Ocean Acidification
Caused by Increased Atmospheric CO₂
And the Effects on Marine Biota
• CO₂ in the atmosphere reacts with ocean water to form an acid.

• With increasing atmospheric CO₂ levels, the ocean’s acidity has been steadily increasing

• An increase in acidity of the ocean can be detrimental to marine life
Anthropogenic CO$_2$

- Oceans serve as an atmospheric carbon sink.

- Since the 1980’s, oceans have absorbed about 30% of anthropogenic CO$_2$. (From a 0.1 pH decrease)

- CO$_2$ concentrations are predicted to be between 550-1000 µ atm by 2100. (Which will cause a 0.2-0.5 pH drop)
The Physics

• Fast moving molecules of a gas strike the ocean surface and dissolve

• Mixing of the ocean and atmosphere:
  - Waves
  - Eddy/wind interaction
  - Marine Life

• Mixing increases chance of reaction
The Biology
The Big Picture

High carbon emissions → Reduced carbon emissions

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The Chemistry

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

- Carbon dioxide “binds” with water, then breaks up into H\(^+\) to acifyify the ocean.

- Though, this just one of the possible reactions CO\(_2\) can take part in at the ocean surface.
• Lower pH means more HCO$_3^-$ and less dissolved CO$_2$
• Organisms have to expend energy to convert HCO$_3^-$ to CO$_2$, a reaction which is catalyzed with carbonic anhydrase
Effect on Marine Biota

The Breakdown of Calcareous Shells

\[
\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{HCO}_3^- + \text{H}^+ \quad \text{excess HCO}_3^- \text{ from CO}_2 \\
\text{H}^+ + \text{CO}_3^{2-} \rightarrow \text{HCO}_3^- \quad \text{carbonate combines with H}^+ \\
\text{CaCO}_3 \rightarrow \text{Ca}^{2+} + \text{CO}_3^{2-} \quad \text{calcareous shells break down}
\]

Net: \( \text{H}_2\text{O} + \text{CO}_2 + \text{CO}_3 \rightarrow 2\text{HCO}_3^- \)
Between 1751 and 1994 surface ocean pH is estimated to have decreased from approximately 8.179 to 8.104 (some other substances in the ocean tend to be basic).

Other ions buffer the changes so that the increase in H+ isn't strictly proportional to the amount of CO₂ (or H₂CO₃) added. *makes for a difficult calculation
Decreasing Calcification Rate

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

**Figure 1.** Potential impact of rising atmospheric \( CO_2 \) on coral reef calcification rate.
• When atmospheric CO2 reaches 450 ppm (projected to occur between 2030-2038), aragonite undersaturation is induced
• Species with aragonite (carbonate) shells cannot survive

Limacina helicina
Why is this Important?

- Plankton provide nearly 50% of the world’s oxygen
- Hypercapnia (acidification of body fluids) of sea creatures
- US fishery landings for calcifiers such as mussels, clams, and scallops were valued at $675 million in 2006 alone
- Talked about as solution for reducing CO2 emissions

Correlation with ocean temperature?
References

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