since the mid-20 century”

- IPPC 4th Assessment Report

(Courtesy of Dick Feely, NOAA)
Greenhouse effect heats the earth
The CO$_2$ Problem: The Good News

- The oceans have played a critical buffering by absorbing heat and CO$_2$ that would have otherwise contributed to global warming

- In the last 200 years the oceans have absorbed nearly half of the human-made CO$_2$
The Bad News: The other CO$_2$ Problem

Ocean Acidification

- The ongoing decrease in the pH of the earth’s oceans caused by their uptake of anthropogenic CO$_2$ from the atmosphere
- Ocean waters are being chemically altered 100 times more rapidly than in the last 650,000 years
Atmospheric CO$_2$, ocean CO$_2$ and pH

Dr. Pieter Tans, NOAA/ESRL
Mechanism of Ocean Acidification

Carbon Dioxide (CO₂)

Results in carbonic acid formation

Increase H ions (lowers pH)

Lowers carbonate ion

Less material to build calcium carbonate shells & other ‘hard parts’
Chemistry of Ocean Acidification

\[
\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{HCO}_3^- + \text{H}^+
\]

\[
\text{H}^+ + \text{CO}_3^{2-} \rightarrow \text{HCO}_3^-
\]

\[
\text{CaCO}_3 \rightarrow \text{Ca}^{2+} + \text{CO}_3^{2-}
\]

Insert graph showing the relationship between atmospheric CO₂ concentration and ocean chemistry.
The pH scale

Acidity is a measure of the Hydrogen ion concentration

\[ \text{pH} = - \log [H^+] \]

In the last 200 years pH has dropped over 0.1 units on the pH scale, becoming 30% more acidic.
How will OA affect marine organisms?

• Compromised shell building
  – Organisms build small, weak or reduced shells
• Dissolved calcium carbonate hard parts
  – Structures dissolve – maybe fate of many corals
• Acidosis (buildup of carbonic acid)
  – Lowered immune response, metabolic decline
• Changes in productivity
  – Shifts in species composition of phytoplankton
• Sound absorption
  – Sound will travel further underwater (pH drop of .3 > 70% increase)
Groups of calcifying marine organisms

- Corals
- Macroalgae
- Echinoderms
- Molluscs
- Crustaceans

This group accounts for 75% of global marine calcium carbonate production
# Groups of calcifying marine organisms

<table>
<thead>
<tr>
<th>Organism</th>
<th>Photosynthetic</th>
<th>Carbonate form</th>
<th>Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coccolithophores</td>
<td>Yes</td>
<td>Calcite</td>
<td>Planktonic</td>
</tr>
<tr>
<td>Macroalgae</td>
<td>Yes</td>
<td>Aragonite/Calcite</td>
<td>Benthic</td>
</tr>
<tr>
<td>Foraminifera</td>
<td>No/some</td>
<td>Calcite</td>
<td>Benthic/Planktonic</td>
</tr>
<tr>
<td>Corals</td>
<td>Yes/no</td>
<td>Aragonite</td>
<td>Benthic</td>
</tr>
<tr>
<td>Pteropods</td>
<td>No</td>
<td>Aragonite</td>
<td>Planktonic</td>
</tr>
<tr>
<td>Non-pteropod molluscs</td>
<td>No</td>
<td>Aragonite/calcite</td>
<td>Benthic/Planktonic</td>
</tr>
<tr>
<td>Echinoderms</td>
<td>No</td>
<td>Mg-calcite</td>
<td>Benthic</td>
</tr>
<tr>
<td>Crustaceans</td>
<td>No</td>
<td>Calcite</td>
<td>Benthic/Planktonic</td>
</tr>
</tbody>
</table>

Next: Example of effects of increased CO$_2$ on echinoderm sea urchin
Life cycle of a purple sea urchin
Urchins raised under different CO$_2$ levels

Morphometrics show **reduced** size of larval endoskeleton

Reduced skeleton at high CO$_2$ levels

Cascading effects on Biodiversity

Global warming is the latest threat to the world’s biologically rich and besieged coral reef ecosystems.
Coral reefs close to tipping point

Diagram showing the relationship between atmospheric CO₂ content and deviation from today's temperature, illustrating the points where reefs may be at risk.

- Interglacial: Normal conditions.
- Glacial: Lower temperatures.
- Thermal threshold (+2°C).
- 0.2 pH:
- Carboate ion concentration:
- Carbonate threshold 480 ppm.
- Non-carbonate reef coral communities.
- Reefs not dominated by corals.
The future for coral reefs?

A: 375 ppm +1°C
B: 450-500 ppm +2°C
C: > 500 ppm >+3°C

2010  2050  2100
Calcification and saturation states

Calcium carbonate occurs in 2 common forms:

- **Aragonite** – more soluble
- **Calcite** – less soluble

**Saturation state** ($\Omega$) – measures the potential for the mineral to form or to dissolve

Increased [CO$_2$] and acidity decreases saturation states and raises saturation horizon closer to surface

Can use $\Omega$ to model the future distribution of marine spp.
Aragonite saturation as CO$_2$ increases

- Pre-Industrial
- Current
- 2030
- 2040
- 2050
- 2060

Ω = 3.25
Climate targets and tipping points

Climate stabilization $[\text{CO}_2]$ target 450 ppm

Global $\Omega$ tipping point = 2.75

<table>
<thead>
<tr>
<th>Year</th>
<th>$[\text{CO}_2]$</th>
<th>$\Omega$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-industrial</td>
<td>280</td>
<td>3.44</td>
</tr>
<tr>
<td>Current</td>
<td>384</td>
<td>2.90</td>
</tr>
<tr>
<td>2025</td>
<td>430</td>
<td>2.75</td>
</tr>
</tbody>
</table>

Reefs $\Omega = 3.25$
How will marine organisms respond?

• Migration
• Tolerance
• Adaptation

Polar species - Limited ability to migrate

Corals

Limited tolerance – already at edge of range

Pteropods
Winners and Losers

• Most marine organisms will respond negatively to OA
• Seagrasses show positive response to increased CO₂

Seagrasses

• Evolved from land plants during high CO₂ conditions
• Photosynthesis is CO₂ limited
• Beds support a high diversity of associated species
Ocean regions most sensitive to OA

- High latitude regions (due to thermodynamics)
- Deep water areas where carbonate is low
- Upwelling ecosystems - EBUS
Coastal Upwelling

Upwelled waters are **cold** and **old** (high in nutrients, dissolved CO₂, low oxygen, pH)
California Current upwelling ecosystem

- Naturally more acidic than most ocean
- Aragonite saturation reaches the surface during strong upwelling
What’s happening locally?

1. Hofmann laboratory UCSB
2. UC OA Research Consortium
3. New CA current OA project
   - Oceanographic monitoring
   - Genetics and Ecophysiology
   - Ecology
Are CC organisms adapted to low pH?

Mussels

Sea urchins
The first local in situ pH measurements

SeaFET pH Sensor
Measures pH using 2 reference electrodes

C. Nelson
Upwelling of highly acidic waters

Yu, Martz, Hofmann (2010) JEMBE (in review)
Coastal upwelling organisms may adapt

• These organisms regularly experience corrosive conditions during upwelling
• How does the frequency and intensity of acidic upwelling affect growth/reprod?
• Will increases in upwelling push them beyond their limits?
Can we avoid ocean acidification?

Not entirely, but can change our trajectory
Worldwide Carbon footprint

**CO₂ emissions from industrial processes**

- North and Central America
- Europe
- Africa
- Asia
- South America
- Oceania

Source: United Nations Framework Convention on Climate Change (UNFCCC)
Save our Seas

Support Clean Energy
Reduce Carbon Footprints