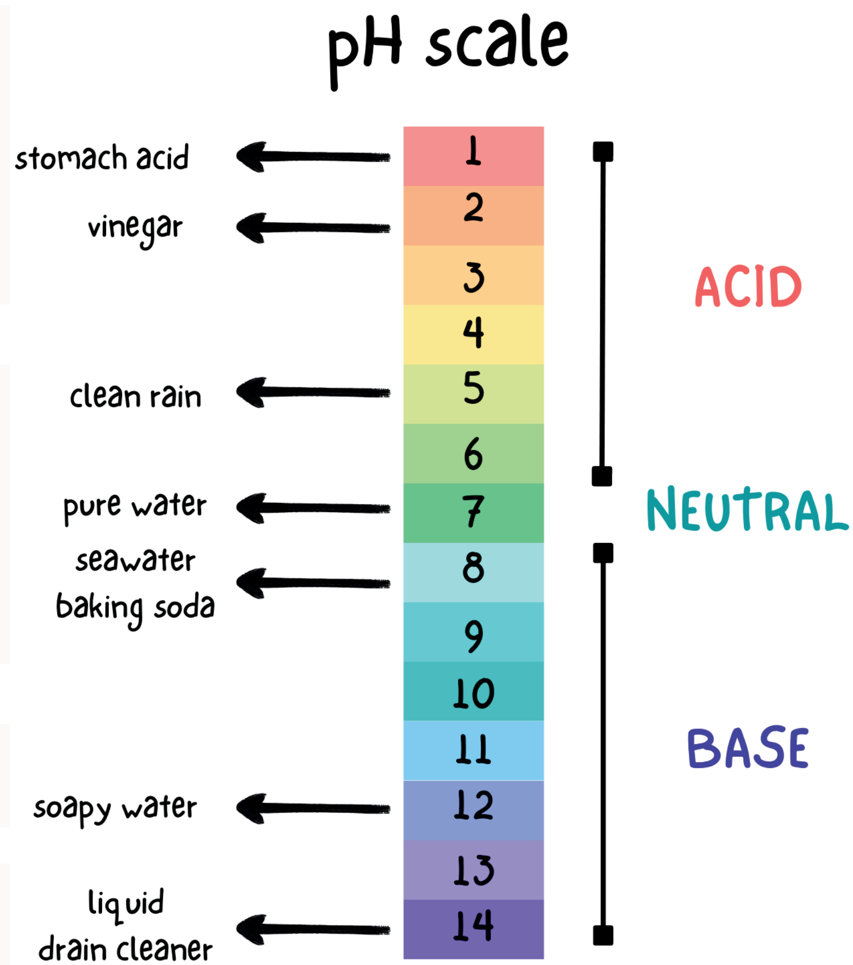
Ocean Acidification: Osteoporosis of the Sea

What are acids and bases?

Acids are chemicals with a pH less than 7 which donate a hydrogen ion during a reaction.
Bases are chemicals with a pH greater than 7 which accept a hydrogen ion during a reaction.

How do we measure pH?

Acids and bases are measured by the concentration of hydrogen ions in the solution and represented by pH with a scale of 1 to 14 with 7 considered neutral. The lower the pH, the more acidic a solution; the higher the pH, the more basic.



What happens when we mix acids and bases?

The reaction produces salt, water, and heat; thus changing its pH. A neutral solution is $pH = 7$. A solution with a $pH < 7$ is considered acidic, and a basic solution has a $pH > 7$. The more hydrogen ions a solution can donate, the more acidic it is.

What are the acids and bases in the ocean?

Weak Acid	Weak Bases		Measuring pH
CO_2	CO_3^{2-}	HCO_3^-	H^+
Carbon dioxide	Carbonate	Bicarbonate	Hydrogen ion

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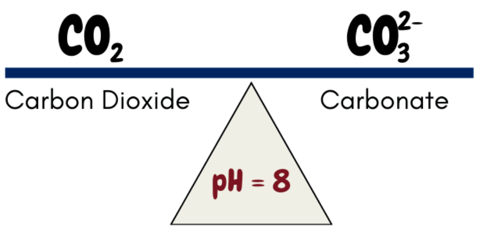
How does ocean acidification work?

Carbon dioxide and carbonate/bicarbonate naturally work together to maintain, or buffer, the pH in the ocean. Absorption of excess carbon dioxide from the atmosphere throws off their ability to balance the ocean's pH.

1

The ocean pH is approximately 8, more basic than freshwater (pH = 7), but not as basic as soapy water (pH = 12).



Note: In the ocean, inorganic carbon concentrations are not equal. Carbon dioxide is about 1%, carbonate 9%, and bicarbonate 90% of the total.

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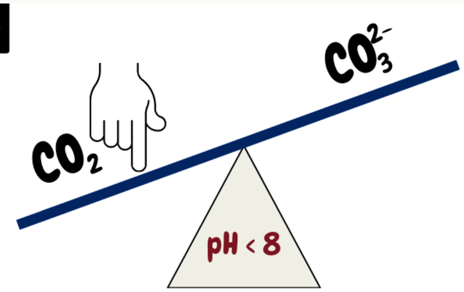

The ocean absorbs excess carbon dioxide from the atmosphere, where it reacts with water and carbonate to form two bicarbonate ions.

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

Bicarbonate

3

$$2HCO_3^- \rightleftarrows 2CO_3^{2-} + 2H^+$$

Hydrogen

These bicarbonate ions will then partially dissolve to form carbonate and hydrogen. The partial dissolution creates an equilibrium, represented by bi-directional arrows.

↑ CO_2 ↑ H^+ ↓ pH

Excess carbon dioxide forces the equilibrium to produce more hydrogen ions. These hydrogen ions acidify the ocean and reduce pH.

4

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

$$2HCO_3^- \rightleftarrows 2CO_3^{2-} + 2H^+$$

Bicarbonate and carbonate buffer the ocean against acidity. Because carbon dioxide reacts with carbonate immediately, the decrease in pH is not at severe as it would be if the ocean didn't have this buffer in place.

↑ CO_3^{2-} ↓ H^+ ↑ pH

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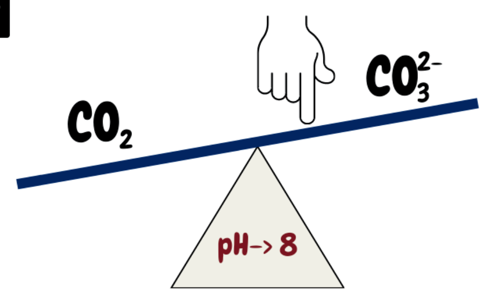

Currently, the region has enough carbonate to buffer against acidity. However, too much carbon dioxide will reduce carbonate availability, slowly increasing acidity and reducing pH.

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Shell-forming organisms, like clams, also need carbonate. They combine calcium, an abundant salt in the ocean, with the carbonate to form calcium carbonate.

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$$

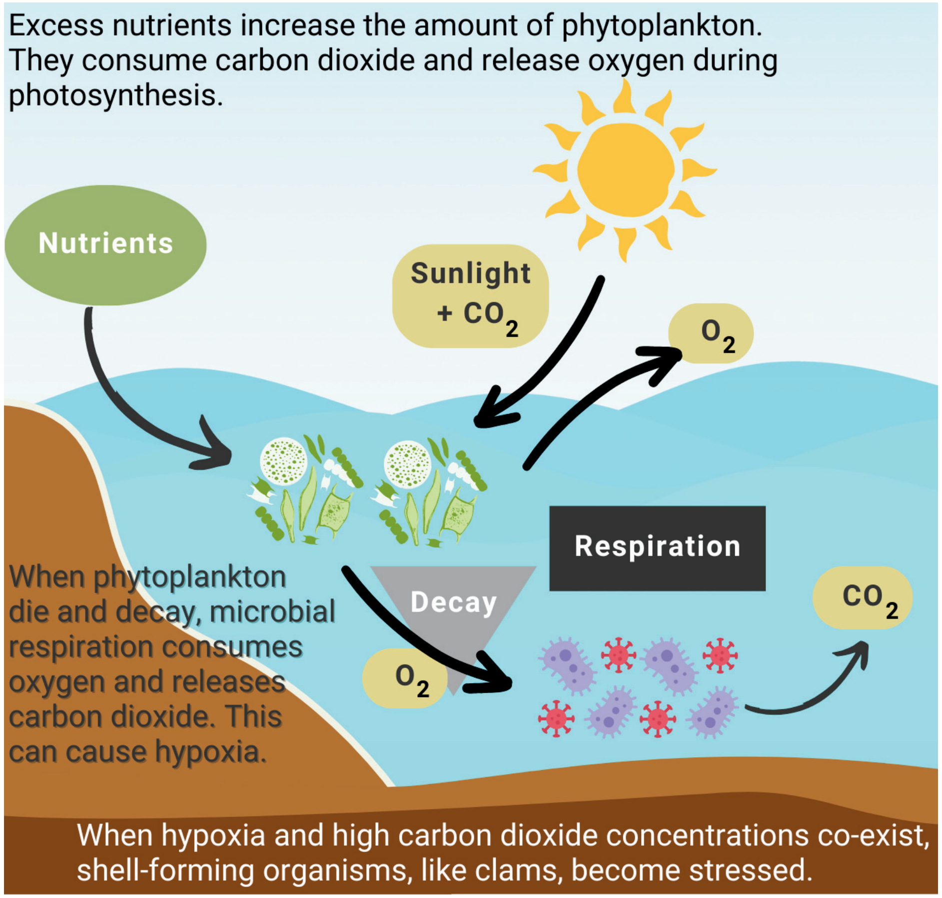
Calcium — Calcium Carbonate

Carbonate is necessary for shells. Increased carbon dioxide reduces carbonate availability, making it harder for shell-forming organisms to form their shells.

Osteoporosis of the sea

Osteoporosis is when bone creation cannot keep up with bone loss, resulting in bones that are weaker and break easily. Ocean acidification does the same to clams, oysters and coral. As pH decreases, shell creation cannot keep up with shell loss. **The shells become weaker, making animals more susceptible to predation or disease, resulting in smaller harvests.**

Wait, there's more?
When ocean acidification meets coastal waters



Carbon dioxide in coastal waters

Carbon dioxide concentrations are impacted by three things:

1. **absorption** into the water from the atmosphere
2. **release** into the water via respiration by aquatic organisms
3. **mixing** of freshwater with saltwater in estuaries

Carbon dioxide and hypoxia

Phytoplankton consume carbon dioxide through photosynthesis. When they die and decay, this enriches the growth of microbes that, in turn, consume oxygen and release carbon dioxide into the water via respiration. This can result in hypoxia.

In bottom waters, **hypoxia and increased carbon dioxide concentrations co-exist**, compounding stress felt by shell-forming organisms. Not only are these organisms unable to get enough carbonate to create their shells, they are also unable to escape the hypoxic conditions.

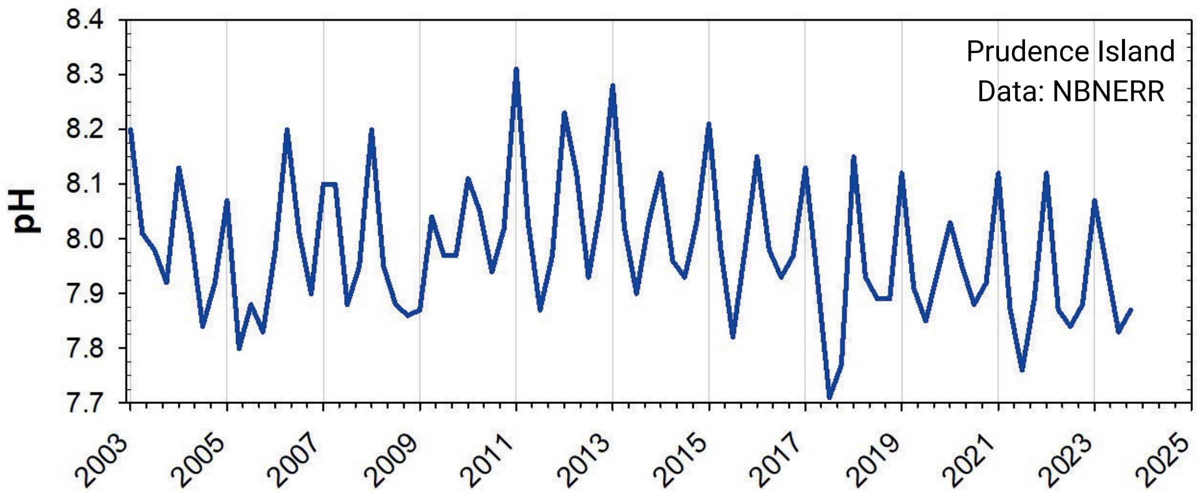
Freshwater input to coastal waters

Coastal waters receive freshwater from precipitation, runoff from land, and groundwater. Precipitation has a pH around 5, making it acidic compared to saltwater. Local groundwater flows over granite rock and contains tannins, which reduces the ability of the water to maintain pH and increases acidity, respectively. **Therefore, freshwater input can increase coastal water acidification.**

The combination of carbon dioxide sources (atmosphere, respiration, and freshwater input) is an added challenge to maintaining pH in coastal waters.

Should we be concerned?

Not at this moment. Long-term measurements of pH in the lower bay (Prudence Island) show a consistent, seasonal pattern with lower pH in the spring and summers when respiration is greatest.



Nutrient Reductions and pH

Using 15 years of data, local researchers found **no significant pH change in the surface waters**. They did note **bottom water pH significantly increased**. They believe this is a result of nutrient reductions which decreased the amount of phytoplankton sinking to the bottom and being respired.

What's next for the region?

Because of human-induced increase in atmospheric carbon dioxide concentrations, coastal waters will continue to absorb excess carbon dioxide. Hypoxia will naturally occur, despite reductions to nutrient loading. Narragansett Bay will always receive precipitation, runoff, and groundwater from land. The buffering capacity, the ability to maintain pH, of the surface and bottom waters will be impacted, and the water will acidify over time.

Local researchers and managers continue to **monitor pH and other water quality parameters**. Nutrient reductions will reduce excess phytoplankton abundance and microbial respiration, alleviating some of the stress felt by bottom-dwelling organisms by reducing hypoxia and carbon dioxide release. Researchers are also exploring how to increase coastal water buffering capacity.

Additional Resources

- NOAA Ocean Acidification Infographics
- Overview of Acidification in the Northeast Region
- Northeast Coastal Acidification Network

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