Ocean Acidification

Bonefish & Tarpon TRUST

Student Reading

pH Review

You likely learned about **pH** in your high school science classes and maybe even in middle school. pH is the measure of the concentration of hydrogen ions, which determines how acidic or how basic a fluid is. The scale runs from zero (a strong acid) to 14 (a strong base). Pure water has a pH of 7 and inside the human body it is around 7.35-7.45. Stomach acid, the body's liquid exception, is about a 3. Basically, any liquid in the world has a pH measure that falls on that 0-14 scale.

The pH of ocean water has been fairly **predictable** and stable for about 55 million years. But suddenly, the pH of ocean water is changing—fast. In fact, our oceans are becoming more acidic (pH is dropping) at what is likely an unprecedented rate. Ocean Acidification (OA), like so many other changes on our planet, is a consequence of global climate change caused by humans polluting Earth's atmosphere with carbon dioxide (CO_2) and other **greenhouse gases**, primarily through the burning of **fossil fuels** such as coal and oil.

Burning fossil fuels contributes the most air pollution in terms of greenhouse gases.

Chemical Processes of Ocean Acidification

The oceans suffer dramatic changes due to symptoms of climate change, including OA. Indeed, OA is a consequence of the oceans' roles as equalizers on our planet. They do so much more than produce valuable fish and reefs, or serve as seafaring highways for the transportation of goods and people. Oceans act as natural **heat sinks**, helping to keep temperatures on our planet regulated and predictable. They also absorb and **sequester** CO_2, which would otherwise be trapped above the water and lead to extreme increases in global air temperatures.

An increase in CO_2 in our atmosphere results in increased amounts of CO_2 being absorbed by our oceans. The increase in CO_2 in the oceans is causing a decrease in ocean pH, making the oceans more acidic. This change has been occurring at an alarming rate. In 1751, the average pH of the oceans was 8.25. This is known as the "pre-industrial" pH level. The **Industrial Revolution** of the 19th century, when factories began emitting greenhouse gases in volumes greater than any source in human history, began the era of human-caused climate change. The average pH today is 8.1. That change might not seem alarming, as it appears to be only a slight change. But pH is a **log measurement** ($pH = -\log[H^+]$), which equates to a 30% change! A change of minus 1 pH unit corresponds to a ten-fold change in the concentration of hydrogen ions and increases in acidity. If the rate of CO_2 absorption into the oceans continues as the same rate, we expect by 2100 to see an average global seawater pH of 7.80.

But the ocean is vast, and pH is not changing at the same rate in every place. Mauna Loa, Hawaii seawater has dropped from a pH of 8.1 to 8.06 in the last 20 years, while other areas are not experiencing major pH declines at all. While the average global seawater pH is expected to reach 7.80 by 2100, this prediction does not fully capture the extremes; in other words, pH in some places around the world may fall much lower.

Presently, OA is already causing many problems for marine life, and scientists worry that such an extreme drop in pH would devastate our oceans, along with many of the goods and services they provide.

Chemical Changes

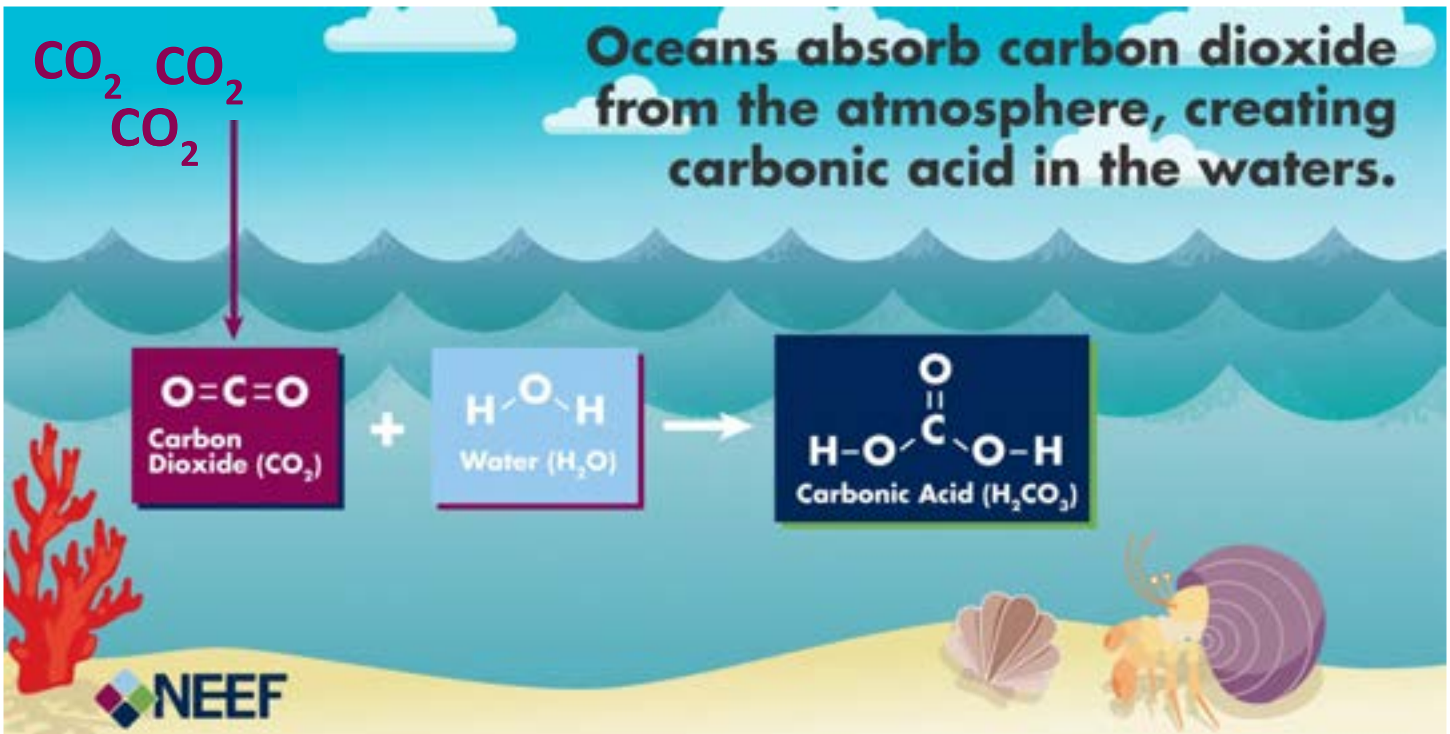


Image modified from NEEF: Carbon dioxide (CO_2) is absorbed by the ocean and transforms into carbonic acid.

How exactly does the water become more acidic? The CO_2 that the ocean absorbs changes into carbonic acid (H_2CO_3.) Carbonic acid is a very weak acid. It is the same acid found in your favorite soda drinks that gives them their appealing fizz, or "carbonation." But put enough H_2CO_3 in the oceans and it causes a **litany** of negative side effects related to the lowering of ocean pH. This carbonic acid in seawater turns into bicarbonate (HCO_3), which means that it loses one of its hydrogen ions and that hydrogen ion is free in **solution**. The bicarbonate then loses another hydrogen ion and transfers into carbonate (CO_3). More hydrogen ions in solution mean that the pH is lowered and the water more acidic. As this process occurs over and over again, and the number of hydrogen ions in the solution increases, many organisms become unable to **metabolize** or develop normally.

Mineral Consequences

As our oceans become more acidic, mineral molecules become more **soluble** as the acidic sea water weakens the molecules' ionic bonds, making it more difficult for calcifying plants and animals to absorb the minerals they need to grow. Increasingly acidic water lowers the availability of **carbonate minerals** such as **calcite** and **aragonite** (shown below) that many organisms need to form skeletons and other structures. Acidic waters essentially melt those minerals, using acid to dissolve them, instead of heat.

Aragonite, one of the crystalline forms of calcium carbonate.

How many times have your parents said, "Drink your milk?" They know that milk is an excellent source of calcium and other minerals that keep your bones strong as your bodies develop. Imagine what would happen to growth and development of humans and other animals if milk couldn't provide sufficient calcium and other vital minerals. That's what's happening in our oceans as the water absorbs CO2, which becomes carbonic acid. By reducing the availability of carbonate minerals, OA is starving marine life of the essential minerals needed to develop bones and shells – the same minerals that animals (including humans) get from milk and other mineral-rich terrestrial food sources. Tiny organisms called zooplankton and invertebrates such as shrimp and lobsters with calcium-based shells – as well as stony corals and certain beneficial algae found in seagrass meadows – are particularly at risk. So are **bivalves** such as clams and oysters, which need readily available carbonate minerals to build the shells that protect them and form important **reefs**.

'Winners and Losers'

Scientists predict that there will be "winners" and "losers" in increasingly acidic oceans. Some calcifying marine organisms may find other ways to get the minerals they need through a process of adaptation. But all living things are made of proteins and these proteins have very specific pH **parameters** in which they function. When those environmental parameters change so quickly, organisms such as corals, shellfish and **zooplankton** may struggle to adapt and may fail to evolve rapidly enough to persist on Earth. Consequently, scientists fear another **mass extinction** event in our oceans. Fossil records indicate that around 55 million years ago there was a rapid drop in oceanic pH and that a mass extinction event took place. No one knows exactly how severe the existential consequences of **anthropogenic** (human-caused) OA pH will be if current acidification trends continue or accelerate. But scientists agree that there will be extinctions of species that are unable to **evolve** rapidly enough.

Fisheries Context: Bonefish, Tarpon & Permit

You might be wondering what this chemistry lesson has to do with anything other than corals and shellfish. All things in an ecosystem are interconnected, and ocean chemistry is the ultimate common connection between water, habitats, forage (food) species and predators. For example, in a coral reef ecosystem complex food chains combine to form food webs that constantly impact thousands of species.

One group of species that may be negatively impacted by OA impacts are fishes that occur at various life stages in the deep blue ocean; on coral reefs; as well as adjacent seagrass and mangrove communities. Those interconnected ecosystems provide a number of services – including protection from predators and a diet of crustaceans for some of the world's most valuable fish species. Let's take a look at bonefish (*Albula vulpes*) tarpon (*Megalops atlanticus*), and permit (*Trachinotus falcatus*).

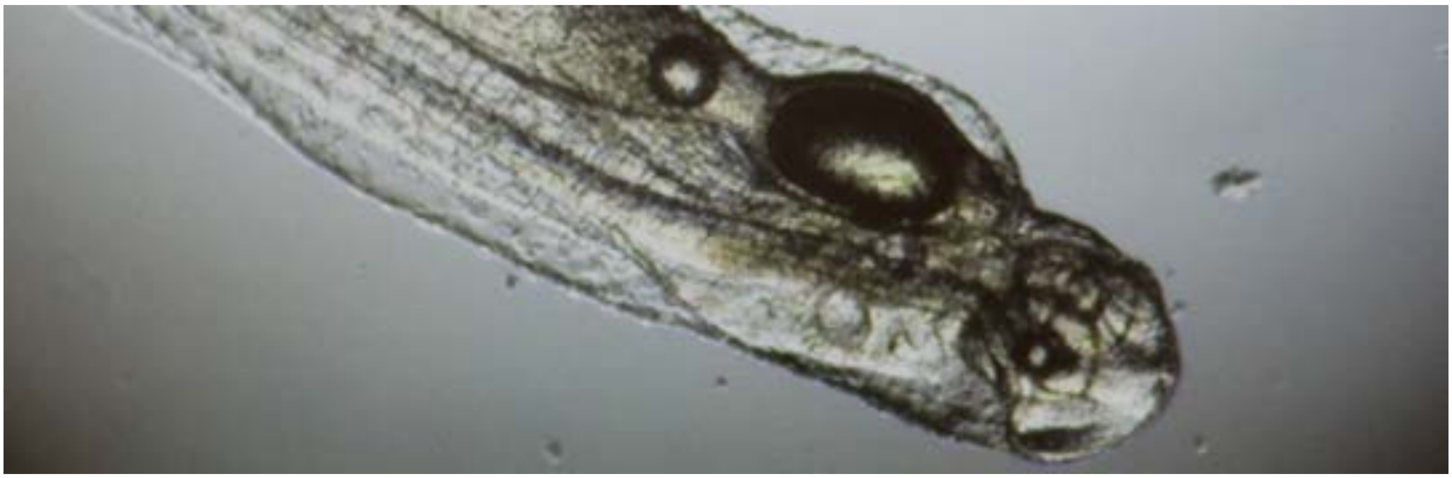
Recreational anglers—fishermen fishing for fun and a challenge—primarily pursue these three hard- to-target species. More people visit Florida to fish than any other place in the world, and historically Florida offered some of the world's best fishing for bonefish, tarpon and permit. Therefore, they are of massive social and economic importance for Florida and many other tropical and subtropical locations where recreational fishing tourism is a major economic driver. Economists estimate that saltwater recreational fishing in Florida produces at least $8 billion annually.

Life Histories

To understand how OA may affect bonefish, tarpon, and permit, you need to understand their basic biology and life cycles, known as "**life histories**," or "**ontogenies**." Through the courses of their lives, these species require several different but related habitats that provide forage and safety, as well as unique advantages related to spawning and **recruitment**. Early juvenile fish are said to "recruit" to the nursery areas that provide best for those young fish.

These species utilize different habitats during different life stages for a variety of reasons. Bonefish and tarpon share very similar life histories and provide interesting examples. Both have been on the planet for a very long time—more than 100 million years—and are related to eels. Indeed, as "leptocephalus" larvae, they look just like slender, transparent eels. We know that bonefish and tarpon spawn out in the deep blue ocean, and that their larvae spend a month or more in that clear-water environment, where transparency is an optimal "color" of camouflage.

Ocean currents and winds transport bonefish, tarpon and permit larvae toward coastlines that offer the specific habitats they need to “settle,” or transform from larvae in the open water to juveniles living on the bottom. Tarpon prefer mangrove creeks, while bonefish settle in shallow sandy or mud- bottomed areas of protected bays. As they mature, both species venture out into estuaries to forage in very different ways, but on some of the same things – including shrimp and crabs which require carbonate molecules to develop their shells. Permit, a species of jack, also begin their lives as fish feeding on tiny, calcifying invertebrates and “graduate” to larger crabs, shrimp, snails, and urchins as they mature.



Bonefish leptocephalus look nothing like their adult form, but their transparency provides camouflage in the open ocean.

OA Puts ‘Fish Food’ at Risk

Over the past decade, scientists have learned a great deal about bonefish and tarpon. Scientists at the Florida Atlantic University Harbor Branch Oceanographic Institute have even succeeded in fertilizing bonefish eggs in captivity, and now are attempting to figure out what to feed the fish in their leptocephalus stage. Researchers think that, in the wild, bonefish and tarpon larvae feed primarily on “marine snow.” Marine snow is an aggregation of calcite and aragonite – minerals that are essential for the growth and development of any organism with a shell or skeleton. The mineral compounds are held together by mucus secreted by **phytoplankton** (tiny plants) and bacteria. Marine snow is denser than ocean water, so it sinks slowly. As the compounds descend through the water column, much the way that snow falls from the sky, myriad organisms consume the minerals. The compounds also help to capture and store carbon on the ocean floor. Of course, as ocean water becomes more acidic, the compounds of this bonefish and tarpon “baby food” are becoming more soluble and presumably harder to capture.

Bonefish, tarpon and permit feed primarily in estuaries and other shallow ecosystems with extensive seagrass coverage. Bonefish and permit feed primarily on shrimp, crabs, and worms, among other invertebrates. Tarpon also feed on those invertebrates, and on a wide variety of forage fish species – some of which depend on small, **calcareous** invertebrates for their food. For example, tarpon eat menhaden, which eat plankton – the same plankton that suffer from the effects of OA. Though healthy estuaries–especially those with thriving seagrass meadows—appear to be acidifying at slower rates than ocean ecosystems, tarpon, bonefish and permit will struggle to persist if critical, calcifying prey species are diminished or eliminated by OA.

OA and Essential Habitats

Bonefish, tarpon, and permit share many habitat preferences in ecosystems threatened by ocean acidification, including coral reefs and estuaries containing seagrasses, bivalves and mangroves. We are still learning about how changes caused by ocean acidification impact these habitats. Permit, and to a lesser degree tarpon, frequent coral reefs, which are particularly vulnerable to OA. Bonefish also frequent what are called “back-reef flats,” the shallow areas on the inside of a coral reef that support certain corals, sponges and other calcifying organisms.

Corals and calcifying algae need minerals from the water column to grow, yet ocean acidification makes those minerals less available.

Corals are calcifying animals that build complex reefs full of colorful nooks and crannies that offer food, shelter, and cover in the form of ambush spots. Corals and some shellfish are negatively impacted by OA. Ocean acidification slows the rate at which corals grow their skeletons, and even chemically erode the limestone rock platform on which they grow.

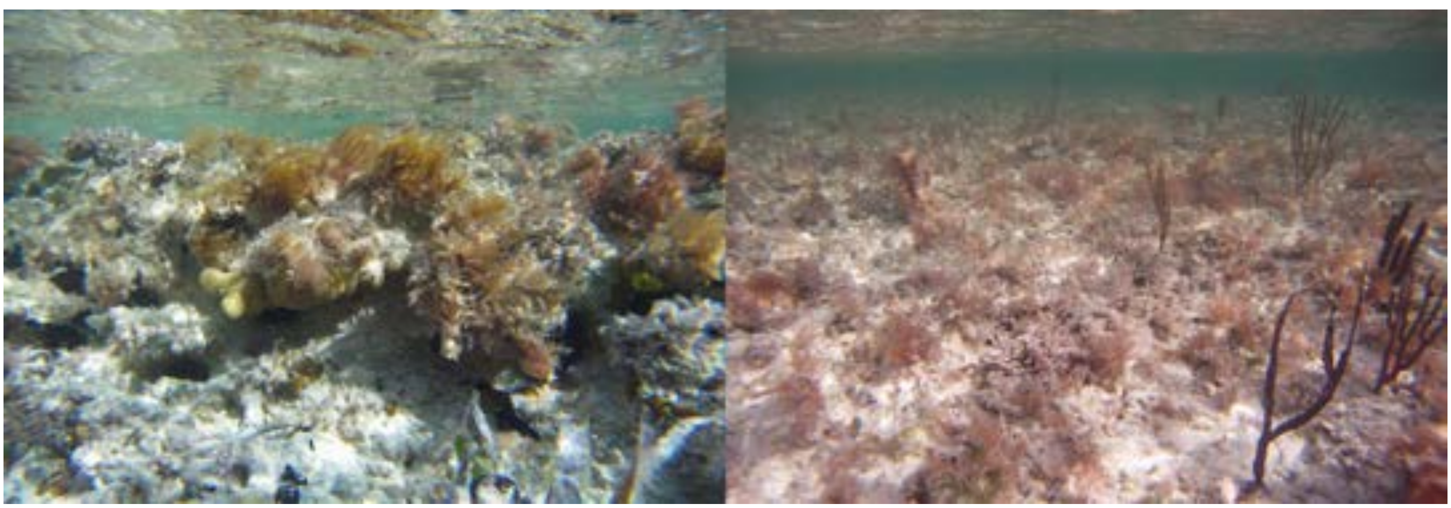
Virtually worldwide, coral reefs have been degrading rapidly over the past few decades, and recent research shows that some reefs in the Florida Keys are beginning to dissolve during certain times of the year from ocean acidification, which was not expected to happen for another few decades. A recent study by the United States Geological Survey (USGS) discovered that coral reefs off the Florida Keys have eroded from three inches to 2.5 feet and the scientists concluded that the corals won’t keep up with **sea-level rise**.

Related threats to coral reefs are warming waters and rising sea levels. As these combine with OA, coral reefs are at serious risk. As the planet warms, the oceans rise primarily because of thermal expansion. Warmer water is less dense than colder water so it takes up more space. Warming air temperatures are also melting ice in the Arctic and Antarctic, which adds tremendous volumes of water to the oceans. Besides hampering reefs from calcifying, rising seas and more turbid water due to erosion may prevent adequate light from reaching the reefs. This starves the beneficial bacteria called “zooxanthellae” that live symbiotically in corals and provide them with sugars for digestion (zooxanthellae are photosynthetic, so use sunlight to create these important sugars). **Coral diseases** then attack the corals’ weakened immune systems.

As sea levels rise, healthy coral reefs struggle to grow quickly enough to remain at the shallow depths they need to receive sufficient sunlight. This hurts their ability to flourish, to support fisheries, and to provide coastal communities with protection against storm surge during weather events such as hurricanes and nor’easters. Ocean acidification stunts coral growth and deprives them of foundation habitats. Therefore, in many places, corals are losing their ability to keep up with sea-level rise as acidic waters and other stressors prevent optimal growth rates.

Solutions, No Pun Intended

Scientists agree that we must reduce all other sources of pollution and other negative impacts in order to help estuaries and the coral reefs they support to survive. These are called “stressors,” and they include carbon pollution; nutrient pollution (phosphorus and nitrogen); sedimentation from dredging and coastal construction projects; physical impacts from vessels; and overfishing – especially overfishing of large adult fish that are needed to maintain fish populations through spawning.



Valuable fish species including bonefish, permit, and tarpon forage on backreef-flat habitats like these, which suffer carbon pollution.

Again, the oceans have already become significantly more acidic. Carbon dioxide takes a long time to cycle out of the atmosphere, and the oceans will absorb much of the CO_2 humans have already emitted. This causes coastal and marine waters to become even more acidic. Scientists agree that the situation will become worse before it becomes better. But there are two major ways that humans can help minimize the impacts of ocean acidification and other climate stressors.

1. First and foremost, humans need to create systems of incentives and regulations that dramatically **curb carbon dioxide emissions** and the emissions of other greenhouse gases through a rapid transition to clean energy technologies such as solar and wind power. This transition is an incredibly complex topic in and of itself, and requires cooperation on a community, state, national, and even international scale. We need to essentially overhaul how our society lives and functions. It is no easy feat, by any means. But it needs to happen fast.

2. At the same time, **it is essential to protect and restore coastal and marine ecosystems** – especially reefs and estuaries – from other sources of pollution and sedimentation. While this is still difficult and complex, there are more specific actions that we can take to make a difference on a daily basis.

Research indicates that pH levels are dropping more slowly in estuaries with healthy seagrass meadows and certain beneficial forms of algae. That's because plants need carbon dioxide to respirate and grow, so higher levels of CO_2 in the water column can encourage seagrasses and beneficial algae to grow more quickly. Then they uptake more CO_2, which reduces rates of acidification. However, in Florida (and around the world), seagrass habitats are generally in sharp decline due to other forms of pollution – primarily from excessive depositions of nitrogen (from inadequately treated sewage) and phosphorus from fertilizers that are used in agricultural and residential areas.

Sedimentation from dredging, pictured here, and other coastal construction, pose major threats to essential fish habitats.

Sedimentation from coastal construction and damage from boat propellers contribute to seagrass and reef decline. Organizations such as Bonefish and Tarpon Trust (BTT) have long advocated for coastal planning and zoning systems that protect seagrasses and reefs from careless watercraft operators and other activities that threaten the resources. For example, the Florida Keys National Marine Sanctuary is undertaking a "Marine Zoning Regulatory Review" that advocates hope will better protect seagrasses, reefs and spawning aggregation sites of species such as permit and others that often spawn in the same places – sometimes at the same time.

Because fish provide the ecosystems to which they belong with goods and services, such as maintaining a proper balance in food webs, and sweeping reefs clear of sediment, fisheries managers must keep fish stocks at healthy levels to keep ecosystems healthy. Fisheries managers in Florida already protect tarpon and bonefish from harvest, because they're far more valuable alive than dead and don't taste very good anyway. For species that are open to harvest, they are supposed to set science-based annual catch limits that ensure enough fish get to reproduce to maintain a healthy population. And in some places, spawning areas are protected from fishing.

The most important of these areas are called "multi-species spawning aggregation sites," and are often coral reefs that tower from great depths toward the edge of the continental shelf. One such area, known as "Riley's Hump" in the Dry Tortugas National Park is a known spawning area for permit, other jack species, and a variety of snappers and groupers. In order to protect the fish while they're making more of themselves to maintain healthy population levels, regulators have put this area off limits to fishing.

Seagrasses and beneficial algae aren't the only plants that are helping in the battle against climate change. Mangroves also provide a number of essential services, including **sequestering** CO_2 and providing protections against sea-level rise and storm surges.

Mangrove forests are one of the most promising "biosequesters" having the highest carbon net productivity among all ecosystems. It is estimated that coastal habitats store up to 50 times more carbon in their soils by area than tropical forests, and ten times more than temperate forests. By capturing carbon dioxide and storing it in their biomass, mangrove species are able to reduce the amount of excess carbon in the air, thereby lessening greenhouse gases' contribution to climate change – including the consequences of ocean acidification. Mangroves are especially suited for carbon capture because they pile most of their carbon in the bottom, while terrestrial forests keep most of it in trees and branches. Coastal environments like mangroves and seagrass meadows capture carbon from the air and water and use their long root systems to bury it deep within the soil. And they keep sequestering large amounts of carbon throughout

Red mangroves capture carbon pollution and store it in the soil. The roots stabilize the sediment that holds the carbon in place.

their life cycle. Coastal vegetation usually spreads deeper below ground than it grows above with some plants going as deep as eight meters. Rather than being stored in the plants, the majority of carbon stays locked away in the sediment below them where it can stay for centuries or even millennia, so only a relatively small amount is released when a plant dies. Thus, the longer mangroves and seagrass grow, the more carbon they store in the soil.

Mangrove roots also trap and stabilize sediments. Even as sea levels rise, mangroves are able to keep up in some places by accumulating sediments around their roots. They are also well-adapted to strong storms such as hurricanes. Again, their roots keep sediment trapped that would otherwise be released into the water column and block light for photosynthesizing organisms such as seagrass. And, they protect coastal communities from storm surge.

Interestingly, mangroves may also serve as one of the last redoubts of corals. Scientists have discovered reef-building corals growing in certain mangrove habitats that help create environmental conditions that protect corals from both ocean warming and ocean acidification. These types of natural environments and adaptations that show resilience to ocean acidification are surprising and offer hope. Protecting these types of environments is a local action that can be taken to help guard against the global threat of ocean acidification. These steps are essential if we are to preserve priceless fisheries such as bonefish, tarpon and permit.

Highlighted Vocabulary from student reading:

Anthropogenic

Originating from human activity

Aragonite

A mineral composed of calcium carbonate, typically found in sea shells and in hot springs

Bivalve

A mollusk with a shell that has two pieces and which is hinged together in one spot. Examples are oysters, clams and mussels.

Calcareous

Containing calcium carbonate

Calcite

A common mineral made of calcium carbonate.

Carbonate minerals

Minerals containing the carbonate ion CO32-

Evolve

Develop gradually, especially from a simple to more complex form.

Fossil fuels

Fuel consisting of the remains of organisms preserved in the Earth’s crust with high carbon and hydrogen content

Greenhouse gases

Gases that contribute to the “greenhouse effect” or warming of the planet through absorption of infrared radiation.

Heat sinks

An object that absorbs heat from the surrounding environment

Industrial Revolution

A period of transition to newer mechanical processes, the increasing use of steam power and the invention of the factory manufacturing era. It occurred roughly between 1760-1850.

Litany

Long and tedious, multiple

Log measurement

The exponent required to produce a given number.

Mass extinction

A sharp decrease in the number of species in a relatively short period of time.

Metabolize

Physical and chemical processes that occur within a living organism to maintain life

Parameters

A feature that distinguishes one thing from others

pH

Measure of the hydrogen ion concentration. The measure of the alkaline or acid content of a solution.

Predictable

Able to be predicted or known ahead of time.

Recruitment

When a juvenile organism joins a population, either by birth or immigration.

Sea-level rise

The increasing depth and distance onshore of the high tide mark due to increased water levels from melting sea ice and glacial formations.

Sequester

To isolate or hide away.

Solution

Homogeneous mixture composed of two or more substances.

Zooplankton

Animal type of plankton, usually refers to larvae or small crustaceans