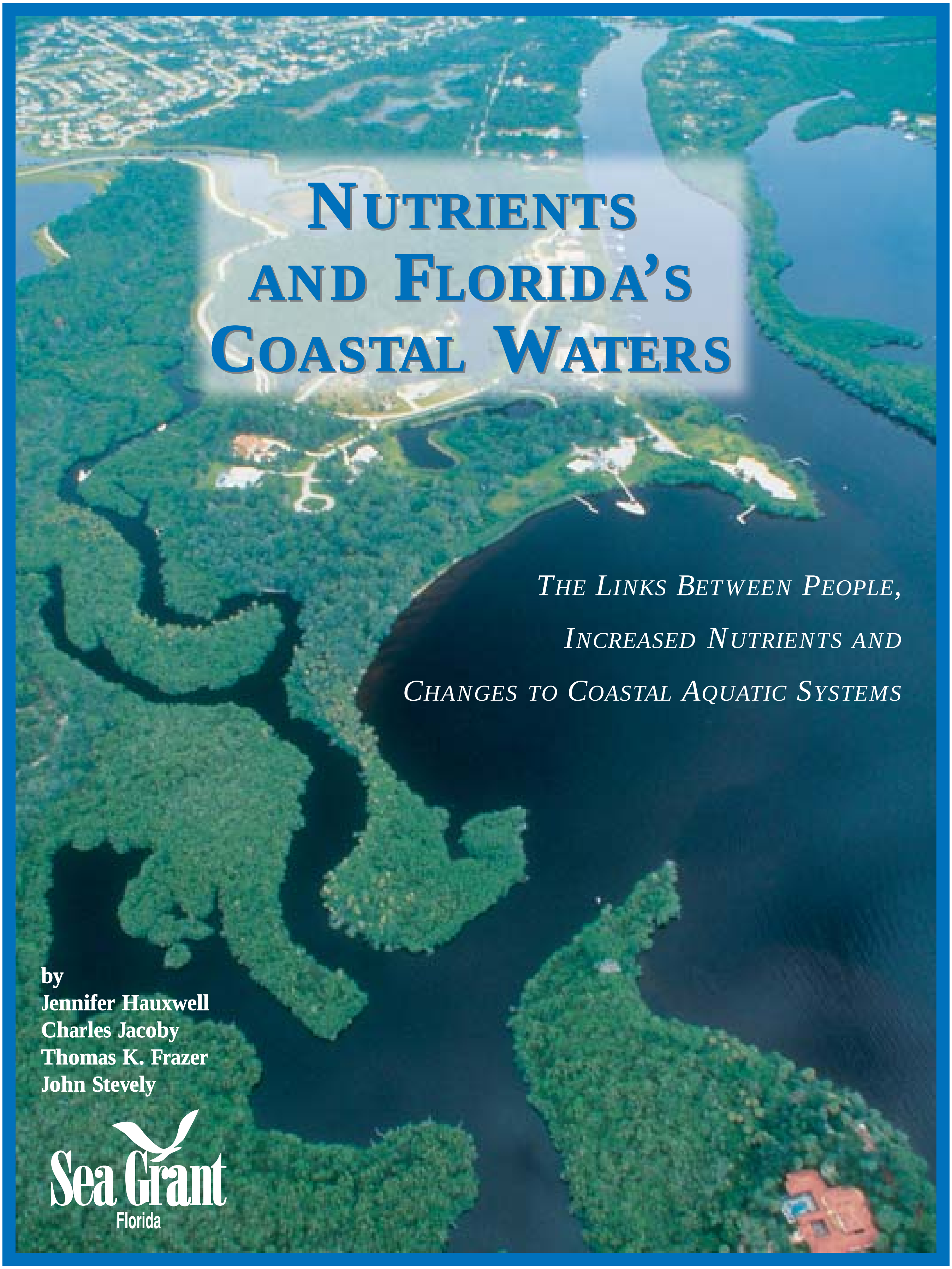

NUTRIENTS AND FLORIDA'S COASTAL WATERS

THE LINKS BETWEEN PEOPLE, INCREASED NUTRIENTS AND CHANGES TO COASTAL AQUATIC SYSTEMS

by
Jennifer Hauxwell
Charles Jacoby
Thomas K. Frazer
John Stevely

Sea Grant
Florida

SGEB-55

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All of us benefit from healthy coastal ecosystems. If we want our recreational, commercial and other social benefits to continue, we have a responsibility to protect the health of these systems. Balancing protection and use of coastal systems creates some difficult decisions.

Florida Sea Grant recognizes the importance and complexity of such decisions. As part of its efforts to enhance the practical use and conservation of coastal and marine resources, it contributes to informed debate by producing and distributing objective, valuable, and understandable information. In order to produce such information, Florida Sea Grant works with scientists from many collaborating organizations.

This brochure represents one of Florida Sea Grant's efforts to generate understanding and debate. In collaboration with researchers from the University of Florida, we introduce an important and complex topic: how nutrients function in coastal aquatic systems and how human activities affect these natural cycles. Although a full explanation of nutrient dynamics is beyond the scope of this brochure, it does help us understand and manage these important phenomena.

Florida Sea Grant also recognizes that the issues related to use and protection of Florida's coast extend beyond nutrients in coastal waters. For that reason, it is producing other documents to accompany this one. For example, *Submarine Groundwater Discharge: An Unseen Yet Potentially Important Coastal Phenomenon (SGEB-54)*, has been released. A citizen's guide to Florida's estuaries is in preparation.

We ask that you read this material and pursue some of the additional information. We also ask that you contact us with questions or comments. Florida Sea Grant's ability to achieve its objectives and our collective ability to ensure sustainable use of coastal systems depend, in large part, on your involvement and input.

Thank you for your time and interest.

Charles Jacoby
Extension Specialist, Estuarine Ecology
Leader, Florida Sea Grant Coastal Environmental and
Water Quality Design Team

Sea Grant Florida

UNIVERSITY OF FLORIDA
Institute of Food and Agricultural Sciences

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The Authors

Jennifer Hauxwell
Department of Natural Resources Research Center
Wisconsin Department of Natural Resources
1350 Femrite Drive
Monona, Wisconsin 53716

Charles Jacoby
Department of Fisheries and Aquatic Sciences
University of Florida
7922 NW 71st Street
Gainesville, Florida 32653-3071

Thomas K. Frazer
Department of Fisheries and Aquatic Sciences
University of Florida
7922 NW 71st Street
Gainesville, Florida 32653-3071

John Stevely
Florida Sea Grant Extension Program
1303 17th Street West
Palmetto, Florida 34221-5998

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Cover photo: Aerial of North Fork of the St. Lucie River. Photo courtesy of South Florida Water Management District.

Coastal aquatic systems, including estuarine and marine nearshore environments, deserve our attention for three key reasons. First, healthy coastal systems provide homes and food for numerous plants and animals. Second, we use these systems extensively for commercial and recreational activities, and third, both our coastal and inland activities can pose threats to the health of coastal aquatic systems.

One of the primary ways we threaten the health of coastal systems is through addition of nutrients. Nutrients occur naturally, and they support natural processes that make coastal systems unique. Unfortunately, our activities can increase nutrients to levels that cause undesirable changes. One of the most important ways we affect coastal waters is through activities on land that increase delivery of nutrients to the sea.

This booklet provides information about the links between nutrients and the health of Florida's coastal ecosystems. It uses definitions, conceptual models, and summaries of current knowledge to explain how coastal ecosystems function under natural conditions and how people are increasingly affecting coastal ecosystems. Sources of more information and suggestions for ways to help protect our precious coastal systems are included. Through a greater understanding of coastal systems, nutrients, and how people affect natural processes, each of us can make informed choices that reduce environmental damage.

COASTAL SYSTEMS AND NUTRIENTS… EXACTLY WHAT ARE WE TALKING ABOUT?

Coastal systems include the water, bacteria, plants, and animals found in bays, lagoons, estuaries, and nearshore areas. All living things in coastal systems are connected as illustrated by a food web (Figure 1). At the base of coastal food webs, primary producers (including seagrass, algae,

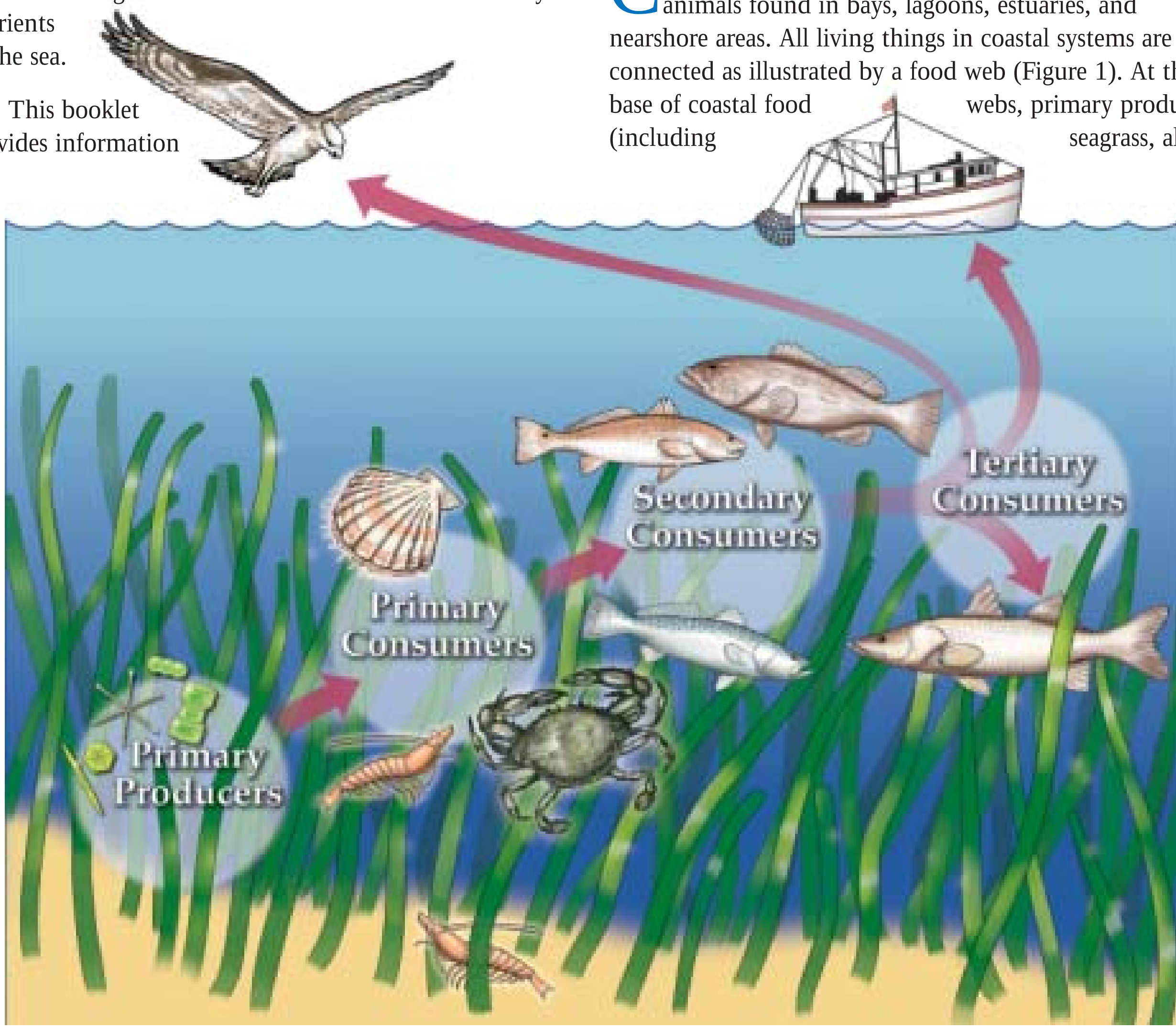

Figure 1: Simplified food web with connections among trophic levels. Primary producers (bacteria, phytoplankton, algae, and seagrass) produce organic matter through photosynthesis. Primary consumers feed directly on bacteria and plants. Secondary consumers eat primary consumers, and, in turn, are eaten by tertiary consumers. In truth, trophic connections are often much more complex, with consumers feeding at several trophic levels. (Source: Florida Sea Grant)

and some species of bacteria) capture nutrients, sunlight, and carbon dioxide (CO_2) and use them to build new tissue and release oxygen (O_2) as a byproduct through a process called photosynthesis. The production of new tissue is referred to as primary production. Consumers, like us, feed on primary producers or other consumers to gain energy for survival, growth, and reproduction. All living things, including primary producers, generate energy by consuming organic material through a process called respiration. In most cases, O_2 is used during the breakdown of organic matter and release of stored energy.

In coastal systems, as in many other ecosystems, primary production is often limited by the availability of nutrients. Nutrients are chemical elements that influence the productivity of all natural systems. Some elements that are essential for the survival of primary producers and consumers include nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, copper, zinc, molybdenum, sodium, cobalt, chlorine, bromine, silicon, boron, and iodine. Primary producers extract these essential nutrients directly from the environment. Like all consumers, we get most of these elements from the food we eat. In other words, we draw our nutrients from a food web.

Inputs of nutrients and other materials from the land are a key feature distinguishing coastal systems from the offshore oceanic environment. Although the exact offshore boundary of a coastal system is difficult to pinpoint, we can think of it as the place where inputs from the land no longer have a significant influence. Inputs from the land support rapid growth and reproduction of primary producers and consumers making these areas among the most highly productive in the world. Research shows that although coastal waters represent only 10 percent of the total ocean surface, they account for 20 percent of total primary production and 50 percent of total fish production in the oceans.[3] In large part, production of fish is high because of the food and shelter provided by primary producers in these relatively nutrient-rich waters (see shaded box, this page).

How are coastal systems threatened?

Coastal systems in Florida are affected both directly and indirectly by many human activities. For example, two key intertidal coastal habitats, mangroves and salt marshes, have often been destroyed to make way for housing and other developments. In Florida, dredging and filling operations have destroyed over 23,000 acres out of the state's 469,000 acres of mangroves.[4,5] In addition, Florida's coastal reefs have been damaged by direct contact from boaters and divers, as well as through the indirect effects arising from nutrient additions these systems.

Direct damage to coastal habitats is something to be avoided, but in many areas, indirect effects from human activities are more threatening.

In Florida and other places around the world, seagrass meadows represent one of the most disturbed coastal habitats and provide a good example of both direct and indirect effects of human activity on habitat.

How do people threaten seagrass meadows?

Under natural conditions, seagrasses often represent a major submerged aquatic habitat (see shaded box, page 3). Seagrass habitat has been lost from waters off Florida, as well as from coastal waters around the world, due to natural and human-induced disturbances.

Measuring the importance of Florida coastal systems

Florida's coastal environments represent one of the state's most distinctive and prominent features. Maintaining the health of these environments is crucial. Not only do they support fisheries, recreational activities, and tourism, but they also provide the quality of life that Floridians have come to enjoy. Did you know that coastal environments:

- border 35 of Florida's 67 counties;
- extend for 1,350 miles, which is longer than the Atlantic coast from Georgia through Maine;
- contain many habitats including coral reefs, sea grasses, mangroves and wetlands;
- shelter, during some part of their lives, grouper, sea trout, redfish, oysters, clams, scallops, blue crabs, lobsters, and other animals adding up to over 80 percent of the animals caught by recreational and commercial fishers;
- house 60 percent of Florida's 16 million residents within a band 10 miles wide;
- draw 10 million tourists each year (twice the number visiting inland parks)[1];
- support beach tourism, which generates approximately $15 billion annually[2]; and
- support marine fisheries worth $10 billion per year?

What are seagrasses?

Although they grow underwater, seagrasses are related to flowering land plants, or angiosperms. Two key characteristics that qualify seagrasses as angiosperms are: 1) a system of tubes, called a vascular system, which transfers material within the plant, and 2) the production of flowers as a way to reproduce sexually. Like many land plants, seagrasses also reproduce vegetatively, with new clones branching from an established plant.

As a result of both sexual and vegetative reproduction, seagrasses often form extensive meadows. Along the coasts of Florida, seagrass meadows cover more than 2.7 million acres.[6] These meadows serve several important ecological roles, including:

1) fixing carbon dioxide (CO_2) into new plant tissue at twice the rate achieved by highly cultivated crops, such as corn or rice. (Some seagrasses can produce more than 800 grams of carbon per square meter per year.);
2) providing food or shelter for thousands of marine organisms (including invertebrates, fish, water fowl, sea turtles, and manatees); and
3) preventing coastal erosion by binding sediments with below-ground root and rhizome systems and by reducing wave energy or the speed of currents with above-ground leaf material.

In Florida, several seagrass species thrive in coastal shallow waters, including:

1) *Thalassia testudinum* (turtle grass);
2) *Halodule wrightii* (shoal grass);
3) *Syringodium filiforme* (manatee grass);
4) *Halophila engelmannii* (star grass);
5) *Halophila johnsonii* (Johnson's seagrass);
6) *Halophila decipiens* (paddle grass); and
7) *Ruppia maritima* (widgeon grass).

Natural disturbances that directly damage seagrasses include hurricanes, earthquakes, ice scour, animals digging through the substrate, animal grazing, and disease. However, these pressures account for less than 20 percent of the worldwide loss of seagrasses.[6]

Human activities also damage seagrass directly. Dredging, construction of docks, mooring of boats, harvesting of shellfish with rakes or trawls, and use of motorboats in shallow waters all physically remove seagrass meadows and created "scarred" areas. Seagrass meadows with scars often suffer erosion and further loss of seagrass during storms. In some meadows, scarring is a significant problem, and overall approximately 6 percent of Florida's seagrass meadows are scarred.[7]

In general, though, the links between many human activities and effects on seagrasses involve multiple steps. These effects are classed as indirect simply because materials first need to be transported to the coast. One example is herbicides carried to coastal waters, which can then poison seagrasses. Another is sediment transported from cleared land to coastal water, which can indirectly damage seagrass by blocking out the light that it needs to grow.[8]

But it is the indirect effects of excess nutrient loading from watersheds to coastal waters that are cited as the most pervasive human impacts on coastal areas and on seagrass habitat. [7,8,9-14] Around the world, increased nutrient loading has accounted for 50 percent of the recorded declines in seagrass, and this problem is growing.[6]

What happens to seagrasses when too many nutrients reach coastal systems?

Algal blooms are one common result of excess nutrients being delivered to coastal waters. Algae differ from seagrasses and terrestrial plants in that they lack vascular structures such as roots and stems. Algae may be microscopic, such as single-celled phytoplankton, or easily seen by the naked eye, macroscopic, and they may be free-living or attached. Many species of algae have lower light requirements than seagrasses, so algal growth is typically limited by the availability of nutrients.

In Florida and many other places around the world, undesirable increases in both small and large algae have become more common due to increased nutrient loading to coastal waters. Increased numbers of microalgae, or phytoplankton, often give the water an opaque, greenish appearance. Increased quantities of macroalgae may result in piles of rotting "seaweed" on the bottom in coastal waters or on beaches. Such undesirable increases in algae indicate that the system is undergoing human-induced eutrophication, or an unnaturally rapid buildup of organic matter.

Increased amounts of phytoplankton or macroalgae may indirectly lead to the loss of seagrass (Figure 2).[10, 12, 14] Increased nutrients in the water column have little direct effect on seagrass growth because seagrass roots generally absorb all the nutrients they need from within the sediment. In contrast, fast-growing phytoplankton, algae that grow on seagrass (epiphytes), and algae that grow on the bottom

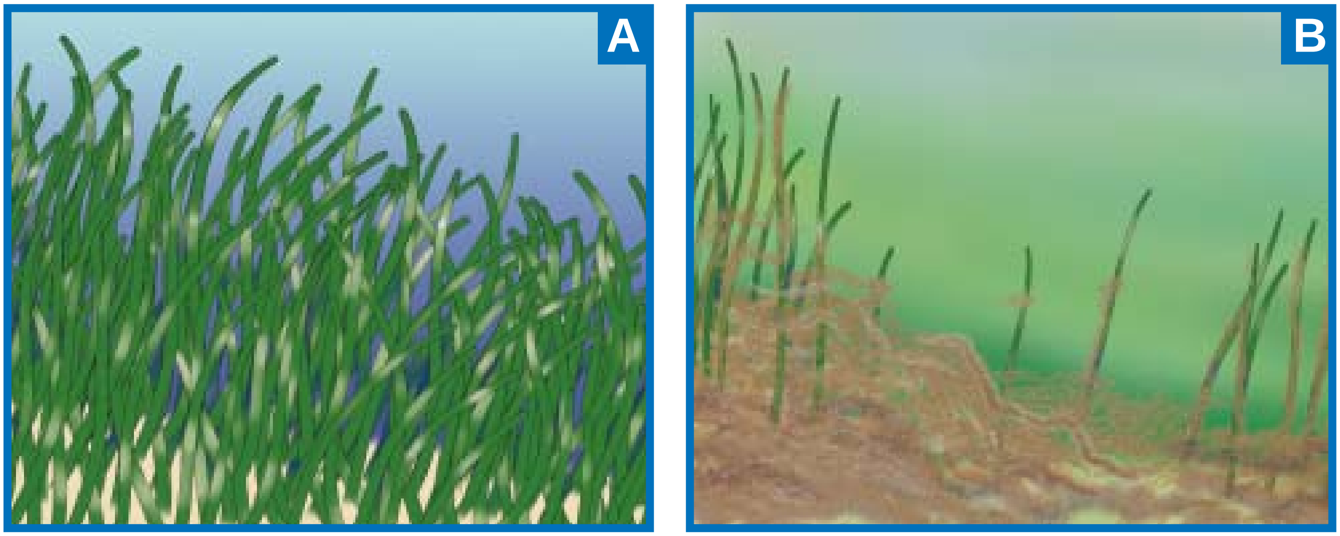

Figure 2: Drawings of a) a healthy seagrass bed and b) an unhealthy seagrass bed shaded and overgrown by phytoplankton and algae as a consequence of increased nutrients. (Source: Florida Sea Grant)

(benthic macroalgae) are often nutrient limited, and they respond to higher nutrient loads by growing faster.[12, 14, 15–18] Increased amounts of these producers remove a large percentage of the light that would otherwise have been available for seagrass photosynthesis, and the seagrasses are "starved" of the light they need to survive. Lack of suitable light, in fact, is probably the major cause of damage to seagrasses. This "shading" effect can also damage habitats other than seagrass. For example, overgrowth of algae leading to reduced light can eventually kill corals.

The indirect effects of increased nutrients do not stop at the loss of seagrass habitat because that loss often means that an important habitat for some animals is degraded. As seagrasses are lost, animal numbers may decline because they rely on seagrass for protection from predators or because they rely on plants and animals in seagrass meadows for food. Examples of animals affected in this manner include certain species of invertebrates (such as amphipods, isopods, shrimps, and snails) that are important in the diet of several species of fishes. Furthermore, juvenile scallops often settle directly upon the leaves of seagrasses, and the loss of seagrass may contribute to diminished numbers of scallops along Florida's Gulf coast. For a few species, increased primary productivity may actually represent an increase in food. For example, growth rates of clams like the quahog, *Mercenaria mercenaria*, may increase in systems with higher nutrient loads because extra nutrients stimulate production of their food – phytoplankton and particles that are filtered from the water column.[19]

The shift from seagrass to a system with more algae and more organic matter (a more eutrophic system) can affect not only the habitat and food available to animals but also the "biogeochemistry" of coastal waters (see box on this page, for an example). Under normal, low nutrient conditions, O_2 concentrations rise during the day as primary producers photosynthesize and produce O_2 and fall during the night as all organisms respire or use O_2 to generate energy. Generally, O_2 concentrations remain high enough for animals to survive. However, excessively low O_2 conditions arise when respiratory use of O_2 by aquatic communities (primary producers and consumers) exceeds the sum of O_2 release during photosynthesis by primary producers and passive diffusion of O_2 from air to water. Under such circumstances, certain invertebrates and fishes may suffocate.

In particular, increased amounts of algae caused by increased nutrient loading can cause O_2 concentrations to

How can biogeochemical changes affect coastal systems?

High concentrations of nutrients, particularly nitrogen, carried by the Mississippi River to the Gulf of Mexico have stimulated substantial increases in algal production. Much of the excess algae settles to the seafloor where it is degraded by bacteria. The degradation process consumes O_2, and greater inputs of algae cause more degradation and more loss of O_2. Extensive loss of oxygen, a biogeochemical change, creates a "dead zone" in the northern Gulf of Mexico.[20–22] In essence, the "dead zone" contains no living plants or animals. During the past 20 summers, the dead zone has increased in size to cover an area the size of New Jersey.

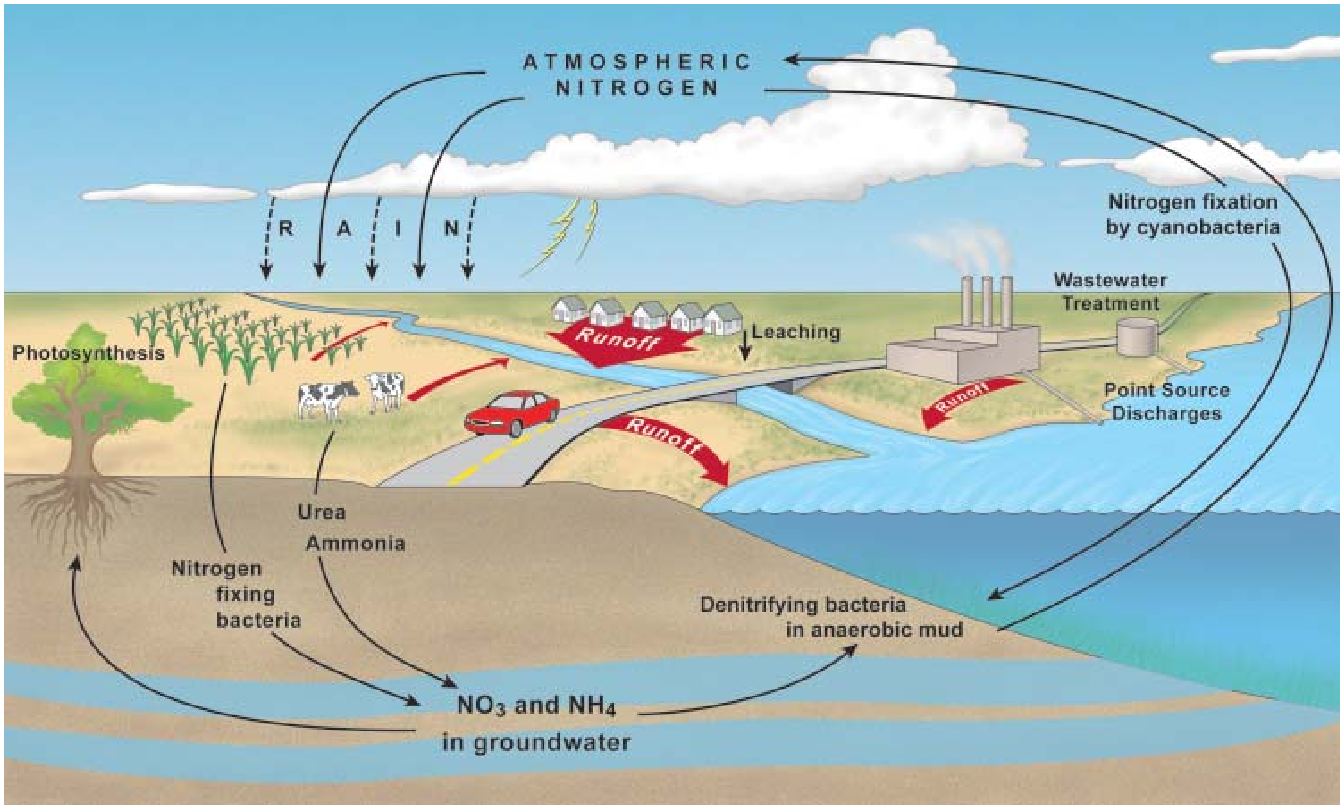

Figure 3: Simplified diagram of the nitrogen cycle showing some key sources of nitrogen (household septic systems; fertilizer from lawns, gardens and agriculture; waste from livestock; point source discharges from wastewater treatment plants and industry; exhaust from cars; and emissions from industry), some key mechanisms that transport nitrogen (rain, runoff, leaching, groundwater, and rivers), and some key processes that transform nitrogen (nitrogen fixation, denitrification and photosynthesis). (Source: Florida Sea Grant)

fluctuate greatly. Although algae contribute O_2 when they photosynthesize, their respiration and the respiration of bacteria that degrade dead algae can use more O_2 than is produced. On sunny days, photosynthetic production is usually greater than respiratory demand and there may be no problem. However, a series of cloudy days can lead to less photosynthesis and less O_2 production, so that respiratory demand can exceed O_2 availability. In these situations, low oxygen concentrations (hypoxia) or loss of all oxygen (anoxia) causes the death of invertebrates and fishes.

What nutrients are we concerned about and why?

Of all the essential nutrients, nitrogen (N) and phosphorus (P) are the two nutrients that most often limit the growth of primary producers. Nitrogen is a key component in 1) chlorophyll, the green pigment in primary producers that absorbs sunlight during photosynthesis, 2) amino acids, the building blocks of proteins, and 3) genetic material, including deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). Nitrogen ranks as the fourth most abundant chemical element in living tissue, behind oxygen, carbon, and hydrogen. Phosphorus is also a key component in DNA, and it is found in adenosine triphosphate (ATP), a molecule that is important in energy transfer and storage in living cells.

Because N and P largely control primary productivity, we are primarily concerned about their addition to our coastal waters. Phosphorus is often the "limiting" nutrient in freshwater environments, meaning the addition of P stimulates primary productivity. Nitrogen is more frequently limiting in marine environments. However, many exceptions to this pattern can be found along the coast of Florida and elsewhere around the world. Some of Florida's coast has sediments that are rich in calcium carbonate ($CaCO_3$). Phosphate (PO_4), the form of P typically used by primary producers, binds to these sediments and becomes less available. So, in Florida's coastal waters, either N or P may limit growth. We focus here on N as an example of how humans affect the natural cycles of key nutrients.

How do plants and algae get nitrogen?

Many essential nutrients are made available to primary producers through natural weathering of the earth's crust. Unlike other nutrients, N is most abundant as di-nitrogen gas (N_2). In fact, this gas comprises 78 percent of the air we breathe. Although it is abundant, N still limits the growth of primary producers, because most plants and algae cannot directly use N_2. Primary producers cannot break the very strong and stable chemical bonds between the atoms in nitrogen gas.

So, how do primary producers get N (Figure 3)? Lightning can produce the immense, focused energy needed to break the bonds in N_2, and it produces nitrite (NO_2), nitrate (NO_3), and ammonia (NH_3). In addition, living organisms called nitrogen-fixers can convert N_2 to ammonium (NH_4), the form of N most readily taken up by primary producers. In terrestrial environments, free-living microbes and symbiotic bacteria in peas, alfalfa, soybeans and other legumes perform this function, and in marine environments, cyanobacteria (commonly called blue-greens) fix N. Plants can also take up NO_3, but this process requires energy (the use of ATP), and NO_3 must be converted to NH_4 before the N can be used in protein synthesis. Other natural sources of N are the production of animal waste, natural burning of organic matter or fossil fuels, and the decomposition of organic material, such as the decay of dead algae.

How do people affect supplies of nitrogen to coastal waters?

There are three primary sources of human-derived N: 1) wastewater, 2) fertilizer, and 3) atmospheric pollution (Figure 3). Nitrogen from these sources is delivered to coastal regions in three ways: 1) point source inputs of water, such as rivers or wastewater outlets; 2) nonpoint source inputs of water, such as direct surface runoff or groundwater that has percolated through the soil, into an aquifer and out to coastal waters as springs or diffuse plumes; and 3) direct atmospheric deposition (Figure 3).[23]

Nitrogen has always been delivered from the land to the sea, and this transfer helps make coastal waters productive. However, increases in N that can be used by primary producers (bioavailable N) arising from increases in human activities pose a threat to healthy coastal systems (see shaded box, on this page). For example, an estimated 37 percent of the world's population currently lives within 62 miles of the coastline, and we can expect 75 percent of the U.S. population to live within 47 miles of the coastline by the year 2010.[24, 25] Increased coastal populations with their residential, commercial, industrial, and agricultural activities have increased the delivery of anthropogenic, or human-derived, N and P to estuaries via point and nonpoint sources of wastewater and fertilizer. Air pollution from industry and cars also contributes N to coastal systems via direct deposition into the sea or via deposition to land and subsequent transport by groundwater or surface runoff.[26]

The pressure on coastal waters in states such as Florida is increased by our country's agricultural practices. A majority of crop production in the United States occurs in the inland, midwestern states, with food being transported to people in coastal states. This translocation means that coastal populations import N in the form of food from inland regions and export N in the form of waste to coastal

How have we affected the availability of nitrogen?

Over the past century, human activities have more than doubled the rate at which atmospheric N_2 or organically-bound N is converted to biologically available forms (Table 1). The transfer of atmospheric N has increased due to 1) increased cultivation of nitrogen-fixing crops such as peas, alfalfa, and soybeans, and 2) production of artificial fertilizers. The technology for the industrial production of artificial fertilizers was developed in Germany during World War I, after Fritz Haber synthesized the base for them, NH_3, by combining N_2 and hydrogen gas (H_2) at high temperature and pressure. We have increased the transfer of organically-bound N by 1) burning fossil fuels, such as coal and oil, and 2) burning or clearing land.

Table 1. Global nitrogen fixation in terrestrial environments. Data are summarized from Vitousek et al. (1997).[23]

Input	New nitrogen (million metric tons per year)
Pre-1900s	
bacterial fixation	90–140
lightning	<10
Total	100–150
Post-1900s	
bacterial fixation	90–140
lightning	<10
cultivation of N-fixing crops	40
fertilizer production	80
burning fossil fuels	>20
burning or clearing existing land	70
Total	310–360

systems. Overall, coastal systems receive a disproportionately high load of nitrogen generated by the activities of people.

Can't we just add the "right" amount of nitrogen?

Scientists and environmental managers are attempting to predict the level of N loading that a system can accommodate. The concept of assimilative capacity or total maximum daily load (TMDL) refers to this threshold. Unfortunately, the nutrient load that causes undesirable changes in coastal ecosystems, the threshold loading, is not a simple thing to predict. Uncertainty arises from many causes, including the complex and interactive cycles of N and other nutrients, geological variation among sites, seasonal variations in rainfall and sunlight, and the influence of isolated events. For example, a system may exceed its assimilative capacity when unusually large rainfalls deliver high pulses of nutrients. Once the system has undergone a change, it may not readily revert back to its former state.

Scientists and managers are also protecting our coastal systems by monitoring their status and adjusting management efforts accordingly. Monitoring often involves measurements of nutrient concentrations in the water column, but these concentrations change rapidly and vary from place to place. Such variation makes it difficult to accurately identify long-term increases. As a "safety net", some monitoring includes bioindicators and bioassays that focus on changes in natural vegetation, changes in growth rates, or changes in the type of N found in plants. The hope is that these "indicators" will integrate short-term pulses to provide an improved view of long-term trends.

What can we do?

First and foremost, we can limit nutrient inputs to coastal waters. Examples of actions that might decrease nutrient loading to coastal waters include:

- *Limit urban development, especially along shorelines.* Increases in development result in increased nutrient loads via many pathways. For example, more development and more people often mean that coastal waters will receive more nutrients from septic systems, wastewater treatment plants, or fertilized lawns and landscaping. Development increases the amount of "impervious surfaces" (such as roads, driveways, or roofs) that generate nutrient-rich, storm water runoff, and it also diminishes forests and natural "green spaces" that slow runoff and remove nutrients.
- *Preserve wetland buffers or green space and submerged aquatic vegetation associated with coastlines, rivers, and streams.* Important "buffer" habitats include salt marshes and mangroves. Plants in these systems remove N and P as they grow. In addition, wetland sediments are good sites for "denitrification", a process in which bacteria convert nitrate (NO_3, a biologically available form of nitrogen) into nitrogen gas (N_2) that enters the atmosphere and becomes less available to coastal primary producers. Efforts should also be made to preserve submerged vegetation, such as seagrasses, because this vegetation also removes nutrients. For example, people should avoid direct removal of submerged vegetation by dredging or raking, and they can minimize indirect loss due to shading by building docks at a proper height, orienting them north–south rather than east–west, and spacing their boards.[27]
- *Limit the use of fertilizers on residential and commercial lawns and landscaping.* When fertilizing, it is important to minimize quantities and avoid fertilizing before heavy rains. Storm water runoff can transport fertilizer intended for yards directly to coastal waters. A University of Florida extension program, Florida Yards and Neighborhoods, provides information to homeowners on environmentally friendly landscaping that reduces storm water runoff, decreases nonpoint source pollution, conserves water, enhances wildlife habitat, and creates attractive landscapes (see the web site listed below for further information).
- *Manage storm water runoff.* Diverting runoff to retention ponds or other temporary storage areas minimizes direct input of nutrients to coastal waters. Minimizing the extent of impervious surfaces while maximizing the cover of natural vegetation also reduces the amount of storm water runoff delivered to coastal waters.
- *Use better septic systems.* Repairing old or leaking septic systems or replacing them with more efficient systems will help keep nutrients from reaching groundwater or runoff. For example, denitrifying systems rely on the natural microbial process of "denitrification" to convert nitrate (NO_3), which can enter groundwater and move to coastal waters, into nitrogen gas (N_2) that is instead released to the atmosphere.

- *Improve sewage treatment plants.* Different levels of wastewater treatment result in different levels of nutrient removal. Tertiary treatment results in the most complete removal of nutrients. Improved wastewater treatment can dramatically affect coastal ecosystems. For example, two decades ago, seagrass coverage in Tampa Bay was less than 30 percent of historical levels. The loss was largely attributed to nutrient loading. In the 1980s, improving treatment of inputs from domestic and industrial point sources created a 50 percent reduction in N loading. Water quality in Tampa Bay has steadily improved, and, as a result, coverage of seagrass has expanded by about 12 percent.[28]
- *Support efforts to improve our knowledge.* We can all support research and monitoring that will supply information that is critical to future improvements. In short, we can strive to know more so that we can make informed decisions.

Understanding the response of coastal primary producers to nutrient loading, the interactions among these producers, and the indirect effects of changes in these producers on other elements of coastal systems is crucial for preventing loss and damage in coastal environments. Preventing loss and damage is the most effective form of management, because restoration of coastal habitats will be far more costly and difficult if not impossible.[29–31]

At this time, it is difficult to accurately predict the amount of nutrients that can be safely added to coastal waters. Small-scale experiments have shown the existence of links between nutrient supply, algal production, and loss of seagrass habitat.[16, 17, 32–36] However, numerical relationships that specify the exact nutrient load resulting in undesirable responses at the estuary scale are only available for a few systems around the world. We need to conduct large-scale experiments and undertake monitoring to validate extrapolations and predictions made from small-scale experiments and to accurately estimate the rate at which nutrients are being added to Florida's coastal waters. Monitoring not only helps us understand the interactions between human activities and coastal systems at larger scales, it also gives us early warnings of problems.

Scientists, managers, and community members need to work together to develop research initiatives and monitoring programs that detect and predict small, relevant changes caused by increased nutrient loads. Such experimental and observational research would allow us to further understand the relationship between nutrient loading and changes to coastal habitats. This understanding can be used to formulate effective, but not unnecessarily restrictive, policies for managing human activities.

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