Ocean Acidification

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 solution 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, 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

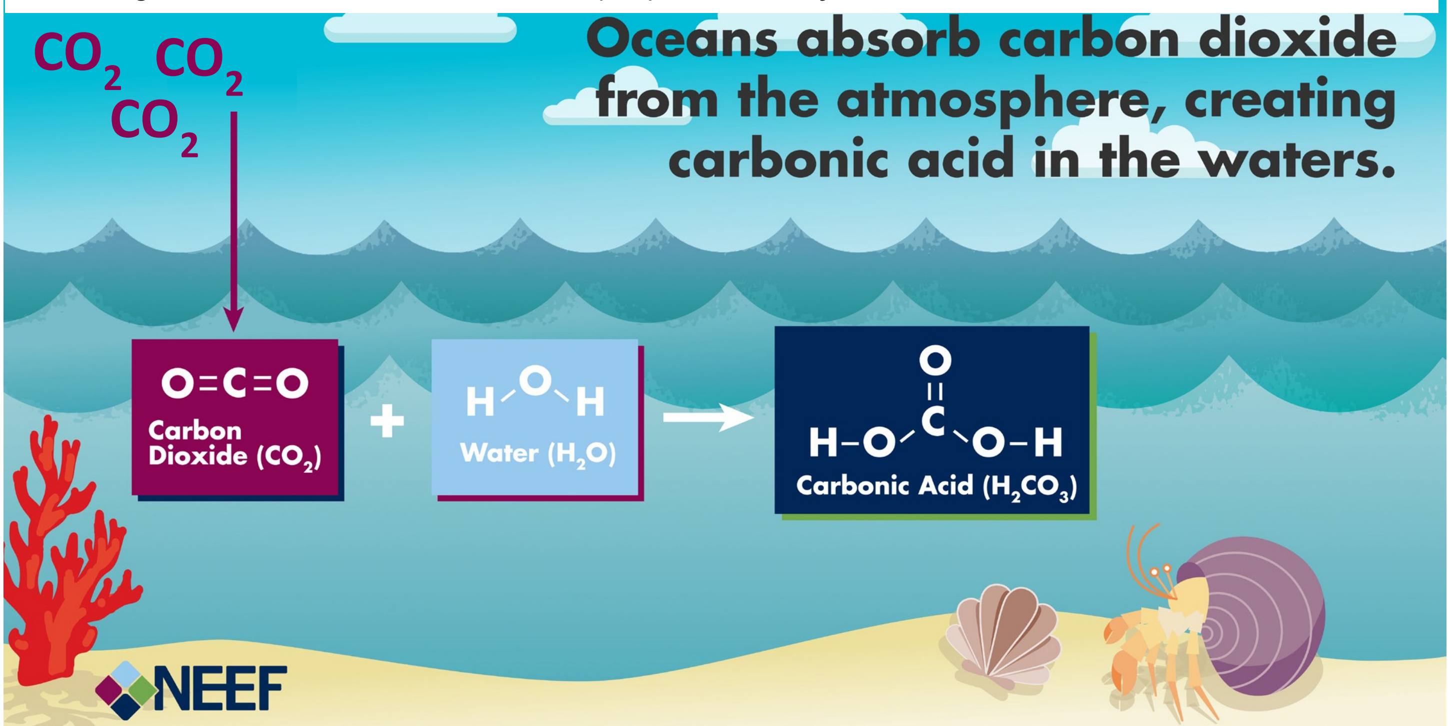
The oceans suffer dramatic changes due to symptoms of climate change, including ocean acidification. Indeed, ocean acidification is a consequence of the oceans' roles as equalizers on our planet. They do so much more than produce valuable fish and reefs, or serve as seafaring highways for the transportation 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, ocean acidification 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.

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



Chemical Changes

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 organisms 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, ocean acidification 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. Soare **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) ocean acidification 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 ocean acidification 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*).

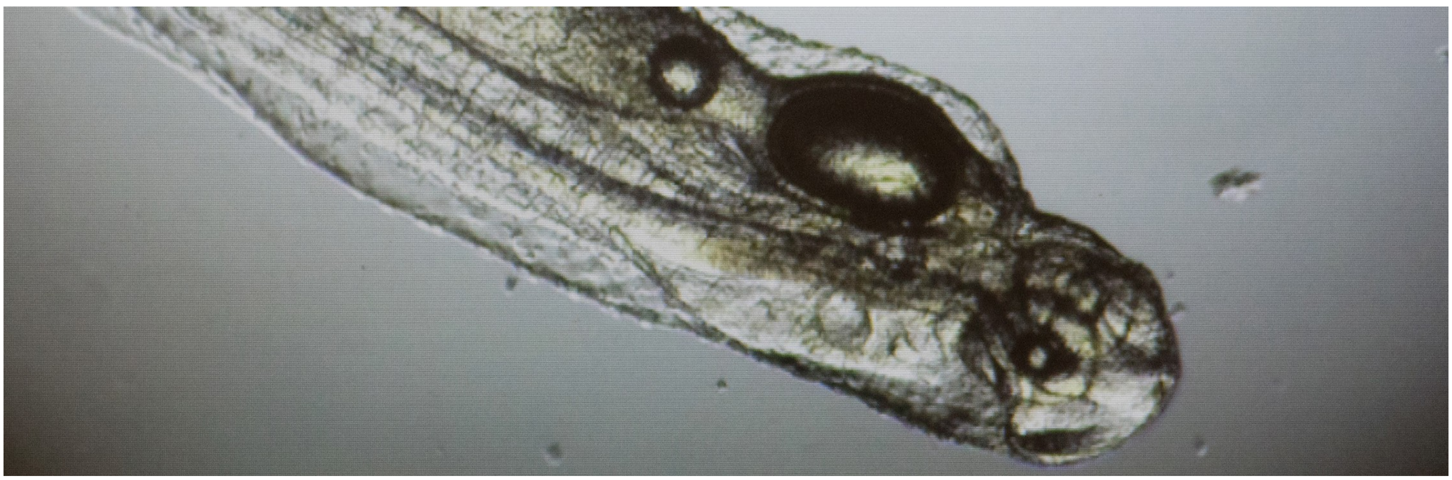
Recreational anglers—fishermen fishing for fun and a challenge—primarily pursue these three hard- to-target species. More people visit Florida to fish than any other place in the world, and historically Florida offered some of the world's best fishing for bonefish, tarpon and permit. Therefore, they 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 ocean acidification 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 species 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.

Ocean Acidification 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, photosynthetic organisms) 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 ocean acidification. 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 ocean acidification.

Ocean Acidification 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 ocean acidification. 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 ocean acidification. 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 (7.6 cm to 76 cm) and the scientists concluded that the corals won't keep up with **sea-level rise**.

As if the challenges of building their skeletons in a more acidic ocean wasn't enough of a challenge, corals also have to deal with the threats posed by warming waters and rising sea levels. 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. The 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 the corals with sugars for digestion (zooxanthellae are photosynthetic, so they use sunlight to create these important sugars). The lack of sugars (energy) from the xoothanthellae means the coral has less energy available fight off diseases.

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.

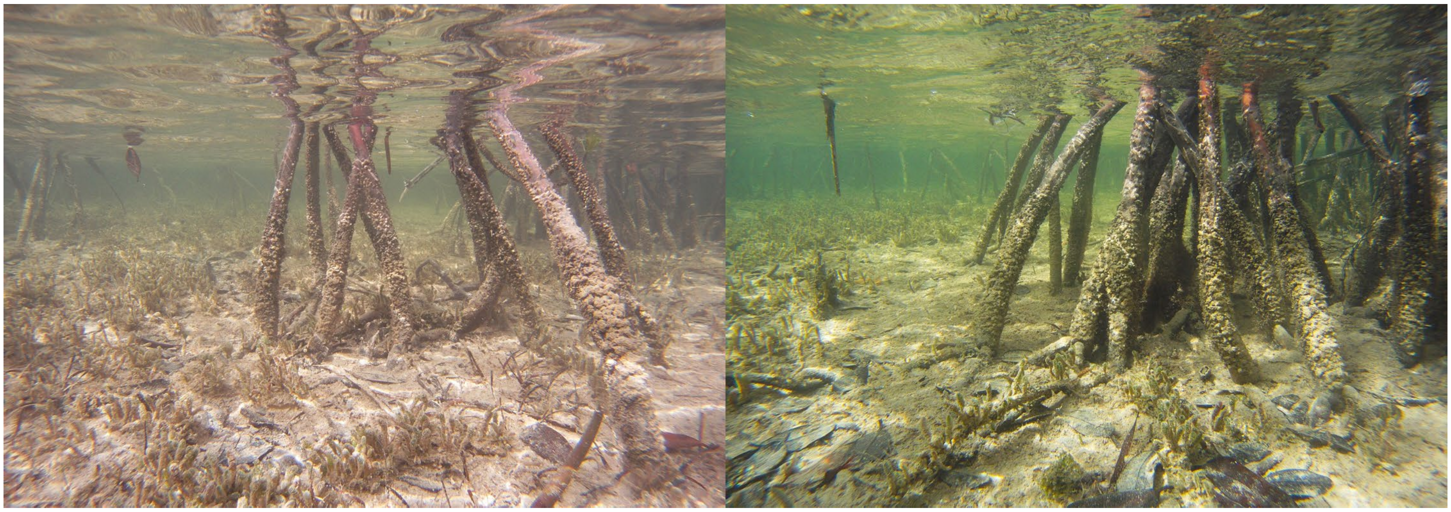
Sedimentation from coastal construction and damage from boat propellers contribute to seagrass and reef decline. Organizations such as Bonefish and Tarpon Trust (BTT) have long advocated for coastal planning and zoning systems that protect seagrasses and reefs from careless watercraft operators and other 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.



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

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 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

Caused by or emanating from human activity

Aragonite

A form of calcium carbonite (one Carbon, one Calcium, three Oxygens – $CACO_3$) that forms a unique structure that makes up the skeletons of corals and shells of molluscs.

Bivalve

A mollusk with two shells which are hinged together, such as oysters, clams, scallops, and mussels.

Calcareous

A term to describe something that contains c calcium carbonate, as in calcareous algae

Calcite

A form of calcium carbonite (one Carbon, one Calcium, three Oxygens – $CACO_3$) that forms a unique hexagonal structure. A calcium carbonite mineral with a different physical structure than aragonite. .

Carbonate minerals

Minerals containing the carbonate ion CO_3-

Evolve

To develop through the process of evolution, from one adaptive state to another.

Fossil fuels

Materials used as fuel by humans that formed from the remains of live organisms in the geological past, such as oil, natural gas, coal, containing high levels of carbon and hydrogen.

Greenhouse gases

Gases that absorb the infrared portion of solar radiation, thus trapping heat in the earth's atmosphere.

Heat sinks

A substance or object that absorbs heat from the surrounding environment

Industrial Revolution

The transition from a mainly farming and rural economy and society to one based on industry and machines, which greatly increased the burning of fossil fuels.

Litany

Long and tedious, multiple

Log measurement

The exponent required to produce a given number.

Mass extinction

The extinction (complete disappearance from earth) of a large number of species in a short amount of geological time.

Metabolize

The process of metabolism, which is the breakdown of substances that are used for energy or storage, and generate waste products.

Parameters

A measurable factor that distinguishes or classifies a system or part of a system.

pH

Measure of the hydrogen ion concentration in a solution, which is on a scale from 0 – 14: alkaline is a pH > 7; acidic is a pH < 7..

Predictable

Able to be predicted or known ahead of time.

Recruitment

When a young (juvenile or larva) organism joins a population.

Sea-level rise

The increase in the level of the earth's oceans due to seawater expanding as it warms, and melting glaciers and sea ice.

Sequester

To isolate or hide away.

Solution

A liquid mixture composed of two or more substances that are uniformly distributed within the liquid.

Zooplankton

Animal (organism that consume other organisms as food) plankton which have limited mobility so drift in water currents.

Ocean Acidification- Tic Tac Toe Choice Board

Instructions: Using the board below please choose two additional activities to complete. ALL STUDENTS must complete box 5.

1 Watch https://youtu.be/qAkhuETYn5U After watching this YouTube video write a one paragraph summary of what ocean acidification means for the world's oceans. Do you believe that a drop of 30% in pH in the past 200 years is alarming? Why or why not? Give specific evidence as to why this drop in pH might be a real issue for species living in the oceans.	**2 Write** a screenplay or conversation between three scientists who are studying ocean acidification. Be sure to include facts and information from online sources that you research. You may choose the setting and situation, but it must include 3 scientists and details. Your screenplay or conversation should take at least 5 minutes to perform.	**3 Create** a model of a species that will be impacted by ocean acidification. This model can be 3D or 2D and should be in color. Some ideas for your model would be a fish species impacted, a coral species impacted or a representation of a taxa group that will be impacted by increased ocean acidification. Detail should be paid to make the model lifelike and realistic in whichever media you choose.
4 Watch https://www.youtube.com/watch?v=8m1X26Auw6Q and write 3 paragraphs about the video. In the video many scientific graphs are Used. In your own words explain what at least one of the graphs is showing; what the X and Y axis points on the graph are; and how this information relates to evidence of ocean acidification. Your response should be in complete sentences and follow proper grammar rules.	**5 Watch** https://youtu.be/GL7qJYKzcsk and while watching this video be sure to take notes. After watching the video please create a quiz along with an answer key to your quiz on a separate sheet of paper. This might require you to watch the video twice or in smaller segments. Your quiz should have a combination of true/false, multiple choice and short answer questions. You will be having a classmate take your quiz (and you will take theirs) so do not make it "impossible" and also not too "easy".	**6 Research** ocean acidification using the material found at https://ocean.si.edu/ocean-life/invertebrates/ocean-acidification Pick one section on this site to read. After reading the section write a two paragraph summary of the section. Be sure to include (a)what the section was about, (b)the issues or solutions regarding ocean acidification that were presented and (c) any other information that you feel is valuable.
7 Develop a plan on how the general public could be made aware of ocean acidification and its impacts on the marine environment. In this plan, you should discuss the target audience, how you will craft your message, how you will distribute your message and some basic topics/facts that should be included in your message. You can combine this box with number 9 and create a product from this outreach campaign such as a t-shirt, website landing page, Facebook or Instagram post or other creative means that you can think of.	**8 Draw** a diagram depicting ocean acidification using research from the Internet. Your diagram can be on impacts to species, the role of the ocean in carbon sequestering or the dramatic rise in CO_2 levels or drop in oceanic pH over a period of time.	**9 Choice**: Create a lesson building activity of your own! The only requirements are that you clear the project with your teacher, the project must be directly tied to ocean acidification and this project should take 30-45 minutes to complete.

Ocean Acidification

Turning curiosity into scientific research

Grade Level: 9th – 12th

Lesson Summary:

Climate change has a multitude of effects, one being the acidification of our oceans. This lesson explains why oceans acidify as human release carbon dioxide into the atmosphere and describes the effects of mild pH change on the ocean's inhabitants. Students perform three tasks related to the topic through a "Tic Tac Toe Choice Board."

Standards:

SC.912.L.17.4 – Describe changes in ecosystems resulting from seasonal variations, climate change and succession.

SC.912.L.17.12 – Discuss the political, social, and environmental consequences of sustainable use of land.

SC.912.L.17.14 – Assess the need for adequate waste management strategies.

SC.912.L.17.16 – Discuss the large-scale environmental impacts resulting from human activity, including waste spills, runoff, greenhouse gases, ozone depletion, and surface and groundwater pollution.

LAFS.1112.WHST.3.8 – Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text.

LAFS.1112.WHST.3.9 – Draw evidence from informational texts to support analysis, reflection, and research.

Project Activity Assessment

Student choice is an excellent way to help your students dive deeper into complex issues such as ocean acidification. Giving students the ability to choose their learning path allows for greater buy-in on their part as well as improved final product quality. This Tic Tac Toe activity is developed in a way that learners of various types of abilities and interests have the opportunity to choose what activities they will complete. There are activities that require additional research, some require creative ability while others only require the student to use the information presented in a video or reading. Students drive their own, personal learning experience in learning menus. If done digitally, this format also allows for the creation of a Google folder on ocean acidification for a digital gallery walk of student work. This would allow students to see each other's responses and learning related to the topic.

Procedure:

- Students should read the "Ocean Acidification" document prior to class, taking notes and referring to the vocabulary listed at the bottom of the reading.

- Refer to the "Tic Tac Toe" choice board, and explain that each student must complete 2 boxes <u>in addition to</u> box 5. By all students participating in box 5, you have the ability to start here, come back together for a class discussion before moving on or coming together after assignment completion for the discussion.

- Below you will find a brief overview of each block, the purpose of the task as well as additional extension activities if you choose to add them.

Box	Purpose of the task	Extension activities
1 Watch https://youtu.be/qAkhuETYn5U After watching this YouTube video write a one paragraph summary of what ocean acidification means for the world's oceans. Do you believe that a drop of 30% in pH in the past 200 years is alarming? Why or why not? Give specific evidence as to why this drop in pH might be a real issue for species living in the oceans.	This is a fast (2 minutes) video with animation that gives a brief overview of the main points behind ocean acidification. This video is a wonderful choice for students who are on level or below level due to the short length and verbal and visual manner in its delivery. This video is a good "hook" for students.	You could group students together and ask them to do their own video on ocean acidification or another environmental concern that they have. The students could take it from storyboard to completion once they have presented their board to you.
2 Write A screenplay or conversation between three scientists who are studying ocean acidification. Be sure to include facts and information from online sources that you research. You may choose the setting and situation, but it must include is 3 scientists and details. Your screenplay or conversation should take at least 5 minutes to perform.	This activity is perfect for your more creative kids. It requires them to think of the dialogue between professional scientists while making them research facts and figures that they otherwise might not be interested in. This activity is geared to make a student who loves drama or creative writing take time to critically think about scientific facts that they might otherwise be less enthralled with.	Students could pick classmates to act out the or dialogue within the class. This would be an excellent way to showcase a student's work while also continuing the learning due to the need for the activity to have science-based data and facts in the script.
3 Create a model of a species that will be impacted by ocean acidification. This model can be 3D or 2D and should be in color. Some ideas for your model would be a fish species impacted, a coral species impacted or a representation of a taxa group that will be impacted by increased ocean acidification. Detail should be paid to make the model lifelike and realistic in whichever media you choose.	This activity is geared towards your more artistic kids. They will create a model of a species in the media of their choosing. Based on the supplies you have available the sky really is the limit on what could be created. It might be helpful to add on the requirement of labeling portions of the model so that it better resembles a scientific drawing, sketch or model in which key areas or pieces are labeled for added clarity.	If a student is computer savvy this model could be done digitally. If your school or classroom has access to 3D printing technology then the model could be uploaded to that and printed.
4 Watch https://www.youtube.com/watch?v=8m1X26Auw6Q and write 3 paragraphs about the video. In the video many scientific graphs are used. In your own words explain what at least one of the graphs is showing; what the X and Y axis points on the graph are; and how this information relates to evidence of ocean acidification. Your response should be in complete sentences and follow proper grammar rules.	This video is a 10 minute Ted Talk. This presenter has an accent so ELD students might find it difficult to follow the video. This video is very basic in its introduction of ocean acidification and covers main topics related to climate change and ocean acidification and would help make this topic understandable.	Students could research a specific aspect of ocean acidification such as animal impacts, carbon footprints, future outlooks or scientific reports related to current conditions with climate change. Students would then take this researched material and present it in their own personal Ted Talk which could easily be filmed with a laptop or smartphone.

5 Watch https://youtu.be/GL7qJYKzcsk and while watching this video be sure to take notes. After watching the video please create a quiz along with an answer key to your quiz on a separate sheet of paper. This might require you to watch the video twice or in smaller segments. Your quiz should have a combination of true/false, multiple choice and short answer questions. You will be having a classmate take your quiz (and you will take theirs) so do not make it "impossible" and also not too "easy."	This activity is a great one for visual learners since it is fast paced, attractive, modern and also very clear in it's messaging and visuals. Lower level students could be pushed towards this video and likely experience success with it. This video should be done prior to any other activities since it acts as a topic introduction.	A great extension for this video would be for visual arts capable students to complete an animation of their own. They could create their animation on diving deeper into a topic or portion of this video that they liked or even digitally animate their questions which they wrote on the actual assignment related to this choice item.
6 Research ocean acidification using the material found at https://ocean.si.edu/ocean-life/invertebrates/ocean-acidification Pick one section on this site to read. After reading the section write a two paragraph summary of the section. Be sure to include (a) what the section was about, (b) the issues or solutions regarding ocean acidification that were presented and (c) any other information that you feel is valuable.	This report is academically challenging but easily readable material. A student who is an avid reader would find this material to be quite understandable and also in depth.	The student could take the information researched in the reading and create a short news story, blog post or other written product which could be shared in a school newspaper, a class newsletter or similar outlet.
7 Develop a plan on how the general public could be made aware of ocean acidification and its impacts on the marine environment. In this plan, you should discuss the target audience, how you will craft your message, how you will distribute your message and some basic topics/facts that should be included in your message. You can combine this box with number 9 and create a product from this outreach campaign such as a t-shirt, website landing page, Facebook or Instagram post or other creative means that you can think of.	This item is geared towards a student with a focus in relationship building, public speaking or marketing. A creative student would be able to complete this choice item and likely enjoy the process.	This task is recommended to be done in conjunction with box 9. If this combination is done then the student will create an example of their outreach product.
8 Draw a diagram depicting ocean acidification using research from the Internet. Your diagram can be on impacts to species, the role of the ocean in carbon sequestering or the dramatic rise in CO2 levels or drop in oceanic pH over a period of time.	An artistic student with either hand drawn art skills or whom is digitally capable would thoroughly enjoy this topic. This diagram could be as elaborate or simple as you feel they are capable of.	The student could create a class anchor chart or digital product that could be shared on a class website etc. This chart could be used throughout the lesson on ocean acidification and is an excellent way for visually talented students to display their abilities.
9 Choice: Create a lesson building activity of your own! The only requirements are that you clear the project with your teacher, the project must be directly tied to ocean acidification and this project should take 30-45 minutes to complete.	This topic allows for student creativity and free thought.	The extension possibilities to this choice are open to your imagination as an instructor.

Project Activity Rubric

AREA	1 Does Not Meet Expectations	2 Partially Meets Expectations	3 Meets Expectations	4 Exceeds Expectations
Science Content	NONE. Student does not exhibit or express the concepts of ocean acidification with clear and defined examples.	SOME. Student exhibits a basic understanding of ocean acidification but does not convey its problems.	MOST. Student grasps the concepts ocean acidification but lacks mastery of the subject.	ALL. Student grasps the principles of ocean acidification. Student can draw comparisons.
Use of Scientific Vocabulary	NONE. Student does not use any introduced concept or use scientific vocabulary to form thoughts and narrative.	SOME. Student attempts to use scientific jargon, but fails to use it properly or in context. Shows some mastery of science language, but fails to use effectively.	MOST. Student uses significant scientific jargon, but fails to identify all principles and concepts. Student exhibits some mastery of scientific concepts and vocabulary.	ALL. Student effectively communicates using scientific jargon and vocabulary to convey narrative. Student has achieved mastery of vocabulary and concepts.
Project completeness	Project was missing more than one major component OR prompts were not answered.	Project was missing one major component OR prompts were not fully answered.	Project contained all components but they were not as complete as they should have been, OR answers to prompts were missing a few key details.	Project or answer to prompt was fully completed, and all important information was present.
Conventions	Spelling, capitalization, and punctuation issues are significant and distract from clear communication and narrative.	Spelling, capitalization, and punctuation errors are present and distract from the story's narrative.	Few spelling, capitalization, and punctuation errors.	No spelling, capitalization, or punctuation errors.