# Sources and Impacts of Nutrient Pollution on Coastal Ecosystems

by

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# Introduction

Sixty-five percent of estuaries and coastal waters studied by researchers in the contiguous United States are impaired by high nutrient loading (NOAA, 2021). Excess nutrients in waterways have many detrimental impacts, including more frequent toxic algal blooms like red tide. Florida's 2018 red tide event had an estimated direct socioeconomic impact of more than $184 million (Court et al., 2021) The following chapters explore 1) the causes of nutrient pollution and 2) the implications nutrient pollution has for one coastal ecosystem.

Nutrient loading into waterways presents a growing threat to coastal systems. This pollution can be linked to human activity. There are two primary categories of pollution: point source and nonpoint source pollution. Both categories have qualities that impact how effectively they can be addressed with state or federal regulation. Compliance with these regulations, improving management strategies, and targeting pollution sources with water quality improvement projects are the most effective ways to battle nutrient pollution, but environment can impact the efficacy of these actions. This is best demonstrated by comparing two case studies within Florida: Tampa Bay and the Indian River Lagoon. Tampa Bay has successfully transformed over the past 50 years from a eutrophic dead zone back to a healthier macrophyte dominated system. Despite efforts to reduce issues associated with nutrient enrichment, the Indian River Lagoon has improved far less. This is partially due to its poor flushing and high residence time. This factor is one of many that impact how easily pollution is remedied. Both Tampa Bay and the Indian River Lagoon have experienced severe seagrass losses because of nutrient pollution.

Seagrasses are an important species within coastal systems, as they perform essential functions within the ecosystem. They provide many ecosystem services by providing food and habitat for many animals and contributing to shoreline stabilization. Seagrass meadows are crucial for nutrient regulation in waterways. They regulate nutrient concentrations in the water by using nitrogen and phosphorus to build biomass and enhance denitrification in sediments by modifying sediment conductions via organic matter trapping and root exudates.

Seagrasses can be negatively impacted by too many nutrients in the water, leading to large scale die offs and  widespread seagrass losses. In high-nutrient conditions, algae grow quickly and outcompete seagrasses. Light reaching the bottom where the seagrasses grow decreases as a result, stressing the plants. As algae die and decompose, oxygen is consumed and hypoxic conditions can occur. Seagrasses depend on oxygen supplies in the water column to carry out respiration during nighttime. Without adequate oxygen supplies, primary productivity becomes limited (Rasmusson et al., 2020). These occurrences decrease overall coastal system function. Combating nutrient pollution is the best way to ensure seagrass system health.

These chapters are written as EDIS documents for members of the scientific community looking for an overview of the interactions between nutrient loading and coastal systems.

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# Chapter 1:
# Sources of Nutrient Pollution to Coastal Waters

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## Introduction:

According to the National Oceanic and Atmospheric Administration, almost 40 percent of Americans live in a coastal county (NOAA, 2021). Coastlines are valuable not only for their breathtaking views, but the ecosystem services they provide. Coastal systems provide food, recreation, and nutrient regulation. These systems are quite valuable, but also particularly vulnerable. Common practices such as dredging and over-exploitation of resources have resulted in significant environmental degradation. Other activities contribute to coastal pollution, particularly nutrient pollution.

Nutrient pollution is a primary driver of coastal ecosystem decline. Humans are increasing nutrient loads into the water through runoff from lawns and agricultural fields, as well as overall poor water treatment. Maintaining proper nutrient balance is crucial for the health of marine environments. Insufficient nutrients can limit organism function. Conversely, high nutrient loads can lead to eutrophication.

In eutrophic conditions, seagrasses are outcompeted by algae that thrive in such high-nutrient environments. When these algae die, they consume oxygen during decomposition. This limits the amount of oxygen available for other organisms, creating hypoxic “dead zone” conditions–for example, fish kills. Eutrophication can also lead to blooms of toxic algae such as *Karenia brevis*, commonly known as red tide (Burkholder et al., 2007, Short and Wyllie-Echeverria, 1996).

Eutrophication is typically a result of additional nutrients entering the system from the land. Polluted runoff can reach surface waters in several ways. In this document, we will examine two categories of pollution: point source and nonpoint source pollution.

## Point sources:

Point sources can be defined as “any discernible, confined and discrete conveyance… from which pollutants are or may be discharged” (EPA 2021). Point sources of pollution are easily identified, as they have an obvious source. For example, effluent discharge piping from a municipal wastewater treatment plant can be easily labeled as a potential pollution source. Simply put, point source pollution consists of a single discharge point that can be directly linked to pollution activity. Point source discharges containing excess nutrients (particularly nitrogen and phosphorus) are especially detrimental for water quality. They are a common polluter in estuaries and coastal waters. These are some of the most common point sources of pollution:

## Examples of Point Sources:

### 1. Animal Feeding Operations (AFOs)

Animal feeding operations (AFOs) are significant contributors to point source pollution. Livestock and poultry manure are the source of many potential pollutants including pathogens, sediments, and nutrients (EPA, 2013). Nitrogen and phosphorus are perhaps the most abundant among the many potential contaminants. Contaminants in manure from AFOs may get discharged to surface waters in various ways. Precipitation runoff, storage issues and improper application are all potential vectors of contamination.

Contaminants can be transported to surface waters or leach into groundwater. The latter is especially perilous since nitrates have adverse health effects, particularly for infants. High nitrate consumption for infants may lead to methemoglobinemia, or "blue baby syndrome," a condition in which hemoglobin in the blood is unable to carry an adequate amount of oxygen. Nitrates are the most common agricultural contaminant found in drinking water supplies (EPA, 2004). Improving manure management practices can reduce nutrient loading into coastal waterways.

Concentrated animal feeding operations (CAFOs) are industrial size farms where over 1,000 animals are confined for more than 45 days per year. CAFOs have been explicitly labeled as point sources of pollution by the EPA due to the likelihood they will discharge pollutants to surface waters (EPA, 2021).

### 2. Wastewater and Stormwater Systems

Wastewater is another example of point source pollution. Wastewater effluent is carried from homes, businesses, and industrial facilities to treatment plants for processing. Effluent is often discharged directly from a pipe into surface waters. Improperly treated wastewater can carry a slew of nutrients and other contaminants with it. Municipal wastewater is an especially significant contributor to nutrient pollution. This type of wastewater contains high concentrations of nitrogen and phosphorus from sewage and industrial waste sources. Several basic physical, biological, and chemical treatment processes are commonly used to ensure that any effluent discharged from a facility meets regulatory standards (EPA, 2004).

Stormwater runoff refers to precipitation that flows over impervious surfaces and does not infiltrate into the ground. The water is collected by sewer systems and eventually discharged to a waterbody. This runoff picks up sediment, nutrients, or other contaminants as it travels over the ground. Some activities in developed areas pose a larger pollution threat. Vast amounts of sediment can quickly leave the boundaries of construction projects if they are not well managed. Manufacturing processes, outdoor raw material storage, and other industrial activity exposed to stormwater may contribute to polluted runoff.

Although wastewater may sometimes be left untreated, stormwater is almost never treated prior to entering waterways. There are two main designs for municipal sewer systems: combined sewers and separate sanitary sewers. Combined sewer systems transport both stormwater runoff and wastewater to a treatment plant. During significant rain events, combined sewer systems may become overloaded and discharge untreated wastewater. Separate sanitary sewer systems are better suited to handle high precipitation areas. In these systems, stormwater and wastewater are collected separately and only wastewater is brought to a plant for treatment. Most major municipalities in Florida operate a separate sewer system known as a Municipal Separate Storm Sewer System, or MS4 (FDEP, 2021). This streamlines the process for treating wastewater by reducing the amount of water that must be treated. However, stormwater is discharged without treating runoff, so any contaminants it carries are brought directly to surface waters.

### 3. Biosolids

Biosolids are a byproduct of the process at wastewater treatment plants. After liquids and solids are separated, the solids are physically and chemically treated. This creates the nutrient-rich substance known as biosolids or 'sewage sludge'. There are many ways to manage and dispose of biosolids: incineration, landfill disposal, deep well injection, or general storage. However, the most popular use for biosolids is land application due to its economic and practical benefits (EPA, 2021). Land application of biosolids provides a boost to soils where nutrients are limited or insufficient for the intended use.

In 2019, 51% of biosolids were applied to land. This amounted to around 2.44 million dry metric tons (dmt). About 1.4 million dmt of that was specific to agricultural land (EPA, 2021). Agricultural use of biosolids is regulated with application rate standards, known as agronomic rate. This metric considers the amount of nitrogen needed by crops to determine the quantity of biosolids that should be applied. Using biosolids to meet nutrient demands reduces reliance on synthetic fertilizers.

Land application of biosolids may also be used to reclaim abandoned mining sites. Biosolids provide many benefits in this case, especially for sites with diminished or absent topsoil. Land application at reclamation sites can help reduce erosion, restore soil structure, and reestablish vegetation (EPA, 2021). Biosolids can also assist with reducing the bioavailability of the trace metals and toxins often found in these soils and restoring nutrients stripped from soils by mining activity (Shrestha and Lal, 2011).

While there are many advantages to the vast utility of biosolids, there are also some drawbacks. While biosolids do contain less nitrogen, phosphorus, and potassium relative to commercial fertilizers, they still present a threat of nutrient pollution. Since land application is typically based on nitrogen requirements, phosphorus may accumulate in soils. This phosphorus may eventually be transported to surface waters, resulting in eutrophication (Liu et al., 2012). Best management practices should be employed when possible to avoid potential pollution.

## Nonpoint Sources:

The EPA defines nonpoint source pollution as coming "from many diffuse sources… nonpoint source pollution is caused by rainfall or snowmelt moving over and through the ground" (EPA 2021). A wide variety of pollutants are carried from their source by natural processes. The ambiguity of pollutant source in these cases makes enforcing regulations especially tricky.

Nonpoint source pollution has been highlighted as a leading cause of water quality issues around the world (EPA, 2021). According to the Florida Department of Environmental Protection (FDEP), nonpoint source pollution is the cause for more than half of the total pollution load to Florida's surface waters (FDEP, 2015). Nonpoint source pollution may include fertilizer application, stormwater runoff, and septic systems, among other sources.

## Examples of Nonpoint Sources:

### 1. Agriculture and Synthetic Fertilizer Application

Agricultural activity is a fundamental part of the U.S. economy. Nearly half of the 2.3 billion acres that make up the United States are devoted to some form of agricultural operations (EPA, 2021). Modern agriculture practices often manipulate soil and water conditions to optimize crop yield, but may cause damage to these resources in the process. The National Water Quality Assessment has named agricultural runoff the top source of water quality degradation for rivers and streams (EPA, 2017).

Millions of tons of pesticides and synthetic fertilizers are applied to crops each year. While much of these substances are taken up for use, the rest are carried away by rain or irrigation waters. Some contaminants infiltrate soils and reach groundwater sources. The primary components of concern within agricultural fertilizers are nitrogen and phosphorus. When excess fertilizer is carried offsite it eventually reaches waterways, contributing to nutrient pollution (EPA, 2021).

Improved management practices are limiting nutrient pollution from agriculture. In Florida, the Department of Agriculture and Consumer Services (FDACS) regulates agricultural pollution with a crop-specific best management practice (BMP) program. Over 4.6 million acres of farmland in Florida is currently enrolled in the BMP program (FDACS, 2020).

Unfortunately, nutrient pollution from fertilizer use is not limited to agricultural activity. Year-round green lawns are the expectation for millions of homes across the country. Copious amounts of water and fertilizers are employed to maintain a vibrant appearance. Homeowners are not as familiar with proper fertilizer practices, which often leads to over-fertilization (Trenholm, 2018). Similar to agricultural applications, many of these nutrients aren't taken up where they are distributed and eventually end up in rivers, lakes, or the ocean.

### 2. Septic Systems

Septic systems (also known as onsite wastewater treatment and disposal systems) represent another suburban nonpoint source threat. More than twenty percent of homes in the United States rely on septic systems for wastewater treatment. They can provide a low-cost, low impact solution for wastewater management in places where connecting to a local utility may not be possible or cost-effective. However, they are sometimes used in subdivisions, where the density of housing and number of septic tanks per area could lead to appreciable sources of nitrogen and phosphorus moving through the soil to waterways. Septic tanks may especially be of concern in areas where the age of houses is approaching the typical duration of septic tank effectiveness.

Regulations for septic systems vary depending on the type of system. Individual onsite systems have historically been regulated by local agencies, while larger systems were regulated by the EPA's Underground Injection Well program. Currently, FDEP is coordinating domestic wastewater compliance efforts with the Florida Department of Health. The agencies providing permits did not typically conduct inspections after a system was installed. This may be changing, as there are growing concerns about the environmental impacts of poorly maintained domestic wastewater systems. (FDEP, 2021, EPA, 2020).

Conventional systems utilize a septic tank and effluent distribution system. Wastewater released into the environment from these systems are not held to the same standards as effluent from a municipal wastewater treatment plant. Septic systems rely on microorganisms present in soil to provide additional treatment. Therefore, it is crucial that these systems are properly managed and maintained. Subpar performance of septic systems can lead to nutrient pollution and a poor outcome for public and environmental health. The responsibility of proper operation and maintenance ultimately falls to the system owner. These systems represent a growing threat, as one third of newly constructed homes rely on septic systems for their wastewater management needs (EPA, 2020). For more information regarding the impact of septic systems on Florida's water quality, see EDIS publication SS693 (https://edis.ifas.ufl.edu/publication/SS693).

## Regulating Pollution Sources

To combat the impact of point source pollution, the EPA created the National Pollutant Discharge Elimination System (NPDES) program under the Clean Water Act (CWA) in 1972. Permitting and enforcement activity for the NPDES program is primarily delegated to state governments, but the EPA broadly manages all CWA programs. The NPDES program aims to limit polluted discharge to surface waters by regulating inputs from potential pollutant areas. There are specific regulatory metrics for each program meant to target the greatest threats to water quality.

The NPDES program requires permit holders to either achieve compliance with prescribed regulatory standards or show effort toward achieving those standards. Ideally, all treatment plants would achieve complete compliance with these standards, but this is not always the case. Total compliance with regulatory standards typically requires a significant investment of both time and money.

There is no nonpoint source regulatory equivalent to the NPDES program. Nonpoint sources of pollution in general are growing as a threat. While a few grants have been created to incentivize designing solutions for nonpoint source problems, most resources have been allocated to point source management. Water quality issues still plague waterways across the country despite a multitude of clean water regulations. State and federal regulations effectively manage most point source pollution, but few such regulations exist for nonpoint sources.

At a landscape scale, landowners and property managers are using innovative methods to reduce nonpoint pollutant inputs. Vegetative filter strips are a successful best management practice being employed to reduce contaminant loading into surface waters. These buffers work by slowing runoff and intercepting any contaminants it may carry (Smyth et al., 2018). Buffer zones are being employed more frequently to combat nutrient loading in developed areas. These areas provide a transition between two opposing environments, such as an agricultural field and a riparian wetland. Buffer zones provide a chance for nutrient removal and improve long-term pollution management efforts. Wetlands are particularly adept at nutrient removal through a variety of biogeochemical processes (Walton et al., 2020). Florida has many naturally occurring wetlands, but these systems can also be constructed. Naturally occurring wetlands are protected by state and federal regulations through environmental resource permitting. Wetland impacts must be mitigated, as there is a federal no-net loss policy for wetlands (NRCS, 2021).

Some smaller scale local regulations are targeting nonpoint source pollution. Enacting a ban or other ordinance regarding fertilizer application has become popular in many Florida counties. Utilizing this method to target nitrogen and phosphorus loading lowers the amount of nutrient pollution that occurs through stormwater runoff. These restrictions are typically put in place during summer months when precipitation is highest. Isotope tracking points to fertilizer application and lawn clippings as a major source of nutrient pollution in waterways (Yang and Toor, 2016).

Although temporary fertilizer bans seem helpful in reducing nutrient loading, they are certainly no panacea. These restrictions do not eliminate nutrient pollution but instead reduce or delay its discharge. Nutrients from fertilizers often reside in soils long after application, so they may still make their way to surface waters eventually. There have been very few efforts to determine exactly how effective fertilizer ordinances really are. The Tampa Bay Estuary Program (TBEP) reports that seven years of monitoring is necessary to determine the extent of nutrient reductions (TBEP, 2015). There are no long-term studies on the efficacy of fertilizer restrictions for improving water quality.

## Case Studies:

Over the past few decades water quality in America has improved, with much of the credit attributed to the NPDES or other CWA programs. Between 1972 and 2001, there was a 12% increase in waters suitable for fishing (Keiser and Shapiro, 2018). Grants provided to local governments through the CWA have lowered the violation rates of waters downstream from municipal wastewater plants across the country (Keiser et al., 2018). These improvements have come from focusing legislation on point source pollution, which is advantageously easy to regulate. Since the source is observable, there is a clear pathway for reducing pollution.

Despite improvements, many coastal systems are dealing with the consequences of rampant nutrient pollution. Federal regulations provide a consistent framework for addressing common threats, but each system presents unique challenges. Local governments and committees have generated their own solutions to deal with the problems they are facing. Some areas like Tampa Bay have found great success restoring water quality. Other systems such as the seagrass meadows in the Indian River Lagoon are still fighting complications from eutrophication no matter what approach they take. Comparing these cases provides valuable insight into which methods work best and what factors have the greatest impact on results.

### Tampa Bay:

Tampa Bay is the largest open-water estuary in Florida. Its watershed encompasses over 2,200 square miles and sustains a population of about 2.7 million people. As the population of the Tampa Bay area grew throughout the mid 20th century, water quality within the Bay seriously declined. Channel dredging, overfishing, and nutrient pollution caused serious harm to environmental quality. High nitrogen loads caused the water to become eutrophic, leading to the disappearance of more than 80% of the original seagrass coverage by the 1970s. The water was murky with very few signs of life. Fortunately, conditions have changed since then. Nutrients in the water have decreased, seagrasses are plentiful, and water clarity has greatly improved. (Waters, 2018).

Generating a solution to Tampa's pollution problem necessitated an understanding of pollution sources within the watershed. Many of the new households within the Tampa Bay watershed utilized septic systems. Part of the pollution reduction strategy involved connecting these residents to the local utility for wastewater management. During this time, the Clean Water Act and NPDES program began to regulate discharge from point sources of pollution. Around the same time, Tampa Bay was designated an "estuary of national significance." This title was accompanied by federal requirements to create a plan for protecting the estuary and its watershed. These efforts helped to reduce nitrogen loading from wastewater into the Bay (TBEP, 2019).

Over the past four decades, nearly 900 public and private projects for water quality improvement have been completed within the Tampa Bay watershed. The primary goal of these projects, further discussed below, was to implement management changes throughout the watershed to target the sources of nutrient pollution. These efforts have proved fruitful, as biodiversity and seagrass levels in the area have returned to conditions last seen in the 1950s. Progress has been primarily attributed to reducing domestic and industrial point source discharges by 60% relative to the 1970s (Johansson, 2002). Between 1977 and 1987, the median nitrogen content of the Bay ranged between 0.57 and 0.88 mg/L depending on salinity conditions. From 2007 to 2017 observed nitrogen values had sunk to a range of 0.33-0.42 mg/L (Beck et al., 2019).

Spatiotemporal analysis of water quality restoration projects reveals some patterns that facilitated this success. Water infrastructure projects were implemented with the intention to target point source pollution. Prominent examples of this include the employment of nutrient loading controls and water treatment process upgrades. These projects were linked to a reduction in chlorophyll-a, a metric used to measure macroalgae and phytoplankton density. Higher chlorophyll is indicative of increased resource competition within the water column for seagrasses (Greening et al., 2014).

A combination of management strategies have been utilized to determine the best course of action for improving water quality. Land-based projects were implemented to decrease runoff into coastal waters, and projects focused on ecosystem protection consistently produced effective results with minimal effort. A combination of implementing buffer zones and point source controls has been identified as the best method to improve conditions quickly and efficiently. However, nonpoint source pollution mitigation also contributes to increased water quality. These efforts include education, outreach, and implementing various BMPs for stormwater or wetland management. For the past few years, the counties surrounding Tampa Bay have even put a fertilizer ban in place during summer months.

Reductions in nutrient loading and improvement in water clarity within the bay preceded seagrass recovery. These improved conditions allowed seagrasses to grow, spread, and provide ecosystem services that further improved water quality (Beck et al., 2019). This positive feedback system combined with sustained efforts to minimize nutrient pollution should ensure that the bay continues to thrive.

### Indian River Lagoon:

The Indian River Lagoon (IRL) is a unique and important estuary system located on the Atlantic coast of Florida. The system is one of the most biodiverse estuaries in North America. The IRL has been given several regulatory protections considering its ecological importance. It has been designated a Surface Water Improvement and Management (SWIM) Program Water Body, an aquatic preserve, and an Outstanding Florida Waterway. Each of these designations come with a set of protections meant to preserve the quality of the system and the services it provides.

In 1990, the Indian River Lagoon Act was passed by Florida Legislature to protect the IRL from nutrient pollution. The Act was successful in stopping most point-source sewage discharges into the lagoon by 1996. However, high-polluting nonpoint sources such as septic tanks have gone almost entirely unaddressed in state resource management plans. By 2017, around 95% of the original seagrass population within the IRL was lost after eutrophication within the lagoon spawned record-breaking occurrences of harmful algal blooms. It is likely that the nitrogen enrichment of the IRL is linked to the plethora of septic tanks installed within the IRL watershed (Lapointe et al., 2020).

Septic systems are thought to account for more than ninety percent of the nitrogen in groundwater within the IRL watershed. This groundwater eventually discharges to the IRL, and the nitrogen with it. An analysis of nitrogen isotopes in benthic macroalgae pinpoint human wastewater as the primary source of nitrogen loading within the IRL, especially in the north area of the lagoon. The north IRL is especially vulnerable to eutrophication due to high residence times of waters that discharge there (Lapointe et al. 2015).

Some local regulatory groups are making strides towards lowering nutrient input to the IRL. Brevard County has used funds from a half cent sales tax increase to fund restoration and infrastructure projects in the portion of the IRL it borders. The county's 2021 Save Our Indian River Lagoon Project Plan includes strategies for septic system upgrades and connections to municipal wastewater systems. The Indian River Lagoon National Estuary Program Council consists of various county and state agencies. Their 2021 Business Implementation Plan seeks to upgrade or connect around 400 septic systems. However, this is barely a drop in the bucket considering the IRL watershed has over 300,000 systems.

Unfortunately, these efforts don't seem to be working quickly enough. Although nutrient pollution is decreasing, coastal communities are still suffering. In April 2021, the US Fish and Wildlife Service confirmed an Unusual Mortality Event for the manatee population within the IRL. Seagrasses are a major food source for manatees, and the dwindling seagrass population in the IRL is no longer able to sustain them (Florida Fish and Wildlife Conservation Commission, 2021). Similar devastating trends are sure to appear if more significant efforts are not taken to address eutrophication within the IRL watershed.

## Why are some forms of pollution easier to fix than others?

The ease with which pollution can be addressed varies depending on economic, regulatory, or natural environmental barriers. Mitigating pollution is a multifaceted issue, but some factors are given greater consideration than others.

### Economic Factors

Fixing water quality may be difficult if there are economic incentives to allow pollution. Pollution may be perceived as too expensive to fix and highly profitable industries benefit from fewer regulatory restrictions. Agriculture provides about 2.6 million jobs and adds more than $1 trillion to America's gross domestic product annually. As previously mentioned, agricultural runoff is the biggest source of pollution to rivers and streams. Farmers could adopt more severe practices to reduce or eliminate their contribution to pollution, but these actions may interfere with farm operations, diminishing crop production and profits (EPA, 2021). In some cases, food supply demands and the incentive of a thriving agricultural industry outweigh the advantages presented by environmental responsibility.

Some pollution may be costly to fix regardless of the benefits. The Clean Water Act made strides in protecting America's waterways, but at a very high price. Almost $2 trillion has been spent since 1960 to battle surface water pollution (Keiser et al., 2018). Precisely quantifying benefits of such legislation is difficult, as there is often substantial lag time in water quality response to improvement efforts (Meals et al. 2010).

### Regulatory Barriers

The CWA provides important protections but neglects regulations for some key areas such as nonpoint source pollution. As previously mentioned, point source pollution is much easier to regulate since its origin is clearly observable. In theory, this is the reason CWA programs are effective despite their cost. Nonpoint source pollution is relatively unregulated. It is much more difficult to document the nitrates leaving an overfertilized lawn or poorly maintained septic system.

Widespread public support can assist with circumventing bureaucratic barriers. Frequent environmental disasters can instill a sense of collective responsibility for protecting environmental quality. When the Cuyahoga River erupted in flames for the thirteenth time in 1969, photos published of the river ablaze sparked a national outcry for environmental reform. This widespread enthusiasm facilitated the creation of the Environmental Protection Agency and passage of the Clean Water Act in the following years.

### Existing Natural Conditions

Public support for environmental policy may also stem from an appreciation for the ecosystem services provided by clean waterways. Ecotourism contributes around $9 billion to Florida’s economy each year (US Fish and Wildlife Service, 2014). Part of the draw to these recreation sites are their unique features. Unfortunately, these characteristics may make waterways more vulnerable to the severe effects of pollution.

Pollution issues may be intensified by natural conditions of surface waters. Analysis of nutrient budgets for estuaries across the North Atlantic correlated nutrient transport and mean residence time of water in each system (Nixon et al, 1996). A system with a low flushing rate and high water residence time will likely have a difficult time managing an increased nutrient load. Contaminants carried by the water will stay in the system longer since the water remains in the system for an extended period. Northern portions of the Indian River Lagoon rely on nontidal flushing for water exchange. Naturally narrow inlets, low river inputs, and human infrastructure alterations contribute to a confined circulation pattern and high residence time of greater than one year (Kim, 2003, Smith, 1993). The North IRL struggles with eutrophication and severe algal blooms spurred on by rapid urbanization within its watershed. Other parts of the lagoon system with lower residence rates have less trouble with maintaining water quality (Lapointe et al, 2015).

Conversely, Tampa Bay has high flushing rates. The bulk residence time for most areas within Tampa Bay is between 48 and 69 days. Much like the IRL, some areas of the upper bay suffer from slow flushing that can be contributed to flow restrictions from inlet arrangement. However, the bay does not rely on tides alone for flushing. Winds, rivers, and gravitational convection are the primary drivers of circulation within Tampa Bay (Zhu et al., 2015). During Tampa Bay’s water quality recovery, this natural advantage was able to supplement improvement efforts.

The pollution medium can also impact the ease of cleanup or prevention. While all types of pollution present serious risks to environmental and public health, some are easier to remedy. Pollution on land is typically concentrated in landfills or restricted to designated industrial areas. Air pollution is monitored at regular intervals by federal agencies all over the country, and the largest air polluters have monitoring systems monitoring every hour. While top water polluters are required to report quarterly discharges, many facilities are inconsistent at best (Keiser et al., 2018).

Water pollution is especially difficult to deal with since water is both essential and ubiquitous. Most places in the world regularly experience precipitation. As rain or snowmelt moves through a system, it easily mixes with contaminants that eventually are discharged to waterways. If an aquifer becomes polluted, it may be decades before water quality is restored. Water resource management is key to maintaining environmental and public health.

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# Chapter 2

# Interactions Between Nutrients, Seagrasses, and Algae

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## What are Seagrasses?

Seagrasses are flowering plants found in salty and brackish marine environments. They are typically found in shallow areas where light needed for photosynthesis can reach the bottom. Their presence alters the environment, as they form the base of an ecosystem with valuable functions and services.

Seagrasses provide structure and habitat for many species, from invertebrates including shrimp, to fishes and sharks, as well as reptiles like turtles and mammals like manatees. In Florida, commercial fisheries heavily depend on seagrasses for this reason. The value of these fisheries for five main species of fish was estimated at $48.7 million each year (Milchakova et al. 2020).

Seagrasses also contribute to shoreline stabilization — the leaf structure reduces wave energy which causes suspended sediment to fall out of the water and onto the bottom and seagrasses anchor those sediments to the bottom with their belowground tissue (e.g. roots and rhizomes) (Short et al. 2007). By increasing sedimentation and sediment retention, which are high in organic matter, seagrasses can increase long term carbon sequestration (Aoki et al., 2019).

Seagrasses also impact nutrients. They use carbon, nitrogen, and phosphorous to build their biomass, keeping nutrient concentrations in the water lower. They bury nitrogen in sediments, temporarily removing it from the system (Aoki et al., 2019). Seagrasses also change the sediment in a way that promotes microbial modification of nutrients. For example, denitrification, or the permanent removal of nitrogen from the water by converting it to nitrogen gas, is enhanced in seagrass sediments (Aoki and McGlathery, 2018).

Through these processes, seagrasses modify their environment making it more favorable their growth. As turbidity in the water column decreases, light becomes available at deeper depth. This facilitates seagrass growth into deeper water, increasing seagrass total seagrass meadow size. This is termed a positive feedback (Figure 1, Carr et al. 2010).

## What are Algae?

Algae are photosynthetic organisms that can be found in the same areas as seagrasses. However, there are differences between the two. Algae can be roughly sorted into two groups based on size and morphology: microalgae and macroalgae. Microalgae are unicellular organisms, not visible to the naked eye unless they are in a group. Macroalgae are multicellular and often resemble common plants. Macroalgae can often be confused with seagrasses, but seagrasses are vascular plants with a root system imbedded in sediment on the seafloor, whereas macroalgae are less complex organisms. They often attach to rocks or coral with a holdfast, but some species can directly attach to the sediment as well.

Both groups of algae are important to ecosystem functioning. All algae photosynthesize and therefore create oxygen. In fact, microalgae produce a considerable amount of the atmospheric oxygen we breathe. Microalgae also serve as a base of the food chain, as they provide a food source for many filtering bivalves such as clams, oysters, and mussels. They are being explored as a biofuel source thanks to the significant amount of carbon compounds they contain. This propensity for carbon storage has also made microalgae an attractive option for climate mitigation prospects (Khan et al. 2018).

Macroalgae and seagrasses are often grouped together when discussing ecosystem services, as both groups perform similar functions. For example, both macroalgae and microalgae photosynthesize and play a role in nutrient cycling (Macreadie et al. 2017). Macroalgae are imperative for the survival of many fish species, as they provide both a food source and a habitat. Many invertebrates such as snails and brittle stars also rely on the services of abundant macroalgae (NOAA, 2021). However, the vascular nature of seagrasses allows them to be much more persistent relative to macroalgae. The lack of persistence of macroalgae in the environment means they have less value within the environment, since they do not provide services as consistently as seagrasses.

## How do coastal systems regulate nutrients?

Coastal ecosystems provide a filter function that reduces the impact of nutrients on oceans. There are four main paths nutrients take within the coastal system:

1) Some nutrients remain unchanged by coastal filter processes, leaving the system in the same form they entered.
2) Other nutrients are transformed and leave the system with slightly altered chemical compositions. For example, nitrogen may enter the system as an inorganic form of nitrogen. However, that same nitrogen atom may leave the system as a dissolved organic form of nitrogen.
3) Nutrients may be retained in a bioavailable form for use by organisms within the system. Organisms assimilate these nutrients into biomass. When they begin to decompose, the nutrients are released and remineralize into a bioavailable form once more.
4) The final pathway is removal from the system. Nutrients are considered removed from the system if they are sequestered for an extended period or converted to a form that physically leaves the system. Nutrients can be buried in the sediment and are considered removed from the system. However, a natural disturbance such as a storm can stir up sediment and release the buried nutrients. A more permanent removal process is denitrification, a process in which nitrogen is removed from the system through microbial activity. Microbial communities in the sediment reduce nitrate and nitrite in the water and convert them to a form that is not bioavailable, such as dinitrogen gas.

Seagrass meadows contribute to this last pathway by modifying their environment in a manner that increases the efficacy of nutrient removal processes. This is done by altering sediment to promote microbial activity and remove nutrients. Oxygen and carbon are released into sediment through seagrass root systems, allowing the soil microbes to function more efficiently and perform denitrification at a higher rate (Asmala et al., 2017, Aoki et al., 2019).

## How do both seagrasses and algae respond to increased nutrients?

Nutrients are essential for all organisms to perform basic life functions. If inadequate amounts of nutrients are available, organisms cannot persist in the environment. However, excessive nutrient amounts may also cause serious issues. The coastal filter system is incredibly effective at regulating nutrients but the capacity to do so is limited. Increased nutrient inputs from human sources are overloading coastal systems globally. If nutrient levels reach critical amounts, these systems may become overwhelmed.

Seagrasses thrive within an optimum nutrient level, and often die back if those levels get too high. In fact, we are experiencing seagrass losses all over the world primarily due to excess nutrients. Nutrient rich runoff has interfered with the balance of seagrass-filled ecosystems. High nutrient inputs have led to extensive eutrophication, a phenomenon that occurs when excess nutrient enrichment in a body of water leads to significant growth of some plant life and death of animal life from depleted oxygen. This enrichment drives seagrass losses by shifting the competitive advantage to algae.

While seagrasses have below ground tissue to store carbohydrates for later use, algae have no such tissue. Any uptake of nutrients is directed to growth and stored as biomass. During times of high nutrient availability algae can grow much more quickly than seagrasses, outcompeting them. Algae thrive in nutrient-rich environments, which are becoming increasingly abundant. Both microalgae and macroalgae are mostly found higher up in the water column relative to seagrasses, so they are able to easily intercept light that would otherwise reach further down. This reduction in light for seagrasses reduces their ability to grow and reproduce.

Algal blooms can have direct impacts on humans aside from seagrass losses. Some algae blooms are more dangerous than others. Harmful algal blooms, known as HABs, are periods of rapid, uncontrolled algal growth. These events can threaten both aquatic life and human health in addition to a variety of other issues (Young et al. 2020). HABs can trigger widespread fish die-offs and hypoxic zones, areas with depleted oxygen. They also produce toxins that are harmful to terrestrial and aquatic life. Bloom frequency appears to be increasing around the world, likely a symptom of human influence. Harmful algae thrive in warm conditions, often blooming during summer or early fall. Climate change is causing global temperatures to rise, making oceans an increasingly suitable habitat for algae. Warmer waters also tend to mix less and allow algae to grow quickly and exist in greater numbers. Other concerning factors are the increased eutrophication and atmospheric carbon dioxide encouraging the occurrence of algal blooms. (Paerl and Paul, 2012).

When resources become limited, algae may begin to die off quickly. As macroalgae die, the decomposition process can add to the existing poor water conditions, further worsening the plight of the seagrasses. As macroalgae decompose, they release high amounts of dissolved organic matter into the water column. This reaction increases biological oxygen demand and triggers hypoxic conditions. Prolonged periods of low oxygen availability limits seagrass growth and alters nutrient regulation processes (Figure 1). This process creates a negative feedback system, where worsening conditions instigate a decrease in system function (Figure 2, Han and Liu, 2014).

Sediment loading has also been discussed as a potential trigger for seagrass loss. As higher loads are carried into coastal zones, the sediment particles remain suspended in the water.

This turbid water does not allow light to penetrate the water column causing similar conditions to an overabundance of algae. Unlike seagrasses, algae can still grow under these lower light conditions. This creates a negative feedback system as well. As more seagrasses are lost, the environment becomes increasingly difficult for the remaining seagrasses to flourish.

Fortunately, these bleak conditions can be reversed with an improved management strategy. One successful approach is the effort to restore seagrasses in areas where they have been diminished. The reestablishment process restores the capacity of seagrass to act as a nitrogen filter through burial and denitrification (Aoki et al. 2019).

Coastal system function can be restored by decreasing nutrient loading into surface waters, so addressing the sources of nutrient pollution is crucial. The complete transformation of Tampa Bay is proof this is possible. Growing pains from a quickly rising population in the 1970s were reflected in the poor water quality conditions of the Bay. Nutrient loads skyrocketed, making eutrophic conditions, algal dominance, and major seagrass loss the new normal. Over the next few decades, hundreds of water quality improvement projects provided much needed rehabilitation. The substantial investments of time and effort paid off tremendously. Today, Tampa Bay has returned to biodiversity conditions and seagrass levels last seen in the 1950s. This success could be replicated in coastal systems around the world with enough focus and resources. Nutrient pollution is a fixable problem, we simply need to commit to the solution.

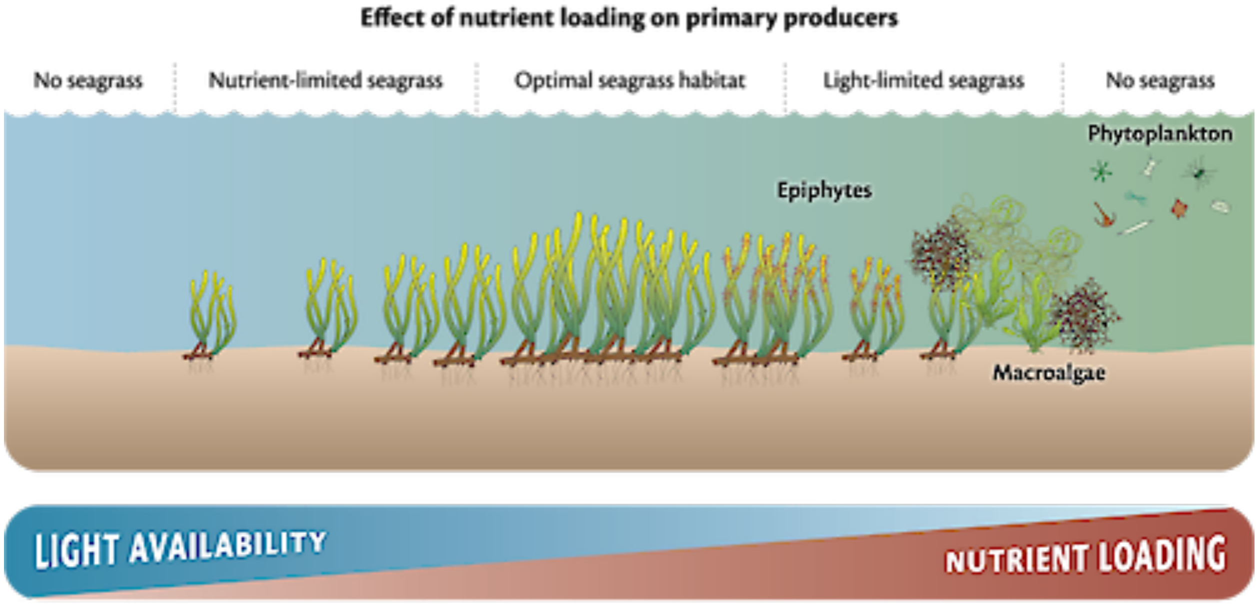

Figure 1. Conceptual diagram illustrating the optimal balance of nutrient load and light availability in a water source for seagrass and other primary producers, such as macroalgae and phytoplankton. Diagram courtesy of the Integration and Application Network (ian.umces.edu), University of Maryland Center for Environmental Science. Source: *Dennison, W.C., J.E. Thomas, C.J. Cain, T.J.C. Carruthers, M.R. Hall, R.V. Jesian, C.E. Wozniak, and D.E. Wilson. 2009. Shifting Sands: Environmental and cultural change in Maryland's Coastal Bays. IAN Press, University of Maryland Center for Environmental Science*

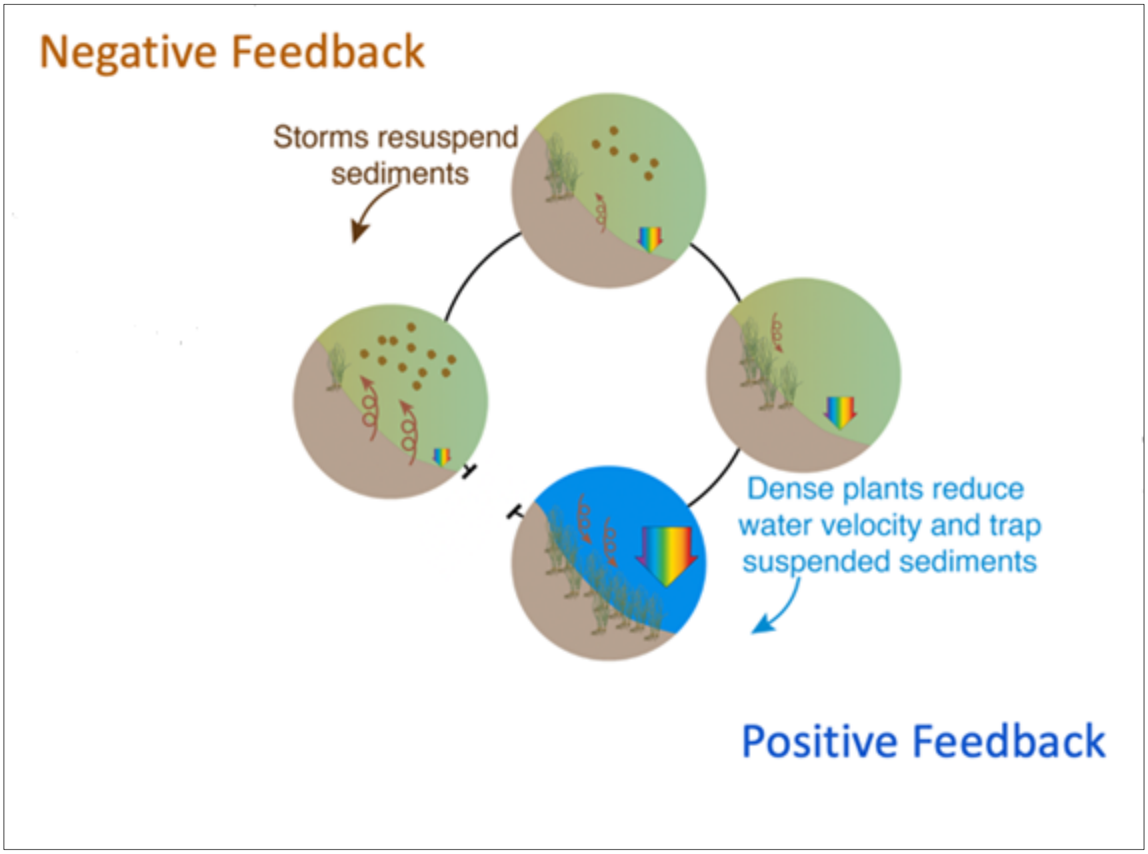

Figure 2. Conceptual figure of positive and negative feedback in coastal systems. Figure drawn by authors using symbols created by the Integration and Application Network (ian.umces.edu).

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