
Sea Level Rise
Bonefish
& Tarpon
TRUST
Student Reading

Introduction

Rising seas is one effect of human-induced climate change that carries with it many consequences. Seas are rising largely because the world's oceans have absorbed more than 90 percent of the heat trapped in the atmosphere by **greenhouse gases,** such as methane (CH_4) and carbon dioxide (CO_2). In fact, 2018 set a new record for ocean heating. If that becomes a trend, which is likely, scientists say even higher sea-surface temperatures will accelerate sea-level rise.

Rising air temperatures cause our oceans to warm, and expand. When water is heated, the kinetic energy of that material increases. Its atoms and molecules move about more. Each atom will take up more space due to its movement, so the material will expand. That's mainly why the seas are rising.

Rising sea levels, especially coupled with intense, heat-fueled tropical cyclones, increasingly jeopardize Florida's coastal habitats, fisheries, and tourism-dependent communities. The threats are direct and indirect, and some human policy and engineering responses to those threats actually damage the ecosystems and the fisheries.

The degradation or loss of essential fish habitats such as coral and nearshore reefs, natural sandy beaches, and estuarine habitats such as seagrasses and **bivalves** can undermine efforts to manage fisheries sustainably. Bonefish, tarpon, permit, and snook are some of Florida's most important fisheries that are threatened directly and indirectly by sea-level rise and the accompanying weather changes like more intense hurricanes.

Climate Change: How it Works

Greenhouse gases are called that because methane, CO_2 and their partners in crime warm the atmosphere by absorbing infrared heat from the sun, which is reflected off the warm earth's surface. Like a blanket, they prevent heat from escaping the atmosphere into space. Heat remaining in the atmosphere causes a cycle of releasing other greenhouse gases trapped in ice and frozen ground, and even heats the earth's surface. This cycle is an example of a **"feedback loop,"** which causes a "greenhouse effect."

You may have visited a greenhouse, where farmers growing plants will pump CO_2 into the enclosed structures – which are essentially enclosed atmospheres like the Earth's – so that the buildings are warmer and the unnaturally high level of gas helps plants grow faster. But what is advantageous for growing plants in a controlled setting is harmful to the dynamics of planet Earth – especially to our coasts and oceans.

Source: US EPA. For a video explaining how the greenhouse effect works, [visit this link.]

How do these gases rise into the atmosphere, heat the planet, and in turn cause ocean levels to rise around the planet? A few major ways that humans are disrupting the earth's climate include:

- Burning fossil fuels, including coal and oil-based products such as gasoline. Coal is most often used to fuel power plants, while oil-based products fuel power plants as well as automobiles and vessels with internal combustion engines instead of batteries charged by renewable energy source devices.

Greenhouse gas pollution increases the greenhouse effect, causing the planet to warm, and seas to rise.

- Some agricultural practices – such as turning over soil before planting, called "tilling" – can release massive amounts of CO_2 that was sequestered in the ground. Breaking up the land and the ground cover before the farmer plants a crop for the season allows carbon to chemically react with oxygen to form – guess what? – carbon dioxide.
- Deforestation – the practice of clear-cutting vast areas of jungle and forest – releases the CO_2 absorbed

by the plants, and can expose the carbon in soils to oxygen, which turns it into CO_2. Since the plants in the forest take in CO_2, the loss of plants means that less of the CO_2 we are producing can be taken out of the atmosphere.

- As the planet warms, permafrost melts. Permafrost is ground located above or near the Arctic circles that is usually frozen year-round. The permafrost contains CO_2 and CH_4 that's nowbeing released, causing the planet to warm even more quickly.

Reasons for Sea-Level Rise

As seas rise, and hurricanes intensify, beaches want to retreat landward. Buildings, seawalls and policies that encourage building along receding shorelines leave no room for beaches to maneuver. We're losing our beaches, which support bonefish and permit.

- **Thermal expansion:** When water heats up, it expands. About half of the sea-level rise over the past 25 years is attributable to warmer oceans simply occupying more space.

- **Melting glaciers:** Large ice formations such as mountain glaciers naturally melt a bit each summer. In the winter, snow – primarily from evaporated seawater – is generally sufficient to balance out the melting. Recently, though, persistently higher temperatures caused by global warming have led to greater-than-average summer melting as well as diminished snowfall due to later winters and earlier springs. That creates an imbalance—more runoff and less snow—causing sea levels to rise.

- **Loss of ice sheets in Greenland and Antarctica:** As with mountain glaciers, increased heat is causing the massive ice sheets that cover Greenland and Antarctica to melt more quickly. Scientists also believe that meltwater from above and seawater from below is seeping beneath Greenland's ice sheets, effectively lubricating ice streams and causing them to move more quickly into the sea. While melting in West Antarctica has drawn considerable focus from scientists, especially with the 2017 break in the Larsen C ice shelf, glaciers in East Antarctica are also showing signs of destabilizing. Please review, Vital Signs of the Planet: Artic Sea Ice Minimum.

History of Sea Level Rise

Because of greenhouse gas emissions, global average sea levels have swelled more than nine inches (23 cm) on average since 1880. Florida's coastal waters have risen by about eight inches since 1950 and are now rising at a rate of about one inch every three years. Given Florida's low elevation, and porous geology, the rate that the water is rushing into **groundwater sources** and over landscapes is alarming.

What set these dramatic changes in motion? The beginning of rapidly accelerating rates of sea-level rise coincides with the historical period known as the "**Industrial Revolution**." Prior to that era, manufacturing was often done in homes and small shops by hand. After the revolution, there was a significant increase in the number of factories – and a shift toward the use of specially designed machinery and mass production that depended on fossil fuels. Energy consumption increased, and burning copious amounts of coal—a fossil fuel—provided most of that energy in the early years. The advent of the **internal combustion engine** in the early 20th century also ignited a rush to discover and exploit the world's oil resources.

Power plants, factories and automobiles – along with industrial farming practices – opened some of the proverbial "chimneys" that continue to belch greenhouse gases into the earth's atmosphere at dangerous rates. Besides the aforementioned practice of tilling, industrial food systems are energy-intensive, and based on farm machinery and crop transportation equipment that depend on fossil fuels. Meanwhile, synthetic fertilizers and pesticides are increasingly likely to wind up in public waters, where we fish, due to more intense rain events and sea-level rise from climate change.

Subsidence Sidebar:

Some places are sinking while the seas rise. Coastal Louisiana is an extreme example: the land is **subsiding** because the creation of channels and levees on the Mississippi River has deprived the region of replenishing sediments at the same time sea levels continue to rise. Essential fish habitats – including marsh grasses and oysters – are being lost at a rate comparable to one football field per hour. Entire fishing communities are suffering economic losses. Some communities even have to relocate away from the rising waters.

Florida, on the other hand, isn't rising or falling significantly. Most of the state sits on a limestone rock foundation—fossil reef—that hasn't shifted significantly in elevation despite having been covered and uncovered by ocean waters many times throughout the peninsula's geologic history.

Nonetheless, Florida's geology places the state at a major disadvantage in the face of rising seas. Florida's porous limestone foundation acts like a sponge, one that allows water to pass right through it. The limestone and sand beneath our feet rule out many traditional engineering solutions. For example, armoring Florida's shorelines with seawalls and other manmade structures damages or destroys natural habitats such as beaches and vegetated estuarine shorelines, while providing little protection against flooding. Seawater flows right under seawalls through the porous ground, bubbling up wherever it can from below. Add a little rain on top of a higher-than-average tide, and perhaps some storm surge, and the freshwater, which isn't as dense as saltwater, just pools up on the surface.

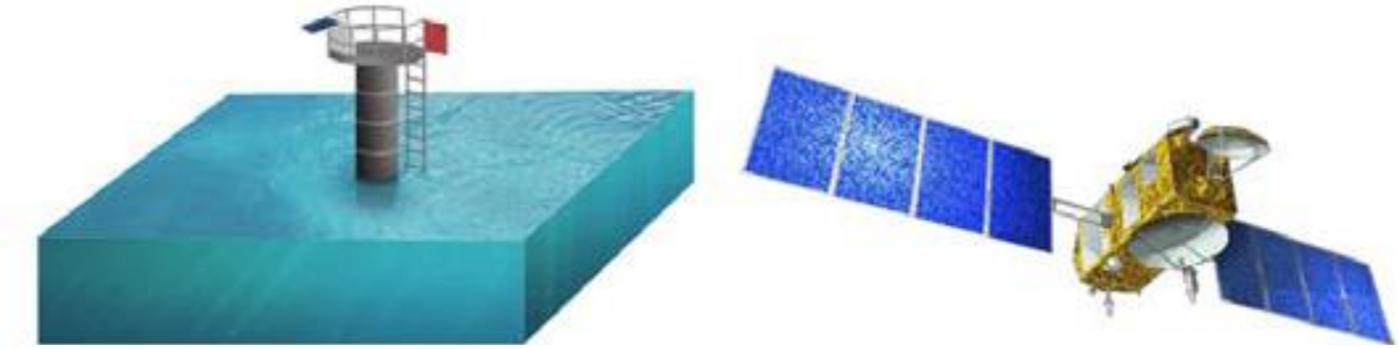
In Miami-Dade County, for example, the groundwater levels in some places are not high enough relative to the rising sea level. This has allowed saltwater to intrude into the drinking water, invade contaminated septic systems, and compromise sewer lines. This flooding allows dangerous contamination of drinking water supplies and coastal waters. As the saltwater intrudes, the fresh ground-water, which is less dense, rises to levels that flood septic systems, and causes human excrement to flow into the water table. Add rain, and the water rises even higher, possibly to levels that cause flooding. Many storm drains and sewer lines are coupled, and flooding overwhelms their capacities, causing direct discharges or spills from ruptures into neighborhoods and fish habitats.

Bay Batiste, Louisiana is an extreme example of coastal erosion. See the time-lapse here.

Small Numbers, Big Impacts: Measuring Sea-Level Rise

How do we know that sea levels are rising, how fast they are rising, and that greenhouse gas emissions are to blame? For accuracy's sake, scientists rely on multiple data sources including tide gauges, satellite measurements, and fossil records.

1. **Tide Gauges** record sea level constantly. They show the trends that present local relative sea level (RSL) – not the global sea level trend. The level of the ocean can also change because the underlying land is rising or falling with respect to the ocean surface. Such relative sea level change usually affects a local or regional area, and in numerous cases such as Louisiana, subsidence (or, conversely, uplifting) is actually outpacing the rate of sea level change. Global sea-level rise is the mean or average of sea levels around the world; however, like the earth, our oceans are not flat. Tide gauge measurements are made with respect to a local fixed reference on land, and measurements are a combination of sea-level rise and the local vertical land motion. Keep in mind that high and low tides happen one or two times apiece per day, depending on where you are in Florida. Moon phases and about thirty other factors also influence tide levels. Sea-level rise is measured as the average increase in water level above the normal fluctuations of the tides.



Tidal Gauge and Satellite.

How can gauges measure sea-level rise accurately while bobbing around on the water? Despite waves, wind and currents, those gauges are designed to precisely measure water levels. A tide gauge is a large (one foot/30 cm or more in diameter), long pipe with a small hole below the water line. This pipe is often called a **stilling well**. Even though ocean waves are changing the water level outside the gauge constantly, they have little effect inside the gauge. The sea level can be read relatively accurately inside this pipe. If scientists read them on a regular basis over a time span of years and then average those levels, they can arrive at an accurate trend reflecting local sea level.

With tide stations of the National Water Level Observation Network operating on all U.S. coastlines, the Center for Operational Oceanographic Products and Services has been measuring sea level for more than 150 years. Center personnel compare and average these data to check for consistency, and to make sure that outliers aren't providing misleading conclusions. For example, a short-term local spike in sea surface elevation—caused by a passing storm—could suggest extremely alarming rates of sea-level rise unless it is averaged monthly across a long period of time.

2. **Satellite altimeter radar measurements** can be combined with precisely known spacecraft orbits to measure sea level on a global basis with unprecedented accuracy. A series of satellite missions that started with TOPEX/Poseidon (T/P) in 1992 and continued with Jason-1 (2001– 2013) and Jason-2 (2008–present) estimate global mean sea level every 10 days with an uncertainty of only 3–4 mm.

   Tide gauge data are used to validate ocean models and to detect errors and drifts in satellite altimetry. Compared to satellite data, tide gauge data offer a longer record and finer temporal resolution but coarser **spatial resolution**. Individual gauges in site-specific areas simply can't provide as much geographic "coverage" as satellite measurements.

3. **Fossil records** in sediments provide geologic evidence of rates of sea-level rise. One type of organism called foraminifera, or "forams" for short, provide strikingly accurate illustrations of rates of sea-level rise. Forams are single-celled amoebas called protists. Their Latin name means "hole borers" because the organisms dig homes into the sediments of marshes and other water bodies.

   Forams only live in narrow depth ranges (less than 10 cm in total vertical range) in the sediment, so fossil **assemblages** can be sampled using **sediment cores**. As sea level rises, the vertical location of the 10 cm band of fossil organisms also corresponds to those changes. Cores are taken from tubes that geologists use to bore—in this case vertically—into sediments to varying depths in order to understand the past through layers of sediment and fossils. Because forams lived in narrow depth ranges in the sediments, the fossil assemblages can be accurately related to sea-level rise.

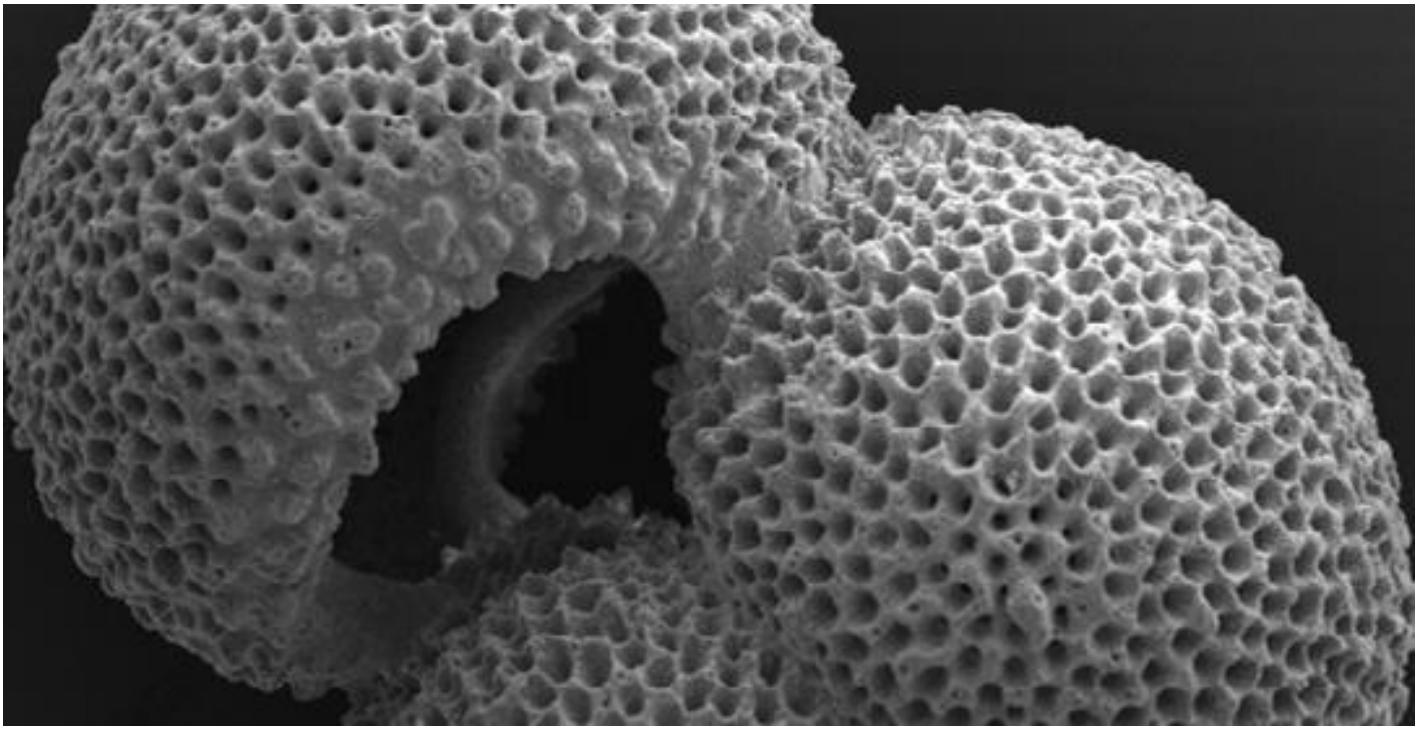


Photo: Dr. Gavin Foster. Image of foraminifera through a microscope.

There's strong agreement between data from the foraminifera-based sea-level curve and tide gauge records – enough that the foram assemblages allow scientists to reconstruct rates of sea-level rise from times before humans had any instruments to measure it. In fact, the fossils buried in coastal sediments can give us an idea of sea levels before and after the Industrial Revolution, for the sake of comparison. Both sources of data indicate an acceleration of sea-level rise that continues today. Tide gauge data, satellite data, and foram data all show similar rates of sea-level rise that coincide with rising inputs of greenhouse gases.

The science is clear: tide gauges, satellite telemetry and fossil records prove that sea-level is rising in direct proportion to increased CO2 levels.

Predicting Rates of Rise

Scientists are uncertain how fast the ocean will warm and how quickly the ice will melt. They expect water levels to continue to rise faster, but are not sure just how fast. Scientists from the National Oceanic and Atmospheric Administration (NOAA) use a global forecast, which offers six projection curves. You can look at those projections here.

Scientists project rates of rise using probabilistic models. Probabilistic models incorporate **random variables** and **probability distributions** into the model of an event or phenomenon. While a deterministic model gives a single possible outcome for an event, a probabilistic model takes into account the fact that we can rarely know everything about a situation, especially with an issue with as many complex variables as sea-level rise. There's nearly always an element of randomness to take into account, so probabilistic models provide a range of outcomes.

The rate at which the glaciers and ice sheets will melt is the big unknown in predicting sea-level rise rates.

Because of variables such as ice losses in the Arctic and Antarctic, models suggest estimates as high as eight meters by the end of the 21st century, which means that planning for worst-case scenarios is wise. In the shorter term, NOAA puts the low-end average for the Fort Myers area at .89 feet and the high end at 2.89 feet, by 2050.

"Drowning" Essential Fish Habitats

In places around Florida, and in many other parts of the world, sea levels are rising so quickly that essential fish habitats such as coral and oyster reefs struggle to grow fast enough to keep apace. They must remain at depths shallow enough to receive sunlight – or in the case of oysters and other bivalves, have access to the tiny plants called "**phytoplankton**" that provide them with nourishment. Plankton primarily occurs in the upper inches of the water column, and filter-feeding bivalves must be close enough to the surface to capture them.

For example, scientists have documented drowning islands and reefs in the Ten Thousand Islands National Wildlife Refuge, which is one of Florida's most popular and frequently visited fishing destinations. Two organisms formed the foundations of those islands: oysters (*Crassostrea virginicus*) and a reef-building snail called a gastropod.

The Ten Thousand Islands as we know them were only formed about 3,500 years ago by reef-building gastropods including *Vermetus (Thylaeodus) nigricans*. Let's call them snails for short. To put that in historical perspective, the Egyptian Empire built the pyramids in the Middle East around then. And people began to write using Cuneiform "letters" instead of communicating only with pictures. In less than 200 years, human activities have reversed many of the processes that created this international treasure. The speed of climate change's impacts to the Ten Thousand Islands speaks to the destructive powers of humans.

Most outer islands in Ten Thousands Island National Wildlife Refuge, such as Coon Island, pictured, are rapidly disappearing because of the combined forces of sea-level rise and incredibly powerful hurricane, like Hurricane Irma, which made landfall in 2017.

The snails, which disappeared for unknown reasons, lived close together in a very confined niche between the high-and low-water marks – a vertical distance of about one meter. As juveniles, they would graze about; as adults they'd form corkscrew-shaped shells that overlapped – shell upon shell – to build massive, pie-plate-shaped structures. The snails secreted a mucus on the substrate that trapped food for themselves and their offspring. The mucus also emitted a chemical signal that allowed their young to find them, and settle amid and atop their parents – over and over again.

While the submerged snail reefs offshore formed protective barriers from strong waves, the shallowest reefs became the foundations of outer islands that support rich, diverse **fauna** and **flora.** Today, federal laws classify those reefs as **Essential Fish Habitat,** which offers them some legal protection in addition to the rules and regulations in the Ten Thousand Islands National Wildlife Refuge. The islands formed when winds and storms piled sand on the reefs, providing enough sediment to support the roots of a succession of vegetation. Those plants ranged from red mangroves on the water's edge to buttonwood hammocks on the islands' highest elevations.

Once established, the vegetation essentially provided its own compost by dropping leaves that decayed into organic soils, providing nutrients for further growth. The trees and shrubs also secured the sediment and helped trap more sediments transported by wind and waves. Meanwhile, the pie-plate formation of the islands allowed lagoons to form in the middle of many of them, which providing lenses of potable fresh water for mammals including the Calusa Indians.

Sea level rise means that shallow water species must grow quickly in order to get enough sunlight.

Stable sea levels also allowed red mangroves, which trap sediment under their spidery prop roots, to expand the islands by colonizing the waters surrounding them. Each of these islands became parts of ecosystems that support the entire food web: insects and invertebrates such as mosquitoes and crabs; birds that feed on them while roosting in the trees or fish swimming in the mangroves; and the apex predators such as bottlenose dolphins and sharks that feed on the fish swarming around the shorelines. Because of the protection they provide and the forage sources they support, red mangroves are one of the important essential fish habitats found in Florida.

Sea-level rise reverses the geological and ecological progress of these ecosystems. The submerged reefs offshore formed protective barriers from strong waves. But as they deepen, more water comes over the reef during normal weather, and rushes in destructively during storm events. As a result, the outer islands are eroding, and drowning, along with the habitats they support. These include trees such as red mangroves that provide essential fish habitat, and other species such as black mangroves, white mangroves, and

Red mangrove prop roots trap sediment, grow shorelines seaward, and offer excellent protection against storm surge and sea-level rise. They are also essential fish habitat.

buttonwoods that provide important habitat for birds, crabs and insects.

Closer to the mainland, the islands are more linear because they formed atop oyster reefs. Oysters **colonize** and build reefs at angles facing into currents to set themselves up to filter feed throughout the incoming and outgoing tides. As sea level rises, the islands built upon fossil reefs are drowning, and the living oyster reefs struggle to keep a high enough elevation to persist and provide their vital ecosystem goods and services.

Oysters filter water and provide shelter and ambush points for thousands of species while feeding many fish like the black drum; birds like oystercatchers; and terrestrial animals such as raccoons. Without these oysters serving as living water purifiers, and without the structure and food they provide other members of the ecosystem, fisheries production will decline, and places such as the Ten Thousand Islands won't draw as many fishermen and other tourists as they once did. The ecological costs of sea-level rise in terms of losses of fish habitats equate to economic losses for communities such as Everglades City, Chokoloskee, and Marco Island/Naples.

Sewage and Runoff

In 1973, President Nixon signed into law the Clean Water Act – landmark legislation designed to protect people and wildlife from point-source and nonpoint source pollution. The legal definition of the term "point-source" in section 502(14) of the Clean Water Act is any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agricultural stormwater discharges and return flows from irrigated agriculture. The term "nonpoint source" refers to any source of water pollution that does not meet the legal definition of "point-source".

Hundreds of billions of dollars were spent on wastewater infrastructure improvements. In Florida, the results were quick and positive: seagrass coverage in Sarasota and Tampa bays returned to World War II-era levels, primarily because utilities quit dumping raw sewage into those waters, and treated it instead.

Sea-level rise and more extreme wet weather events flood septic tanks and overwhelm sewer systems. Harmful algal blooms, like the cyanobacteria pictured, thrive off nutrients from human excrement, which also release diseases into waterways.

Unfortunately, the majority of Florida's wastewater treatment systems are now inadequate, ailing, or failing in the face of sea-level rise and more extreme wet weather events such as rainier hurricanes. In some cases, population growth has exceeded treatment plant capacities. Lateral lines–the pipes that connect our homes and businesses to sewer mains—have rusted, cracked or decayed, depending upon what they're made of. Meanwhile, sewer mains and lift stations become overwhelmed during flood events caused by higher-than-normal tides and rainfall, causing raw sewage to spill into gutters that carry the pollution and contamination into nearshore waters.

The latter issue is becoming an increasing problem as sea levels rise and climate change causes wet weather events to become more extreme. Meanwhile, as the water table rises, it floods out septic tanks, which trap solids but allow fluids from human excrement to flow freely through the state's porous geology into surface waters.

Raw or partially treated sewage is one of the most harmful sources of pollution in terms of impacts on marine life. It provides a concentration of phosphorus and nitrogen that is "superfood" for about 24 species of harmful algae – including the infamous red tide (*Karenia brevis*) and the blue-green Cyanobacteria that periodically appears on Lake Okeechobee and blooms dramatically in coastal estuaries where it encounters nutrient pollution from septic tanks and other sources of inadequately treated sewage.

Additionally, flooding related to sea-level rise carries myriad other pollutants into surface waters – including synthetic fertilizers used in agriculture, animal wastes, and petrochemicals. Point-source or nonpoint-source, all of those pollutants create water quality issues that threaten essential fish habitats such as reefs, seagrasses and bivalves that are responsible for fisheries production.

Policy and Engineering Responses: High Costs and Big Risks

If we are to protect our most valuable fisheries, for example, the tarpon pictured, coastal management policies must change.

By and large, elected officials have ignored the growing threats of sea-level rise and more intense hurricanes, or enacted or defended short-sighted policies in response to those gathering threats.

The Federal Emergency Management Agency's National Flood Insurance Program is one of the most notorious and contentious of taxpayer-subsidized government programs. It provides incentives for people to live in harm's way. For example, flood-zone residents and business owners know that the federal government will bail them out after a disaster. They can rebuild in exactly the same place, in the same way, with the money from the insurance payouts. Additionally, the insurance policies encourage flood-plain property owners to "mitigate" flood risk, which could involve armoring a shoreline or draining polluted stormwater quickly into nearby water bodies.

Tarpon are one of many species being impacted by loss of mangrove habitats.

Florida's 1995 Bert J. Harris Jr. Private Property Rights Protection Act also creates problems for public trust resources including ecosystems and the fisheries they support.

For example, a property owner may want to build a house that relies on a septic tank next to a creek that is essential habitat for juvenile tarpon. But the water table will rise with even a modest rise in sea level, and/or in the event of a strong, wet storm. This sends untreated human excrement flowing into the nursery. If a regulating jurisdiction or agency told the property owner that he/she must not build there, the property owner could file a lawsuit demanding monetary reparations by arguing that the government impacted her/his property value.

While less than ten percent of Bert Harris claims are successful, just the threat of Bert Harris Act litigation usually causes elected officials to avoid denying building permits, or restricting other activities, even when those uses of the property will impact the value of a public trust resource—in this example the state-owned waters where the baby tarpon spend their earliest and most vulnerable days. The costs associated with hiring experts in this legal field are so high that government entities often cave into the property owner.

Real estate development interests have often succeeded in forcing a political narrative of climate change denial, which results in policies that continue to encourage people to build and live in dangerously flood-prone areas. Also, when flooding occurs due to an extremely high tide and/or storm event such as a hurricane, emergency permits for shoreline armoring or other "shore-protection" projects are often issued without much consideration for environmental impacts. In fact, emergency declarations can essentially waive a citizen's right to oppose the project in a court of law. While some engineering responses are needed in light of sea-level rise—such as water treatment upgrades including septic-to-sewer conversions and stormwater retrofits—others, such as coastal armoring projects and massive dredge-and-fill projects, are usually unnecessary – especially when we consider the costs assumed by fisheries and the ecosystems that support them.

Case Study Sidebar

If you're interested in becoming a lawyer or a policy expert to protect fish and wildlife, the arena of law and policy related to public trust resources and sea-level rise provides exciting new intellectual and political challenges. Indeed, it is a blossoming arena of legal research and litigation, one where the cutting edges of science, policy, and law meet. Early **case law** decisions – a set of past rulings by tribunals to be cited as precedent – are now being set. A **precedent** provides judges with guidance on future, related legal questions.

Climate change has caused hurricanes to intensify in terms of wind speeds, storm surge, and rainfall. Sea-level rise only adds to the flooding and pollution.

One of the early precedents, the famous Jordan vs. St. Johns County, known as the "Castles in the Sand" case, involved a beachfront road that provided a handful of property owners with access to their properties. Road building by the state had encouraged more development on a spit of sand between the Atlantic Ocean and a local river. The "new" road continuously washed out, and St.

Johns County decided it was neither possible nor affordable to continue to maintain it. The property owners sued, arguing that failing to maintain the road constituted taking of their properties. One judge ruled, importantly that a taking must be "affirmative in action." In other words, the fact that the road fell into the ocean was a fault of the waves – not of the county's willful intent to damage property values.

The Castles in the Sand case included many important rulings. Using the journal article above, please explain the implications of one to three of these rulings for future coastal management.

Armoring

Seawalls, bulkheads, and other manmade hard structures are usually built near the water's edge along barrier island beaches and shorelines of lakes, rivers and estuaries. Developers, builders and engineers often replace natural features such as vegetated sand dunes, mangroves, and marsh grasses with such structures, destroying habitats that provide far superior ecosystem benefits of fisheries production and storm and flood protection.

Seawalls destroy beaches by reflecting waves that scour out the beach, causing it to lose elevation, width and ecological functions.

—Sand dunes, which provide essential habitats for animals such as ghost crabs and sea turtles, absorb waves during storm events the way a punching bag responds to a fist: the sand moved by the energy is just redistributed left, right, and to the rear. Vegetation such as dune grasses, railroad vines, and sea grapes helps hold sediment in place.

—Red mangroves are sometimes called "walking trees" because their roots run out into the water, trapping sediment beneath them, and holding the shoreline in place. They provide an effective first line of defense against sea-level rise and storm surge. Black and white mangroves also offer protection shoreward of red mangroves.

—Marsh grasses, such as *Spartina sp.,* also hold sediments in place and slow the advance of rising waters, especially during storm surges which are magnified by sea-level rise.

On the other hand, coastal armoring replaces all of those natural functions with rigid barriers that accelerate erosion and increase turbidity. When waves from storms and boat wakes smash into seawalls and other hard structures, the waves are reflected back into open water or along the shoreline without absorbing any energy or allowing sediments to pile up in helpful places. In fact, these hard structures accelerate erosion. The "backwash" waves scour out shorelines in front of the structures. And the waves rush back out into open water, churning up the sediments they dragged out there, leaving sand and silt in long periods of **suspension** that reduces the amount of light that can reach seagrasses and other organisms that need direct sun rays.

Eventually, after costing a stretch of natural shoreline or beach most of its natural functions, seawalls and other hard structures, eventually fail. Lacking any “give,” powerful waves can collapse them, or scour under the structures, allowing water to rush beneath them and into the property they’re supposed to protect. Regardless of their short-term efficacy in terms of protecting property and infrastructure, sea levels rises ineluctably through the porous subterranean sand and limestone.

Dredging Policy

Most “beach nourishment” or “re-nourishment” projects involve a powerful dredge stripping the seafloor of sediment which is then pumped to the shore through large pipes and bulldozed into nearshore waters and on the beach. The idea is to artificially elevate and broaden the beach primarily for shore-protection purposes, which means the protection of public and private property.

Massive dredge-and-fill projects disguised as “beach nourishment” kill food sources for bonefish and permit that live in the sand, damage reefs, and cause chronic turbidity. Source: World Wide Metric.

The impacts to benthic (bottom-dwelling) organisms are immediately lethal, and scientists do not fully understand how long it takes for sediment-dwelling organisms such as worms, crabs and sand dollars to recover and to what extent – if at all. Dredges often kill sea turtles, and if the dredging activity takes place too close to a reef, then turbidity can impact corals and other important reef-building and reef-dwelling organisms.

Additionally, the act of bulldozing the sediment in and near the beach routinely buries a very important type of reef habitat called “nearshore hardbottom,” or NHB. The projects initially smother beach-dwelling invertebrates – coquina clams, worms, and mole crabs, a.k.a. “sand fleas” – which are important forage sources for bonefish, permit, and many other surf-zone species. Recovery times for those organisms depend on latitude, temperature, and – most importantly – the compatibility of the dredge spoil to natural beach sands. Many critics complain that the state’s sand compatibility rules aren’t strict enough to prevent rapid erosion and chronic turbidity, nor do they address impacts to beach-dwelling invertebrates, nesting shorebirds, and nesting sea turtles.

Fisheries Impacts

A rare and important type of reef, nearshore hardbottom, attract many fish species, including forage fish and the prized snook, the big fish shown in the foreground here.

Though difficult to estimate, scientists have documented negative dredging impacts to species such as permit and bonefish that spend parts of their lives in the surf zone. These include:

—Trophic impacts, or "food web" impacts, play a role in the types and amounts of forage available in an ecosystem. Dredge-and-fill projects can limit the availability of forage for juvenile bonefish and permit, which include worms and tiny crustaceans called amphipods and isopods. They can also limit the availability of forage species like coquina clams and mole crabs for adult surf zone fishes.

—Because of sediment incompatibility issues, water clarity often suffers persistently near dredge-and-fill sites. Turbidity can limit the abilities of predator fishes to forage, especially when they are young.

—Habitat loss, especially the burial of nearshore hardbottom, deprives juvenile fishes of cover and forage, including diverse species of worms and crustaceans.

Many leading geologists contend that the only way to preserve natural beaches is to let the rising seas take their course, and let the beaches respond as they have in the past. That will inevitably require a plan for strategic relocation of buildings and infrastructure through a combination of tactics including buyouts, land swaps, and land condemnations. As of now, federal insurance policies, laws designed to protect private property rights, and an over-reliance on costly coastal engineering practices, all stand in the way.

Habitat Restoration Sidebar

Well-designed habitat restoration projects can improve ecosystem productivity and provide flood protection in cost-effective ways. For example, Everglades Restoration Projects may help stem the tide of sea-level rise, while promoting better fishing and nature-based tourism activities. Living shorelines, where organisms such as marsh grasses, mangroves, and oysters can be constructed to block waves and storm surge while creating new natural areas that support fish and wildlife.

Laws and policies don't improve unless determined citizens convince elected officials that they must. To make a difference, you can call or write your elected officials and deliver the following messages:

—Greenhouse gas emissions continue to increase dramatically, which compounds the severity of the sea-level rise threats significantly. Please put a price on greenhouse gas emissions in a system that dramatically reduces emissions.

—State and federal laws and policies must be changed to give us the flexibility to adapt to sea-level rise. In particular, Congress needs to remove incentives for floodplain development offered by federal flood insurance. Florida needs to do a better job of balancing property rights with the public interest, in terms of protecting our natural resources.

—We aren't going to engineer our way out of sea-level rise and intensifying hurricanes. Instead of permitting and funding armoring and dredging projects, we should use the funds to leverage buyouts and legitimate habitat restoration projects with real flood-protection benefits.

Links and Resources from this reading:

Videos:

The greenhouse effect: https://www.youtube.com/watch?v=VYMjSule0Bw
Coastal erosion time-lapse: https://www.youtube.com/watch?v=bEumDAFWnqw

Articles:

Arctic sea ice minimum: https://climate.nasa.gov/vital-signs/arctic-sea-ice/
Predicting sea level rise: https://sealevelrise.org/forecast/
Ten thousand Islands: https://www.fws.gov/refuge/ten_thousand_islands/
FEMA's National Flood Insurance Program: https://www.nwf.org/Our-Work/Habitats/Floodplains
Castles in the Sand: https://www.flseagrant.org/wp-content/uploads/Castles-and-Roads-In-the-Sand_2018_48_ELR_10914.pdf
Everglades restoration: https://www.noworneverglades.com/about-us/
Florida living shorelines: http://floridalivingshorelines.com/

Highlighted Vocabulary from student reading:

Assemblages:

Taxonomic subsets of an ecological community. For example, the bonefish population in a given estuary constitutes an assemblage.

Case law:

Includes reported decisions of appeals courts and other courts which make new interpretation of the law and therefore can be cited as precedents.

Colonization:

The process in biology by which a species spreads to new areas.

Fauna:

The collective name for animals of a certain region or time.

Feedback loop:

The section of a control system that allows for feedback and self-correction and that adjusts its operation according to differences between the actual and the desired or optimal output.

Flora:

The collective name for plants of a certain region or time.

Fossil records:

The history of life as documented by the remains or imprints of organisms from earlier geological periods preserved in sediments.

Greenhouse gases:

A gas that absorbs and emits radiant energy within the thermal infrared range.

Groundwater sources:

The water found underground in the cracks and spaces in soil, sand and rock. It is stored in and moves slowly through geologic formations of soil, sand and rocks called aquifers.

Industrial Revolution:

Also known as the First Industrial Revolution, it was the transition to new manufacturing processes in Europe and the US, from about 1760 to sometime between 1820 and 1840. This transition included going from hand production methods to machines; new chemical manufacturing and iron-production processes; the increasing use of steam and waterpower; the development of machines and the rise of the mechanized factory system. The Industrial Revolution also led to an unprecedented rise in the rate of population growth.

Internal combustion engine:

A heat engine where the combustion of a fuel occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit.

Precedent:

A judicial decision that serves as an authority for deciding a later case.

Probability distributions:

A statistical function that describes all the possible values and likelihoods that a random variable can take within a given range.

Phytoplankton:

Microscopic organisms that live in watery environments, both salty and fresh. Some phytoplankton are bacteria, some are protists, and most are single-celled plants.

Random variables:

A function that maps the outcomes of an unpredictable process to numerical quantities, typically real numbers. It is a variable (specifically a dependent variable), in the sense that it depends on the outcome of an underlying process providing the input to this function. It is random in the sense that the underlying process is assumed to be random.

Sediment cores:

Generally, long narrow metal (generally aluminum) tube used by geologists to sample the soil deposits in the bottom of a lake or wetland.

Spatial resolution:

A measure of the accuracy or detail of a graphic display, expressed as dots per inch, pixels per line, lines per millimeter, etc.

Stilling well:

A pipe, chamber, or compartment with one or more comparatively small inlets connected with a main body of water or flow channel. The purpose of a stilling well is to dampen waves or surges while permitting the water level in the well to rise and fall with the major fluctuations of the main body of water or flow channel.

Subsidence:

The sudden sinking or gradual downward settling of the ground’s surface with little or no horizontal motion.