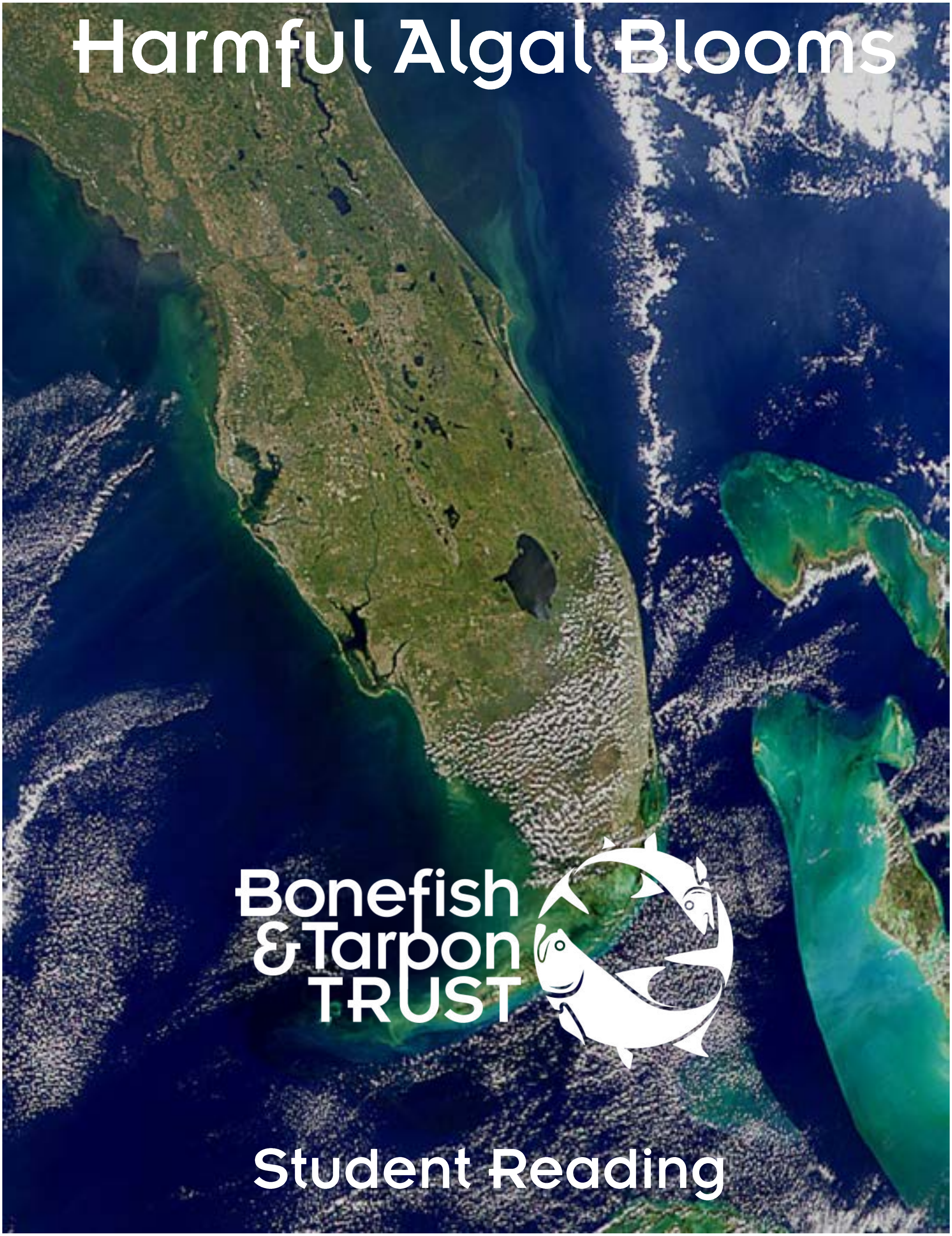
Harmful Algal Blooms



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Student Reading

Harmful Algal Booms

Harmful algal blooms, or HABs, occur when proliferations of algae cells – simple photosynthetic organisms that live in the sea and freshwater – grow out of control – producing toxic or harmful effects on people and fish, as well as shellfish, marine mammals, and birds. HABs occur virtually worldwide in coastal ecosystems, in freshwater bodies such as the Great Lakes, and in stagnant, nutrient-rich, oxygen-poor backwaters. The organisms that cause HABs have been on the earth far longer than humans have, but in today's world, these organisms undergo population explosions. They become harmful due to human activities that provide sufficient volumes of phosphorus, nitrogen and minerals to the waters where the organisms occur naturally.

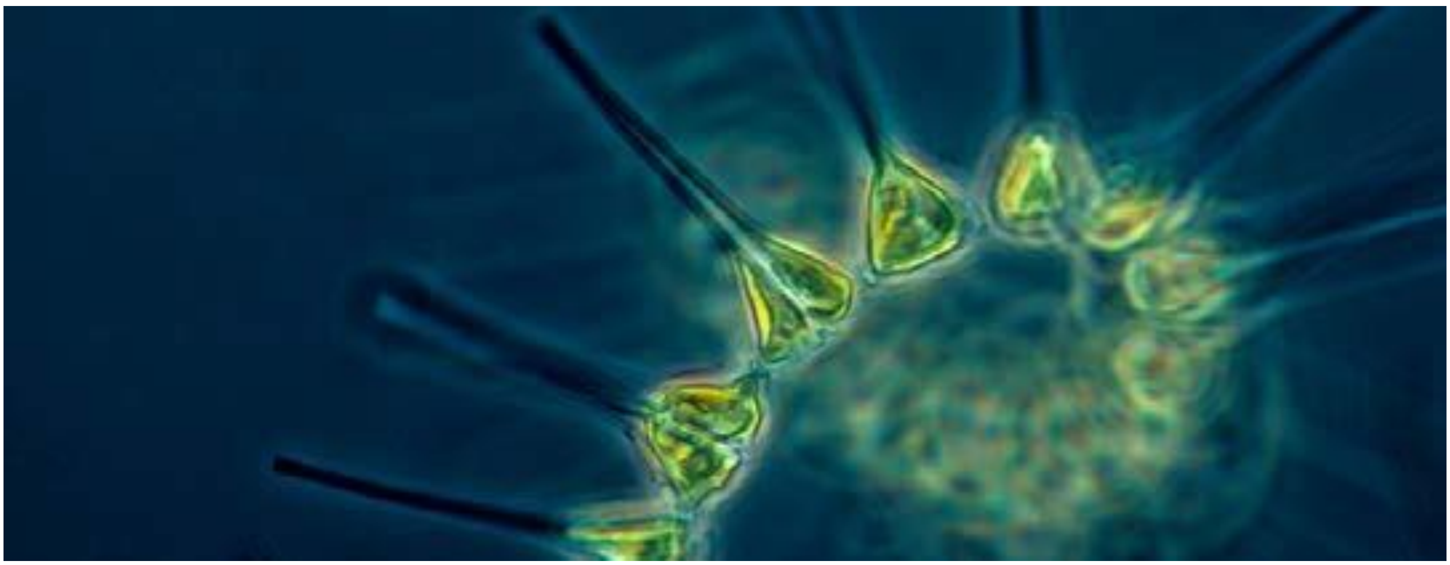
Toxic cyanobacteria paints the surface of a South Florida waterway. Wastewater, including raw sewage and septic tank effluent fuel

HABs fueled by human pollution are an increasing problem in many places around the world. They are a major concern because they affect the health of people and ecosystems, as well as the health of local and regional economies. Given Florida's large human population, and ecosystems that are particularly vulnerable to nutrient pollution, the state's water-based economy is threatened by HABs. The Sunshine State's waters increasingly suffer from blooms of many species of HABs including red tide (*Karenia brevis*), brown tide (*Aureoumbra lagunensis*), "blue-green algae" or "Cyanobacteria," as well as seaweeds. Let's learn how these organisms function, and why the blooms are becoming more frequent, more widespread, longer lasting, and more toxic.

Beneficial vs. Harmful Algae

Phytoplankton include many types of tiny **protist** algae—including beneficial and harmful species— found primarily toward the surface of a water body. In fact, the word “phytoplankton” means “drifting” (planktos) “plant” (phyto). Protists have many plant-like capabilities such as the ability to photosynthesize, and some have animal-like abilities including preying on other algae and bacteria.

Phytoplankton generally are classified into several groups, including: chlorophytes (green algae), euglenophytes (non cell- walled algae), phaeophytes (brown algae), rhodophytes (red algae), pyrrophytes **(dinoflagellates)** and chrysophytes **(diatoms and golden algae).** Dinoflagellates, use one or more whip-like tails, or **flagella**, to propel their armored cells through the water. Diatoms also have shells, but they are made of a different substance and their structure is rigid and made of interlocking parts. Diatoms do not rely on flagella to move through the water and instead rely on ocean currents to carry them through the water.



Phytoplankton is the base of several aquatic food webs. In a balanced ecosystem, they provide food for a wide range of sea creatures

Both beneficial and harmful algae species are **“primary producers,”** which means they grow, flourish and reproduce using energy from the sun, and from minerals and nutrients drawn directly from the environment in which they occur. These elements include nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, copper, zinc, molybdenum, sodium, cobalt, chlorine, bromine, silicon, boron, and iodine.

By uptaking, storing and metabolizing essential nutrients and minerals, many helpful algal species of plankton form the energetic bases of aquatic food webs. Through photosynthesis, beneficial phytoplankton convert limited inorganic nutrients such as nitrates, phosphates, and sulfur into proteins, fats, and carbohydrates. In a balanced ecosystem, they provide food for a wide range of creatures, including fish; whales; shrimp; oysters; and jellyfish. Animals higher in the **food web** eat the algae – most notably, zooplankton – an important source of food for higher food web organisms. Some forage fish species, including menhaden, filter energy-rich algae and zooplankton as they get larger. In fact, menhaden are called “the most important fish in the ocean” because they filter water and in turn feed many predator fish, birds, and marine mammals that occur where they do.

Consumers, such as humans, receive essential elements from what we eat. As omnivores, we eat plants – which are primary producers – as well as animals even lower on the food web that also consume primary producers and animals lower on the food web. For example, you may like to eat free-range chickens – which feed on plant products such as grains – as well as insects such as grasshoppers that feed exclusively on primary producers.

In aquatic ecosystems, pinfish are another extremely important species of forage fish in a low trophic level that live primarily in seagrass meadows. They graze algae off the blades of seagrass and turn the energy stored in the algae into extremely rich oils and proteins. Tarpon and snook – two of Florida's most prized fish – as well as most species of grouper and snapper like to eat pinfish when and where they're available because they are easy to catch and provide such high-quality nutrition. In turn, mammals near the top of food webs such as humans and dolphins eat some of the fish species that eat pinfish.

Photo credit: ecomagazine.com: Red tide (*Karina brevis*) is one of the most toxic harmful algae species. Land-based sources of pollution fuel the blooms and toxin production. Meanwhile, red tide cells can consume other algae species for energy and to outcompete them.

Harmful algae species also occur naturally, yet they typically have several evolutionary advantages over beneficial algae so they can outcompete them – especially if conditions such as nutrient availability and water temperature favor them. For example, red tide (*Karenia brevis*), a dinoflagellate that causes large-scale HABs along Florida's west coast, is a **facultative autotroph**. It is an organism that, depending on conditions, can grow either by autotrophy (photosynthesis or chemosynthesis) or by heterotrophy by **predating** (eating) on other algae. High nutrient levels allow red tide cells to feed photosynthetically, reproduce, and dominate the algal makeup of phytoplankton.

Perhaps you've played the video game "Pac Man," – traveling around a maze, gobbling up dots for points. Though not an animal, red tide dinoflagellates can feed on other algae "dots" by engulfing and ingesting other algae and bacteria, and breaking the cell down chemically, with enzymes. This type of predation is called "**phagotrophy,**" and the red tide cells ingest their prey through a **phagocytic vacuole**. Phagotrophy is also the way that your white blood cells attack and destroy viruses and bacteria that make you sick.

Menhaden Sidebar

Menhaden are called "the most important fish in the ocean" because as "filter feeders" they sift plankton out of the water at a rate of four gallons of water per minute, cleaning the water while the plankton enriches their bodies. As a planktivore, menhaden offer larger fish and **cetaceans** (marine mammals such as dolphins and whales) an incredibly rich source of fats and proteins.

Because Atlantic menhaden are abundant in many different places, they are called by many different names. The scientific, or "universal" name is *Brevoortia tyrannus*, but across the East Coast they are fondly referred to as menhaden, pogy, bunker, and even bug-head after the parasitic isopod often found on (or replacing) their tongue.

Menhaden are slow moving and live in dense schools, so predators need not expend many calories catching this swimming species of "superfood." They're so important that researchers think that the Mediterranean population of bluefin tuna swim across the Atlantic Ocean to the Eastern Seaboard of the United States to feed on them, before returning to the Mediterranean Sea to spawn. Menhaden are critically important food sources for migrating tarpon, which expend huge amounts of energy travelling and producing eggs and sperm for spawning. Snook and many other predator fish that live in Florida estuaries rely heavily on menhaden where they occur.

Unfortunately, because of their rich oily flesh, menhaden are highly valued for products such as animal feed, fish oil pills, and makeup among others. For decades, conservationists have tried to rein in industrial-scale harvests that overfished the menhaden populations, because this overharvest takes away an important food source for other valuable fish species including striped bass, weakfish, and tarpon, as well as the previously mentioned giant bluefin tuna. In 2012, a broad coalition of fishermen, wildlife enthusiasts, and conservation organizations succeeded in convincing the Atlantic States Marine Fisheries Commission (ASMFC) to reduce the harvest of menhaden by 25 percent. Almost immediately, the menhaden population began to rebound, and menhaden appeared in places they hadn't in decades.

But as the menhaden population rebounded, so did the political pressure to harvest more menhaden. Over great objections, and against the advice of scientists, ASMFC has since allowed more and more menhaden to be harvested once again, driving population numbers down. However, conservationists are hopeful that ASMFC will establish what are called ecological reference points, that would make a harvest contingent on meeting the dietary needs of birds, fish and cetaceans first.

HABs Before Human Pollution

You may have heard and been puzzled by officials saying that the species that cause harmful algal blooms are "naturally occurring," and that HABs such as red tide have occurred throughout history. It's true that these species are naturally occurring and, in the past, have caused some HABs. But it's only part of the story, especially in this latest chapter in earth's history. We live in a geological epoch that many experts are calling the **"Anthropocene,"** because ours is a time when human activity, including air and water pollution, is the dominant influence on climate and the environment.

Photo: David Hawgood. Harmful algal blooms are not just happening in Florida. They can occur anywhere that pollution causes too many nutrients to enter the water.

To better understand the dynamics of HABs in the Anthropocene era, let's examine the evolutionary history of HABs and what aquatic ecosystems in and around Florida probably looked like before intensive anthropogenic (human) development and pollution occurred.

Many species of HABs are among the Earth's oldest organisms, or have descended from the oldest organisms. They've survived for millions of years, event through long periods of time in environments that don't especially favor algal blooms. Their **evolutionary plasticity**—changes in an organism's behavior, morphology and physiology in response to a unique environment—allowed them to persist even when nutrients and minerals were scarce.

Many HABs began their existence millions of years ago in extremely **oligotrophic** environments— nutrient-limited ecosystems—so they began their "careers" with a distinct survival advantage in nutrient-poor waters. Over time, through the process of **adaptation** – some improved function that favors an organism's survival – a species must modify its **phenotypes**, or characteristics, in ways that allow it to succeed in changing environments. Early and more recently appearing algal species either refined or developed improved metabolic abilities to uptake limited sources of orthophosphate, ammonium (NH_4), nitrate (NO_3), and nitrite (NO_2). That's how HABs managed to persist when other algal species could not, despite low levels of limiting nutrients and minerals. And when nutrients and minerals that other species can use become more available, HABs can take advantage of the influx to outcompete other plants and animals.

HABs in Untamed Florida

Evolutionary plasticity allowed these ancient species that cause harmful algal blooms to persist in low levels of abundance. At low levels of abundance they aren't harmful. However, given warm water and enough nutrients, they can bloom and make the water and air toxic.

A cyanobacteria species found in freshwater reacts to saltwater by increasing cell production and toxins, thanks to local nutrient sources including sewage.

Red tides, for example, were reported even in the clear, clean waters around the peninsula that early 16th century Spanish explorer Juan Ponce de Leon named, "Florida," or "full of flowers." Early explorers and settlers of Florida recounted experiences with red tides. The difference between then and now is that settlers encountered undamaged ecosystems that only occasionally offered enough nutrients for these organisms to undergo the population explosions that cause and sustain major harmful algal blooms. The skeletal remains of algae in rocks and soils evidence their long, natural presence in Florida waters, where they were uniquely qualified to persist.

So how did harmful algal species persist in such nutrient-poor environments? The resident species persisted in low densities through Florida's dry season—roughly late October through mid May—because of their superior abilities to uptake limited nutrients. It was during the wet season—roughly mid May through mid October—that resident harmful algal species could flourish, and when red tide cells that were brought inshore by winds and currents would find sufficient nutrients to bloom and generate toxins. But these large-scale blooms were uncommon.

HABs and Florida's Hydroperiod

A hydroperiod is defined as the season in which the ground is largely saturated. Not by coincidence, most harmful algal blooms in Florida occurred and continue to occur during the rainy season. Floodwaters carried nutrients to the water bodies with conditions ripe for blooms.

The region's hydroperiod has long taken place between May through October. That's when thundershowers build through the heat of the day and drop heavy but brief summer rainfall. During late summer and early fall, Florida also experiences decaying tropical low-pressure systems and occasionally landfalling tropical cyclones that dump tremendous amounts of rain. Intense rainfall keeps the ground saturated, and causes lakes, creeks and rivers to overflow, driving water downstream and downhill toward the coasts.

Boating and fishing make up two of the Florida's most powerful economic engines. But HABs including Cyanobacteria blooms (pictured) are causing lasting damage to the economy.

Before Florida's development and nutrification, flowing water provided nutrients and minerals almost exclusively by eroding mineral and phosphorus-rich rocks and sand, as well as nitrogen-rich organic materials such as muck, and **detritus** (decaying plant matter). Storms can also **re-suspend** nutrient-rich sediments that rest on the bottom of freshwater bodies and estuaries. Some of the materials probably flowed into the calmer, hotter, less oxygenated backwaters that are conducive to the growth of HABs such as Cyanobacteria. Nutrients also made their ways to open saltwater, where they fed beneficial algae, Cyanobacteria species, and occasionally, red tide.

Florida's many springs and spring-fed rivers also played key roles in transporting nutrients from water body to water body – including from land to sea. Before tens of millions of people moved to Florida, consuming so much of the states' groundwater and paving over aquifer recharging areas, very high volumes of freshwater flowed through springsheds. These are underground rivers that occasionally bubble up to the surface—especially during the rainy season, when runoff deposited minerals, phosphorus, and nitrogen-rich detritus into the typically crystal-clear springs. Thanks to Florida's porous, **karstic** geology, underground rivers flowed through soluble limestone caverns that hydrologically connect Florida lakes and offshore upwellings—places where freshwater bubbled out of springs beneath estuaries and from the bottom of the sea. In fact, the springs flowed so strongly that sailors and fishermen restocked their drinking water supplies by the bucketful from offshore springs. The same springs probably also played important roles in delivering enough nutrients to support the species that cause harmful algal blooms, sometimes triggering events like red tides.

HABs, Altered Hydrology and Human Pollution

Boating and fishing make up two of the Florida's most powerful economic engines. But HABs including Cyanobacteria blooms (pictured) are causing lasting damage to the economy.

As nutrient delivery systems, Florida's natural watersheds have been compromised by pollution, in large part because ditches and canals accelerate the delivery of pollution-laden runoff into water bodies where harmful algal blooms can thrive. Runoff that once moved slowly over bare earth and through vegetation now rushes off concrete and asphalt through canals and ditches that act like sluiceways – rapidly ferrying nutrients and other types of pollution into state waters. Fish excrement also provides limited nutrients to algae. By and large, fish populations have been greatly diminished by fishing pressure, habitat loss, and fish kills caused by harmful algal blooms.

Sources of nutrient pollution include sewage from septic tanks, animal wastes from pets and livestock, and synthetic fertilizers from yards and farms. Worse, inadequate and/or aging wastewater treatment systems routinely discharge raw or partially treated sewage into lakes, rivers and estuaries, or discharge them offshore onto delicate coral reefs.

These high, persistent concentrations of anthropogenic nutrients are particularly easy for many harmful algae species to turn into energy. Such species include those that are killing Florida springs and fueling HABs in many aquatic ecosystems. These high outflows of anthropogenic nutrients have replaced the natural systems that previously provided a more limited and seasonally controlled source of nutrients. Humans have created what scientists call "**luxury uptake**" conditions ideal for HABs to outcompete beneficial algae. There are so many available nutrients and minerals that the organisms can store them in their cells, with plenty remaining in the water. When waters get so loaded with nutrients, they are said to be **eutrophic** or hypereutrophic. They're so high in nutrients that they support dense productions of algae that eventually die off and cause **hypoxic** (oxygen-deficient) conditions that have major consequences for human health as well as aquatic plant and animal populations. For example, dying harmful algae release dangerous toxins into the air and water that harm humans and wildlife. Water with low dissolved oxygen or essentially anoxic water also causes fish kills—mass die-offs of fish populations in affected waters. Such conditions typically favor the persistence and increased toxicity of harmful algal blooms rather than the diverse phytoplankton communities found in balanced ecosystems.

Kissimmee River Sidebar

Before and after images show an aerial perspective of one of the largest aquatic restoration projects in human history.

The straightening of the mighty Kissimmee River, which connects a series of more than twenty-four lakes between Orlando and Okeechobee as part of the Everglades ecosystem, is an example of how dramatically the alteration of natural water flows – combined with anthropogenic nutrient pollution – changed the health of Lake Okeechobee. Historically, the Kissimmee River meandered 103 miles from Lake Kissimmee to Lake Okeechobee through a one-to three-mile-wide biodiverse wetland floodplain. Because natural wet-season flooding threatened agriculture and development, the Kissimmee River between 1960 and 1971 was transformed into a 56-mile-long ditch—300 feet wide and 30 feet deep – known as the C-38 canal. The canal forced water to flow swiftly and directly south, denying the floodplain—the low, vegetated areas along the river's banks— the opportunity to capture increasing nutrient pollution from sprawling urban development and agricultural operations nearby.

As a result of this massive drainage effort, the wetland-dependent flora and fauna that once thrived in the Kissimmee system declined drastically. Popular fisheries such as largemouth bass largely disappeared, as did waterfowl populations. And lakes such as the iconic Lake Okeechobee became eutrophic.

This economically and ecologically devastating blunder prompted the State of Florida and the United States Congress—through the U.S. Army Corps of Engineers—to partner in one of the world's largest wetland restoration projects. As of 2019, the project is nearing completion and will return flow to 44 miles of the river's historic channel and restore about 40 square miles of river/floodplain ecosystem. The ecosystems have responded positively in terms of fish and wildlife populations. But even with this completed project, less than half of the original meandering river will exist. We will never again realize the full benefits of a healthy Kissimmee River, which is unfortunately the case in many restoration projects.

Phosphorus & Nitrogen Limitations

Florida's freshwater ecosystems are "phosphorus limited." Phosphorus acts as the limiting nutrient to growth stimulation that facilitates the passage of other nutrients through the plant membranes. Phosphorus is an abundant nutrient in Florida, mostly contained within sedimentary rock and in Florida's natural soil. However, because phosphorus is the limiting nutrient, even small increases are problematic because more phosphorus unlocks access to many other nutrients (natural and anthropogenic) in the system. So even slight additions of phosphorus from fertilizers and other sources turn the nutrient become a pollutant in freshwater bodies that encourages non-native plants such as cattails and algae to crowd out the plants preferred by native fish and wildlife. The situation is a bit different in the ocean, where nitrogen is generally the limiting nutrient for algae, plant and ultimately, fisheries production. So as humans add more phosphorus and nitrogen to the system, both freshwater and marine ecosystems suffer.

Everglades Law & Policy Sidebar

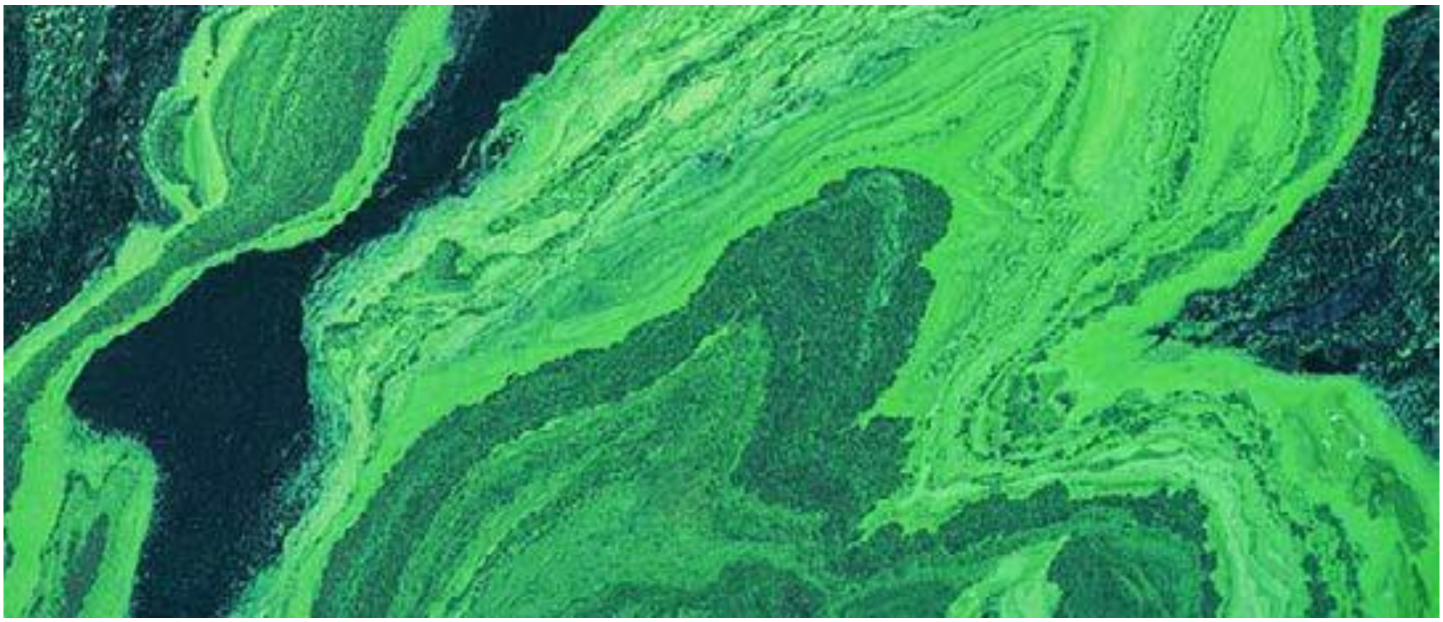
In the 1992 "Moreno Decision," a federal judge ruled that the State of Florida was violating the 1972 Clean Water Act. Judge Moreno required the state of Florida to build Stormwater Treatment Areas (STAs) and to enforce Best Management Practices (BMPs) on farmlands in the Everglades Agricultural Area that would reduce phosphorus levels to 10 parts per billion, or 10 micrograms per liter. In 1994, the state legislature passed the Florida Forever Act, which mandated and funded the construction of the STAs – manmade marshes designed to uptake phosphorus pollution before the cleaned water is sent into the Everglades. The legal decision, called a "consent decree," forced the construction of the STAs. The STAS and the enforcement of Best Management Practices led to significant reductions of phosphorus levels in freshwater Everglades ecosystems. Many other Everglades Restoration Projects are underway, to help deliver the right amounts of clean water – at the right times – to the right water bodies.

While Everglades advocates, including many fishermen, were overjoyed, others remain dismayed the state has not addressed nitrogen pollution adequately in coastal and marine ecosystems. Florida's estuaries and nearshore waters are naturally nitrogen-limited. They contain ample phosphorus to catalyze the growth of undesirable plants and algae. But when the ecosystems were balanced, they usually lacked enough nitrogen-based ammonium, nitrate, and nitrite to allow significant blooms of HABs. But humans add to nitrogen levels by spilling sewage and fertilizers into priceless nursery areas such as the Indian River Lagoon (IRL) and the

Caloosahatchee estuary. The IRL is now classified as "hypereutrophic." Nitrogen levels are so high that excessive algae production (blooms) with periods of oxygen deficiency have caused most of the seagrass and bivalves to die. Low oxygen levels also result in periodic, large-scale fish kills. In 2018, the Florida legislature provided significant funding to address wastewater pollution; however the state lacks any comprehensive policy or plan to reduce the contributions of nitrogen pollution.

Florida's Triple HAB Threat

Though there are at least two dozen species that cause harmful algal blooms in Florida waters, the worst culprits include several species of Cyanobacteria, several species of "brown tide," and *K. brevis* that causes red tides.



Stormwater Treatment Areas (STAs) can successfully reduce nutrient pollution so that the water does not support harmful algal blooms.

Cyanobacteria

Sometimes called "blue-green algae," they are actually "blue-green bacteria" that are closely related to algae. Cyanobacteria are some of the earth's oldest organisms. Paleobiologists—scientists who study the origin and development of life—have concluded that Cyanobacteria were part of the "primal ooze" that produced the earth's first oxygen (O_2) molecules.

Billions of years ago, Earth's atmosphere essentially lacked O_2. But through time, Cyanobacteria absorbed a smaller cell that used chlorophyll to photosynthesize. In an early example of **symbiosis**, the Cyanobacteria protected the little cell, while the cell fed its protector, creating oxygen as a byproduct. This successful harmony resulted in a large number of photosynthesizing cells that use sunlight as the power source to extract the hydrogen from water (H_2O), for food, and release the oxygen molecule. The released oxygen found its way into the atmosphere. This is the exact chemical reaction that continues today in all plants and algae, which allows oxygen-breathing animals to live on Earth.

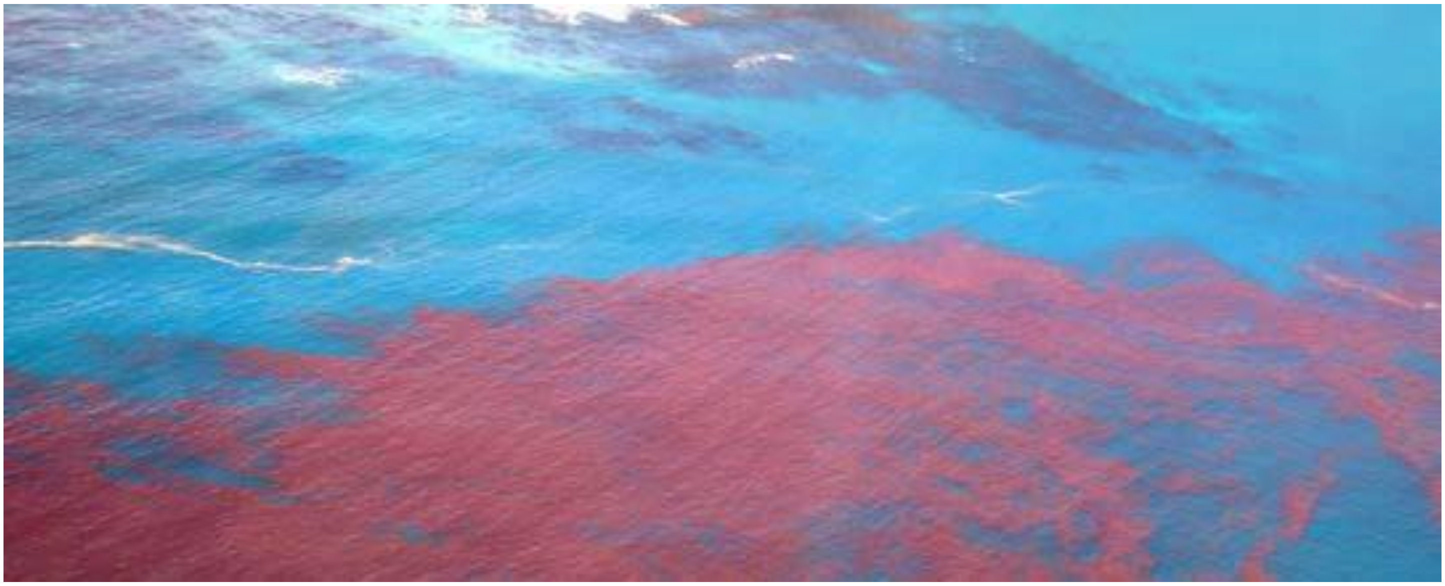
Of course, untold species of cyanobacteria persist today and occur naturally in fresh- , brackish- and saltwater. The species come in many colors, shapes and sizes. The most infamous, however, are the bright, blue-green-colored species that make national headlines as they blanket and poison legendary water bodies including the Great Lakes; Florida's Lake Okeechobee; the St. Lucie Estuary; the Caloosahatchee River; and parts of the St. Johns River.

The toxins produced by HABs are strong enough to kill even the largest, toughest marine mammals, including bottlenose dolphins.

Excessive nutrients and extremely high water temperatures allow the blooms to grow across water bodies such as Lake Okeechobee, which regularly fills up with runoff. Historically, that water flowed south through the Everglades (a.k.a. the "River of Grass") and was filtered slowly and thoroughly by native plants. Farmland has replaced the "River of Grass." Since the water can no longer filter south through the Everglades, the U.S. Army Corps of Engineers, which manages Lake Okeechobee's water, releases millions and even billions of gallons of water per day into the St. Lucie and Caloosahatchee rivers every time high water levels threaten the earthen dike that surrounds the lake and protects surrounding communities from flooding. Essentially, the Corps redirects the lake water and the algae blooms east and west into the coastal estuaries. There, in the narrow confines of the river systems, the Cyanobacteria encounters new, concentrated sources of nitrogen, primarily from sewage pollution leaching through the ground from septic tanks in local communities. Tidal action brings the Cyanobacteria into contact with saltwater, and these particular freshwater species respond by ramping up their biomass and toxin production.

Marine life as well as humans can also be affected by Cyanobacteria toxins, including a neurotoxin of increasing concern called β-methylamino-L-alanine, or (BMAA). BMAA has been linked to forms of dementia, including Alzheimer's disease. Scientists recently found neurofibrillary tangles consistent with dietary exposure to BMAA in dolphins that died mysteriously by "stranding" themselves on shorelines. The animals may literally have lost their minds from exposure to Cyanobacteria blooms that humans induced through nutrient pollution. In freshwater ecosystems, cattle, eagles and other higher food web species often succumb to toxins produced by dense cyanobacteria blooms.

Red Tide



***Karenia brevis,* like other organisms that cause HABs, is always present in the water, but only "blooms" when conditions are right.**

Karenia brevis earned its "colorful" moniker because of the rusty hue that intense blooms give to normally blue/green coastal waters. The cells contain red-colored chlorophyll – an adaptation that allows them to survive deep on the ocean floor where the blooms originate, and where there is little penetrating sunlight. It is one of many adaptations that make this toxic species of dinoflagellate so remarkably persistent and dangerous. Always searching for its photosynthetic sweet spot, *K. brevis* has the ability – thanks to its flagella – to alter its depth in the water column and find the light levels that allow it to reproduce optimally.

Again, unlike resident harmful alga, red tide cells originate deep on the bottom of the Gulf of Mexico. They are driven to the surface by upwelling currents and carried toward the coast by winds and currents. During transport, they survive in the nutrient-poor surface waters thanks to their abilities to efficiently metabolize limited nutrients.

When red tide cells reach coastal waters, they encounter high levels of nutrients coming from land- based sources which provide the additional energy they need to create a bloom. As the cells increase in density, the dinoflagellates can then feed on the abundant nutrients both through photosynthesis and by feeding on other algae species. They outcompete other algae by reproducing more rapidly, by toxifying the water, and by consuming the rivals and the nutrients that sustained them.

Meanwhile, high nutrient saturation, especially in hot brackish estuaries and nearshore waters, allows red tide dinoflagellates to ramp up toxins that can cause respiratory illnesses in people, and kill fish and wildlife. The nutrients from those dead competitors are then returned to the water, where *K. brevis* cells consume them, gathering even more energy for reproduction and the producing toxins. These neurotoxins or "brevetoxins," persist in the fatty cells of shellfish and other filter feeders after the bloom has passed. Organisms that feed on them continue to die by bio-accumulating brevetoxins. In fact, fish lose their equilibrium in the water and swim in jerky motions before becoming paralyzed and losing all ability to swim. They can die within an hour of ingesting this neurotoxin. Such effects are not limited to fish: neurotoxin attacks kill marine mammals, sea turtles, and land-based pets and wildlife—even humans who are already in poor health.

Typically, when humans encounter *K. brevis*, the symptoms include itchy and watery eyes, difficulty breathing, and extreme irritation of the epithelial tissues of the throat and nose. The red tide toxin may be more of a problem to those with respiratory issues and sensitivity to these toxins. Leaving the affected area usually alleviates the symptoms, although long-term exposure can lead to lung tissue damage and neurological issues. If contaminated seafood is consumed, the symptoms include upset stomach and diarrhea.

Brown Tide

Brown tide has caused repeated major fish kills, decimating fish populations in Florida's Indian River Lagoon.

Brown tide (*Aureoumbra lagunensis*) is a relative new-comer among harmful algal blooms to Florida waters, and has become problematic in the northern and central Indian River Lagoon (IRL) ecosystem along Florida's east coast. Brown tide blooms have disrupted ecosystems in the other shallow estuaries of the US, including Long Island, New York and Texas. Suddenly, during the summer of 2012, a dense brown tide occurred in the Mosquito Lagoon and northern Indian River Lagoon on Florida's east-central coast. Hypereutrophic conditions, thanks to nutrient pollution, allowed it to thrive.

The Indian River Lagoon complex includes the Loxahatchee River Estuary; the St. Lucie Estuary; the 152-mile-long Indian River Lagoon itself; the St. Sebastian River; Banana River Lagoon; and Mosquito Lagoon. Prior to the arrival of the brown tide, these waters had experienced ecological phase shifts that are symptoms of nutrient over-enrichment in nitrogen-limited systems.

In the northern and central IRL waters, which are hydrologically connected to the St. Johns River basin, raw sewage pollution from wastewater plants and from leaking septic tanks are important sources of pollution that help to feed HABs. We've learned this through technologies that allow scientists to identify the isotopic values or "chemical signatures" of different sources of nitrogen, such as human waste vs. synthetic fertilizers.

In the southern IRL – one of the northern Everglades estuaries – canal discharges that occur during peak flooding events transport urban and agricultural runoff, while septic tanks provide chronic inputs of easily metabolized forms of nitrogen and phosphorus, such as ammonium and reactive phosphate.

Essentially the IRL complex habitat transitioned from a seagrass-dominant community to a seaweed dominated community to a community dominated by single-celled algae species. As nitrogen levels initially increased, valuable organisms such as clams and oysters responded favorably to additional "healthy" phytoplankton for them to eat, such as chlorophytes and chrysophytes. Their populations temporarily increased, and clam and oyster harvesters profited. Seagrass meadows also became more robust, benefitting fisheries.

However, increases in available nitrogen also set insidious changes in motion. Tiny algae that grow on seagrass blades also increased, and outpaced the abilities of grazing fish such as pinfish to clean off the clinging algae. As phytoplankton concentrations increased, the clear waters took on a greenish hue. As nutrient levels continued to increase and less sunlight reached the seagrass blades, larger "macroalgae' such as the red seaweed, *Gracilaria*, and the filamentous Cyanobacteria, *Lyngbya* spp., began to outcompete the seagrasses.

Over several decades, nitrogen loading increased and caused the lagoon to become eutrophic—at a level where Cyanobacteria and algae thrived through "luxury uptake" in over-enriched waters. At least 24 species of HABs are among the IRL's phytoplankton, and once these toxin-producing phytoplankton—especially the brown tide—dominated the water column, they killed off the bivalves and blocked off sunlight to remaining seagrasses. This caused even the macroalgae – including the dominant species, *Gracilaria* and *Lyngbya* spp. – to perish. Thick mats of *Gracilaria* rotted on the IRL's shores, causing waterfront residents to complain loudly about the smell as the nutrients in the dead macroalgae were returned to the water. The brown tide virtually eliminated the remaining seagrasses and bivalves, and hypoxic conditions have caused more than 30 fish kills. Observing the destruction, scientists concluded that, "The expansion of harmful brown tides caused by *A. lagunensis* to these estuaries represents a new threat to the US Southeast Coast."

Solutions

Scientists in the fields of water quality and phycology—the branch of botany concerned with algae—agree that the best way to limit the frequency, duration, and intensity of harmful algal blooms is to stop the flows of anthropogenic nutrients that have over-enriched waters in Florida, and around the world. They also advocate for the restoration of natural hydrological systems, such as the unique Everglades, with strategies that include filter marshes that give plants enough time to uptake excessive nutrients.

How do we wrap our minds around such complex problems and solve them? Historically, resource managers examined nutrient-pollution loading problems in the contexts of watersheds or "basins." In Florida, managers have typically addressed nutrient loading by assigning "Total Maximum Daily Loads," or TMDLs, to "Basin Action Management Plans," or BMAPs. Section 303(d) of the Clean Water Act (CWA) "authorizes the

Environmental Protection Agency to assist states, territories and authorized tribes in listing impaired waters and developing Total Maximum Daily Loads (TMDLs) for impaired water bodies." A TMDL is supposed to establish the maximum amount of a pollutant allowed in a water body, and serves as the starting point or planning tool for restoring water quality. According to the Florida Dept. of Environmental Protection (FDEP), a BMAP is:

> *"The "blueprint" for restoring impaired waters by reducing pollutant loadings to meet the allowable loadings established in a Total Maximum Daily Load (TMDL). It represents a comprehensive set of strategies - permit limits on wastewater facilities, urban and agricultural best management practices, conservation programs, financial assistance and revenue generating activities, etc. - designed to implement the pollutant reductions established by the TMDL."*

Lasting solutions may require relatively customized approaches to basin-specific pollution sources. Most basins have multiple sources of pollution, such as wastewater and agricultural sources, so resources and regulations may be needed to address nutrient inputs in ways that make sense on the local level.

But especially in Florida, the basins often suffer from persistent lesser culprits, as well as one or more culprit(s) that is occasionally problematic. Runoff from summer rains can carry diluted cattle manure across pasturelands into watersheds, while failing wastewater facilities and septic tanks provide major concentrations of superfood for algae – often during hydroperiods when HABs are particularly able to flourish. In those cases, the wastewater issues may deserve specific attention. Wastewater treatment plants are operating over capacity, and stormwater/wastewater lines burst or otherwise require direct discharges during peak rain events. Concentrated Animal Feeding Operations (CAFOs) such as dairy, chicken, or pig farms spill animal wastes into state waters when they can't contain their own effluent.

Those are all "point-sources" of pollution that deserve special attention. Non-point-sources of pollution are defined by the Environmental Protection Agency as pollution that, "generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrologic modification." Non-point source (NPS) pollution, unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources, including:

- Excess fertilizers, herbicides and insecticides from agricultural lands and residential areas
- Oil, grease and toxic chemicals from urban runoff and energy production
- Sediment from improperly managed construction sites, crop and forest lands, and eroding stream banks
- Salt from irrigation practices and acid drainage from abandoned mines
- Bacteria and nutrients from livestock, pet wastes and faulty septic systems
- Atmospheric deposition and hydromodification

Overarching recommendations include:

- Updating wastewater infrastructure to advanced treatment levels

- Repairing the hydrology of Florida's unique Everglades ecosystem
- Adopting growth management policies that require stormwater and wastewater concurrency
- Anticipating rising sea levels, more intense rains, and exposed infrastructure
- Enacting bans on wet-season fertilizer application
- Approving policies that incentivize planting Florida yards with native species

Highlighted Vocabulary from Student Reading:

adaptation:

Over the course of time, species modify their phenotypes or "characteristics" in ways that permit them to succeed in their environment.

anthropocene:

Relating to or denoting the current geological age, viewed as the period during which human activity has been the dominant influence on climate and the environment.

cetacean:

A whale, dolphin, or porpoise.

consumer:

Living creatures in a food web that eat organisms from a different population.

detritus:

Disintegrated or eroded matter, especially decayed vegetation.

diatom:

A single-celled alga which has a cell wall of silica.

dinoflagellate:

Any of numerous one-celled aquatic organisms bearing two dissimilar flagella and having characteristics of both plants and animals. Most are marine, though some live in freshwater habitats.

eutrophic:

When a body of water becomes overly enriched with minerals and nutrients which induce excessive growth of algae.

evolutionary plasticity:

The capacity for evolutionary innovation.

facultative autotroph:

Organisms that can produce their own food from the substances available in their surroundings using photosynthesis, or chemical energy (chemosynthesis), or can rely on consuming other organisms — both plants and animals — for nutrition.

flagella:

A lash-like appendage that protrudes from the cell body of certain bacteria and eukaryotic cells. Flagella allow propulsion and assist with predation by facultative autotrophs.

food web:

A system of interlocking and interdependent food chains.

golden algae:

Prymnesium parvum is a single-celled organism that lives in water. It occurs worldwide, primarily in coastal waters, but it's also found in rivers and lakes. It doesn't always cause problems, but when it "blooms" (enters a phase of rapid growth and reproduction) this alga can produce toxins that cause fish kills. The toxins affect organisms that have gills: all types of fish, freshwater mussels and clams, and the gill-breathing juvenile stage of frogs and other amphibians.

hypoxic:

Deficient in the amount of oxygen in the water column.

karstic:

Describing a landscape underlain by limestone which has been eroded by dissolution, producing ridges, towers, fissures, sinkholes and other characteristic landforms.

luxury uptake:

When a plant takes up nutrients beyond those that contribute to plant growth, and the concentration shows up in the plant tissue.

oligotrophic:

Relatively low in plant nutrients and containing abundant oxygen in the deeper parts.

phagotrophy:

Feeding by engulfing a food cell or particle and ingesting it in a phagocytic vacuole, in the manner of some flagellates.

phenotypes:

The set of observable characteristics of an individual resulting from the interaction of its genotype with the environment.

phycology:

The branch of botany concerned with seaweeds and other algae.

phytoplankton:

Photosynthesizing microscopic biotic organisms that inhabit the upper sunlit layer of almost all oceans and bodies of freshwater on Earth.

predate:

To capture prey for food.

primary producers:

The foundation of an ecosystem. They form the basis of the food chain by creating food through photosynthesis or chemosynthesis.

protist:

A single-celled organism of the kingdom Protista, such as a protozoan or simple alga.

re-suspend:

Refers to the removal of deposited material from the bottom of a water body to the water column as a result of wind and wave energy.

symbiosis:

Interaction between two different organisms living in close physical association, typically to the advantage of both.