# Water Column

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**In a nutshell:**

- The diverse habitats and living marine resources within the Florida Keys marine ecosystem rely upon oligotrophic conditions (low nutrient and phytoplankton concentrations) to exist and thrive.
- People value the oligotrophic conditions because they result in clear water for diving and fishing; few toxins and pathogens lead to good quality seafood, fisheries, and beaches.
- Small increases in nutrients and/or decreases in grazers can produce dramatic, ecologically-detrimental results, such as macroalgal overgrowth on coral reefs and phytoplankton blooms. The major threat to the Florida Keys water column is increased nutrient loading from local terrestrial sources in the nearshore and far-field sources in the offshore and/or the loss of grazers due to human manipulations including the harvest of grazer species.

The water column is defined as the physical, chemical, and biological characteristics of the water column, including suspended benthic sediment, phytoplankton, and zooplankton. It encompasses all aspects of water quality, in addition to zooplankton and physical properties (e.g., temperature and salinity, etc.). It does not include benthic organisms that are incorporated into the hardbottom and seagrass submodels or fauna not captured by standard plankton nets. These fauna are incorporated into the fisheries or protected species submodels. All other aspects of the ecosystem rely upon the biological, chemical, and physical habitat traits encompassed in the water column submodel.

Maintaining oligotrophic conditions is essential to sustain the key characteristics that make the Florida Keys a desirable ecosystem for tourism.

The water column in the Florida Keys marine ecosystem is characterized by persistent, widespread oligotrophic conditions. The primary characteristic of an oligotrophic ecosystem is very low nutrient concentrations. In the Florida Keys, low nutrient concentrations result in low phytoplankton and organic matter concentrations with high water clarity and dissolved oxygen concentrations. If nutrient concentrations increase, it is likely that phytoplankton (Boyer *et al.,* 2009), benthic macroalgae (Duarte, 1995;

Valiela *et al.,* 1997), and harmful algal bloom frequency will increase (Brand and Compton, 2007). Depending on the prevailing oceanographic conditions and location, nutrient sources in the Florida Keys are dominated by near-field (e.g., sediment and nutrient loading from the Florida Keys) or far-field processes (e.g., Mississippi River and Southwest Florida Shelf runoff).

Increases in nutrient loading from either area will result in more phytoplankton blooms and decreased water clarity in the Florida Keys. This is a concern because water clarity is already lower in the Florida Keys than other Caribbean locations (Palandro *et al.,* 2004). Moreover, the Florida Keys marine ecosystem must remain oligotrophic to support the highly valuable and characteristic benthic habitats, such as seagrass beds, sponges, and coral reefs.

## Role in Ecosystem: The Water Column Supports Fisheries and Their Habitat

The Florida Keys marine ecosystem is currently dominated by benthic productivity. Healthy seagrass beds, coral reefs, and hardbottom provide vital habitat for many commercial fishery species (Luo *et al.,* 2009). If pelagic primary productivity (i.e., phytoplankton blooms) begins to dominate, there is likely to be numerous detrimental effects on fish and shellfish, as well as the benthic habitat communities. The most prominent supporting service provided by the water column to benthic habitats (coral and hardbottom and seagrass submodels) is good water clarity, allowing sufficient light to reach the benthos and provide energy to the benthic primary producers. Corals require sufficient light to provide maximize growth rates (Cooper *et al.,* 2009). However, too much light on the coral reefs can cause ultraviolet stress and lead to coral bleaching (Glynn, 1993). Seagrass require greater than 10 percent of surface irradiance to reach the benthos (Duarte, 1991). Thus, increasing the magnitude of phytoplankton blooms will decrease light availability at the benthos and could lead to seagrass die-offs. These die-offs lead to the development of a positive feedback loop. Seagrass die-offs release nutrients as their leaves decay and destabilize sediments, leading to increased nutrient resuspension (Zieman *et al.,* 1999), and the loss of sponges decreases the grazing pressure on phytoplankton (Lynch and Phlips, 2000). The increase in nutrients and decrease in grazing help to maintain and may intensify the phytoplankton blooms.

The water column supports fisheries through previously mentioned habitat-supporting services and directly by providing the base of the food web and a potential pathway for pathogens and toxins. The loss of benthic habitat results in a decrease in commercial fishery populations, as was seen when the lobster population decreased after a *Synechococcus* bloom caused a sponge die-off (Butler *et al.,* 1995). However, phytoplankton also provide food for zooplankton which, in turn, are consumed by higher trophic level fish and shellfish species (Harris *et al.,* 2000). Grazer biomass is tightly coupled to phytoplankton biomass, and phytoplankton can both limit and be limited by grazer biomass. However, phytoplankton species have different sizes and nutritional characteristics (Hitchcock, 1982). Thus, the species of phytoplankton present significantly affects the efficiency of trophic transfers and the amount of energy available to upper trophic levels (Richardson *et al.,* 2003). Moreover, zooplankton grazing upon some harmful algal species can accumulate toxins and cause fish kills (White, 1981).

## Attributes People Care About

The Florida Keys water column supports attributes of the Florida Keys marine environment that people care about (Figure 1). These attributes are directly related to ecosystem services provided by the Florida Keys marine ecosystem:

- Harmful algal blooms
- Water clarity
- Quality of beaches and shoreline
- Protected species
- Seafood safety
- Fisheries

### Harmful Algal Blooms

Harmful algal blooms are a naturally-occurring part of the Florida Keys but, in recent years, debate has intensified as to whether anthropogenic activities are increasing their frequency and duration. A recent metadata review suggested

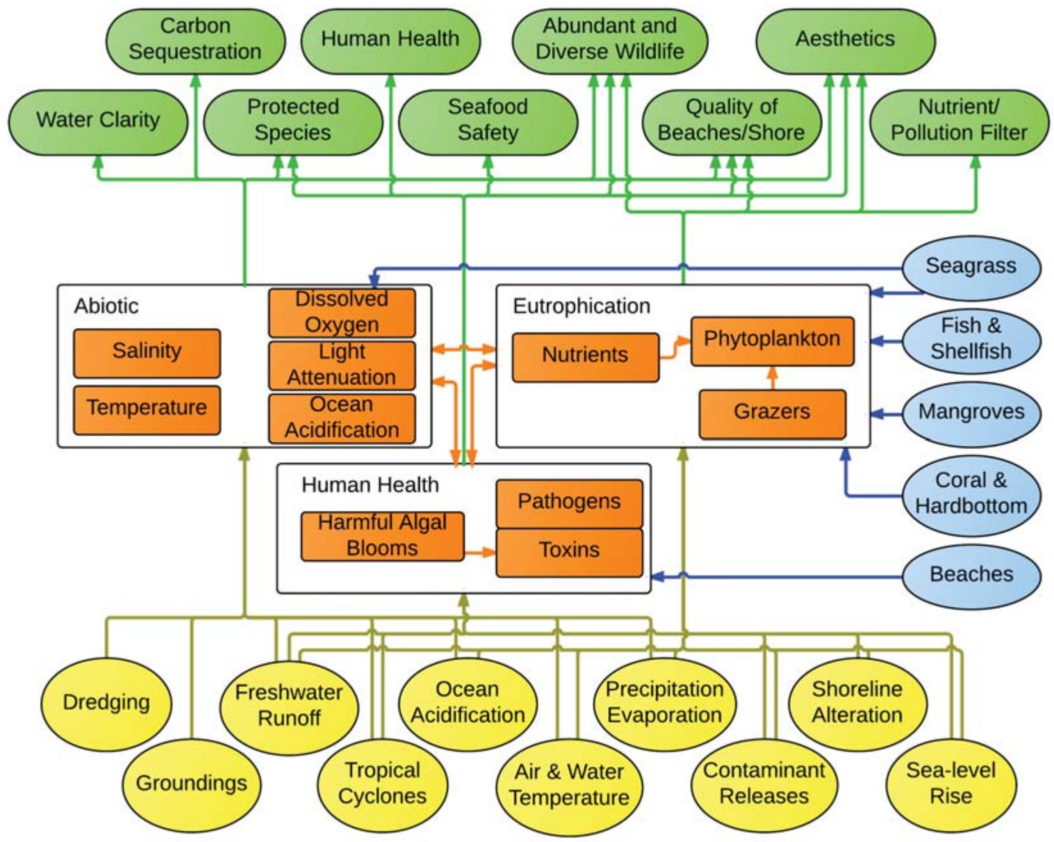


Figure 1. Water column submodel diagram for the Florida Keys/Dry Tortugas.

that increases in harmful algal blooms along southwest Florida are related to increased nutrient availability (Brand and Compton, 2007). Harmful algal blooms in the Florida Keys are primarily composed of the dinoflagellate, *Karenia brevis*. Moreover, large blooms of *K. brevis* result in hypoxic conditions (low dissolved oxygen) under specific oceanographic conditions (Hu *et al.,* 2006).

## Water Clarity

The clarity of the water is a direct product of light attenuation and is dependent upon the concentrations of chromophoric dissolved organic matter (CDOM), phytoplankton, and suspended particulate matter. The diving and fishing industries rely upon good water clarity to ensure business remains optimal. Water clarity is already lower in the Florida Keys than in other Caribbean locations, and further degradation should be prevented (Palandro *et al.,* 2004).

## Quality of Beaches and Shoreline

The quality of beaches and the shoreline of the Florida Keys is important to tourists and residents. One of the appealing features of the Florida Keys is the impressive color mosaics one can view when driving on the Overseas Highway or sailing along in a boat. Moreover, water sports are one of the main reasons for visiting and living in the Florida Keys. The quality of the shoreline, beaches, and water is measured in terms of aesthetics and the likelihood of contracting a health problem.

Aesthetics can be impacted by the health of nearby seagrass beds, suspended particulate matter, and phytoplankton blooms. Threats to beach and shoreline quality include air quality and water quality concerns. The two primary causes of poor air quality are harmful algal blooms and hypoxia. The hypoxia concern is particularly unpleasant in man-made canals that turn over during high winds, causing a hydrogen sulfide (rotten egg) odor to be released. The dominant harmful algal bloom species in the Keys, *K. brevis*, contains a brevetoxin compound that can aerate and cause respiratory distress (Fleming *et al.,* 2011).

### Protected Species

One of the many reasons tourists and residents enjoy the Florida Keys is the ample opportunity to view charismatic megafauna that inhabit the ecosystem. These range from reptiles, such as sea turtles, to fish, such as marlins, to marine mammals, such as manatees and dolphins. These animals are most sensitive to toxins from chemicals that tend to bioaccumulate up the food chain. Dolphins have been found to have high levels of polychlorinated biphenyls (PCBs) in nearby embayments (Litz *et al.,* 2007), and high mercury levels have been observed in large fish species within Florida Bay (Evans and Crumley, 2005). Dolphin mortality has been associated with high brevetoxin concentrations and harmful algal blooms along the southwest coast of Florida (Fire *et al.,* 2008; de la Riva *et al.,* 2009). Loggerhead turtles, *Caretta caretta*, in South Florida have been found with a neurological disorder that suggests lethal toxin levels in their diet (Jacobson *et al.,* 2006). The red-tide neurotoxin has been reported to have a high affinity for binding to specific nerve preparations in manatee brains, likely increasing strandings and mortality in affected populations (Trainer and Baden, 1999). The red-tide neurotoxin has also been implicated in degraded health in whale species known to migrate through the Florida Keys (Doucette *et al.,* 2006). These species are also dependent upon the seagrass for habitat and, in the case of manatees and sea turtles, for food.

### Seafood Safety

The safe consumption of seafood from the Florida Keys is necessary to maintain the economic health of the fisheries. Harmful algal blooms can cause shellfish, including oysters, to be unsafe for consumption and leave humans susceptible to paralytic shellfish poisoning (Kirkpatrick *et al.,* 2004). Toxin loading in the form of mercury can endanger the consumption of higher trophic level fish species (Plessi *et al.,* 2001). This attribute is equally important for residents and tourists, but also for anyone who consumes seafood from the Florida Keys.

### Fisheries

Fisheries, both commercial and recreational, contribute a large percent of both dollars and jobs to the South Florida economy (Johns *et al.,* 2001; Fedler, 2009). These fisheries rely on energy in the form of their prey base, which ultimately derive their energy from primary producers, many of which are the phytoplankton located within the water column. The right concentration and species composition of primary producers is necessary to have the productive fisheries in the Florida Keys that we have grown accustomed to having.

## Quantifiable Attributes

There are several monitoring programs of varying scope being conducted to assess the water column of the Florida Keys. The Florida International University's Southeast Environmental Research Center (FIU/SERC, http://serc.fiu.edu/wqmnetwork/) and NOAA's Atlantic Oceanographic and Meteorological Laboratory (NOAA/AOML, http://www.aoml.noaa.gov/sfp) conduct the two programs with the longest records and greatest spatial coverage. Both programs aim to assess long-term trends of water quality and potential eutrophication in the Florida Keys through the systematic measurement of water column parameters. However, there are some key differences. The NOAA/AOML program focuses on producing synoptic spatial maps of key parameters for the entire South Florida coastal ecosystem, whereas FIU/SERC focuses on the measurement of more nutrient parameters at each station. The NOAA/AOML program also has a physical oceanographic focus and conducts regular current measurements and drifter deployments. While these monitoring programs are essential, they are not optimal due to funding realities. Thus, they are insufficient to provide a comprehensive understanding of the complex dynamics within the Florida Keys water column.

The following key characteristics are or should be measured to assess the status of the Florida Keys water column:

- Nutrients
- Chromophoric dissolved organic matter (CDOM)
- Suspended particulate matter
- Phytoplankton blooms
- Dissolved oxygen
- Salinity
- Pathogens and toxins
- Grazers

### Nutrients

The oligotrophic nature of the Florida Keys allows corals, seagrasses, and hardbottom communities to thrive and clear water to dominate. Nutrient concentrations are likely to change in response to changes in nutrient loading or nutrient cycling caused by land-use changes. If nutrient concentrations increase, it is likely that phytoplankton (Boyer *et al.,* 2009), benthic macroalgae (Duarte, 1995; Valiela *et al.,* 1997), and harmful algal bloom frequency will increase (Brand and Compton, 2007). This could damage the key characteristics that make the Florida Keys a desirable ecosystem for tourism.

### Chromophoric Dissolved Organic Matter

Chromophoric dissolved organic matter is primarily derived from terrigenous sources; however, in South Florida there can also be a significant component produced in the marine environment (Milbrandt *et al.,* 2010). Chromophoric dissolved organic matter contributes to light attenuation (Kelble *et al.,* 2005).

### Suspended Particulate Matter

Concentrations of suspended particulate matter in the water column affect light attenuation and thus water clarity in the Florida Keys (Kelble *et al.,* 2005). The effect on light attenuation is likely to be important given that the light field of nearby ecosystems is dominated by suspended particulate matter (Kelble *et al.,* 2005). This concentration is affected by sediment loading from the terrestrial system that has been altered by land-use changes (Wood and Armitage, 1997). Benthic vegetation also alters the concentration of suspended sediment in the Florida Keys by stabilizing benthic sediments and minimizing resuspension (Peterson *et al.,* 2002). Suspended particulate matter can also clog filter feeders, particularly sponges, causing an increase in phytoplankton blooms. Depending on sediment type, however, these species may also be able to filter suspended sediments out of the water column (Lohrer *et al.,* 2006).

### Phytoplankton Blooms

Phytoplankton are single-celled photoautotrophic plankton. They consist of a wide variety of taxa, including both prokaryotes and eukaryotes. They form the base of the pelagic food web. Thus, the ecosystem requires low levels of the right types of phytoplankton to maintain the proper productivity necessary to support higher trophic level species. However, too much phytoplankton will discolor the water, causing light attenuation to decrease (Phlips *et al.,* 1995). The biomass of phytoplankton in the water column is, to a large degree, dependent upon nutrient concentrations and water temperature that may be altered by climate change. High phytoplankton biomass has the potential to cause senescence in seagrass and sponges due to insufficient light at the benthos, and clogging, respectively (Butler *et al.,* 1995). These changes increase phytoplankton concentration by decreasing the grazing pressure and increasing the nutrient loading from the benthos by destabilizing sediments (Zieman *et al.,* 1999).

Harmful algal blooms are a type of phytoplankton bloom and a naturally-occurring part of the Florida Keys. Harmful algal blooms are not initiated in the Florida Keys. Instead, they are advected into the Florida Keys after their initiation on the Southwest Florida Shelf. Harmful algal blooms in the Florida Keys are primarily composed of the dinoflagellate, *K. brevis*. *K brevis* contains a brevetoxin compound that can aerate and cause respiratory distress. It can also cause paralytic shellfish poisoning via consumption of contaminated shellfish from an area with a recent *K. brevis* bloom (Kirkpatrick *et al.,* 2004). Moreover, large blooms of *K. brevis* result in hypoxic conditions (low dissolved oxygen) under specific oceanographic conditions (Hu *et al.,* 2006).

### Dissolved Oxygen

Hypoxia is a state of low oxygen levels in the water column. It typically occurs when a large amount of plant material is consumed or decomposed by bacteria or other organisms that are not readily available to the next trophic level. Thus, phytoplankton blooms alter dissolved oxygen by producing oxygen during photosynthesis; however, blooms composed of phytoplankton types that are not easily consumed by secondary producers can lower dissolved oxygen at the benthos when phytoplankton senesce and are decomposed (Turner *et al.,* 2006). These hypoxia events typically occur when stratification is present such that the oxygen produced by primary production is not readily mixed with the hypoxic waters (Livingston, 2007). Dissolved oxygen concentrations are significantly affected by benthic vegetation that produce oxygen during the day and consume oxygen at night (Yarbro and Carlson, 2008). Low dissolved oxygen concentrations can lead to air quality concerns. In particular, hypoxia can create an undesirable odor from the production of hydrogen sulfide by decomposers. This is most prominent when a stratified water column is turned over. Hypoxia can also affect the health of fish, dolphins, sea turtles, manatees, and whales by restricting their habitat and influencing the size of prey populations (Zhang *et al.,* 2009).

### Salinity

Maintaining the appropriate salinities in the water column of the Florida Keys is essential for ecosystem health and to sustain the species assemblage characteristic of the Florida Keys. Many fish species are found in a wide range of salinities, but nearly all have optimal salinities at which they thrive (Serrano *et al.,* 2007; Serrano *et al.,* 2010). Salinity concentrations are a product of the prior salinity and the net freshwater supply, which is precipitation plus runoff minus evaporation (Kelble *et al.,* 2007). Within the Florida Keys, salinity is typically near oceanographic values of 36.4; however, nearshore salinities are much lower due to the influence of runoff. Salinity can also be affected by far-field runoff from sources such as the Mississippi River (Ortner *et al.,* 1995).

### Pathogens and Toxins

Pathogen and toxin concentrations in the ecosystem affect both ecological and human health. Pathogens are microrganisms that cause disease either directly or indirectly through the production of toxins. Toxins are chemical compounds that negatively affect human and organismal health. Contaminant spills (Moore and Swain, 1991), harmful algal blooms (Kirkpatrick *et al.,* 2004), toxin loading, and changing land-use patterns (Paul and Meyer, 2001) all alter pathogen and toxin concentrations in the water. Specifically, increasing the percent of impermeable surface area on the land increases the loading of toxins to coastal systems (Paul and Meyer, 2001). Marine species such as fish, manatees, sea turtles, whales, and dolphins exhibit degraded health and increased mortality in the presence of high toxin concentrations. Toxins degrade air quality and can cause respiratory distress in humans (Kirkpatrick *et al.,* 2004). Moreover, consumption of seafood with high toxin levels can cause paralytic shellfish poisoning, gastrointestinal distress, and developmental disorders (Stewart, 2008; Kirkpatrick *et al.,* 2010). Swimming in water with high pathogen and toxin levels can also negatively impact human health (Abdelzaher *et al.,* 2011).

### Grazers

Grazers play a crucial role in ecosystems via consumption of phytoplankton that minimize blooms and transfer energy to higher trophic levels. Grazers can take many forms from benthic sponges and shellfish to microscopic zooplankton to parrotfish. For more detail on benthic grazers, please consult the coral and hardbottom submodel and, for fish species, please consult the fish submodel. Zooplankton provide a key pathway from phytoplankton to higher trophic level fish and shellfish species (Harris *et al.,* 2000). Grazer biomass is tightly coupled to phytoplankton biomass, and phytoplankton can both limit and be limited by grazer biomass. Grazers, zooplankton in particular, are also governed by kinetics and thus show a large temperature influence that may be altered by climate change (Huntley and Lopez, 1992). Grazers also consume oxygen and thus decrease the dissolved oxygen concentration.

## Drivers of Change in the Florida Keys Water Column

Changes to the Florida Keys water column stem from both near-field and far-field pressures. These pressures can be both natural and anthropogenic; however, henceforth we will focus on anthropogenic pressures because they respond to management actions. Although drivers can be delineated into near- and far-field, they all share the same ultimate driver of human population and its demands. Interestingly, human population growth has slowed in the Florida Keys and has even stabilized in recent years, while the global population has continued to experience exponential growth. The human population and civilization attempt to meet demands for food, water, and shelter, as well as energy, recreation, and economic growth. Meeting these demands both within the Florida Keys and beyond results in pressures on the Florida Keys marine ecosystem.

To meet food demands requires agriculture and fisheries in South Florida, as well as increased shipping to import foods grown in other regions. This means altered land-use and altered freshwater quantity, quality, timing, and distribution (QQTD) for agriculture to thrive and increased dredging and altered shoreline to support shipping. The alteration of freshwater QQTD in South Florida has also been undertaken to meet freshwater demand and increase the area of habitable land for humans. The shoreline will also be altered to meet shelter demands of both tourists and residents and, to meet these shelter demands, also requires increased disposal of wastewater and thus a likely increase in wastewater discharge. Energy demands in the Florida Keys are currently met by burning fossil fuels within the Florida Keys or importing energy produced elsewhere. These practices are increasing $CO_2$ in the atmosphere, which increases ocean acidification and causes changes to climate (IPCC, 2007). In addition, there are environmental impacts from marine exploration and extraction of hydrocarbons. Although this is not currently performed in the Florida Keys, upstream activities in the Gulf of Mexico and off the northern coast of Cuba can impact the Florida Keys marine water column. Most recreational activities in the Florida Keys occur in or adjacent to the marine environment through boating, fishing, diving, and visiting beaches. Boating has many of the same impacts as shipping in the form of dredging, altered shoreline, groundings, and increased contaminant spills at marinas. Diving requires boating in many cases and thus shares these pressures. Going to beaches places pressures on the water column largely through toxin and pathogen loading from beaches to the marine ecosystem.

## Fisheries

Fisheries, both recreational and commercial, systematically remove large-bodied top predators from the ecosystem, drastically altering the food web (Jackson, 2001; Jackson *et al.,* 2001; Myers and Worm, 2003). These altered food webs can have downward cascades that have been observed to alter zooplankton concentrations and thus are likely to alter grazing upon phytoplankton (Shackell *et al.,* 2010). These fishery impacts are primarily near-field and subject to management controls.

## Freshwater QQTD

To meet freshwater requirements and drain land to make it more habitable for humans, we have drastically altered the QQTD in South Florida (Light and Dineen, 1994). The decrease in runoff may be 60 percent or greater in some areas of South Florida (Smith *et al.,* 1989; Marshall *et al.,*2009). These changes in runoff patterns result in salinity alterations, but also change all parameters that are transported into the marine environment through freshwater runoff. The system is especially sensitive to increases in nutrients because it is an oligotrophic system. Thus, minimizing nutrient loading is critical to maintain the health of this system (Collado-Vides *et al.,* 2007).

## Altered Land Use and Shoreline

Changing land use to meet human demands is an important process that can have ecological implications for the Florida Keys. The development of agricultural lands in the watershed can result in increased loading of nutrients, chromophoric dissolved organic matter, and toxins if not properly managed. Removal of mangrove forests and other plants that stabilize sediments can cause increases in suspended sediment. The development of high-density population structures can affect nutrient levels, toxin levels, and suspended sediment. Specifically, increasing the percent of impermeable surface area on the land increases the loading of toxins to coastal systems (Paul and Meyer, 2001). Agricultural activities on the Florida peninsula may also affect the Florida Keys water column when runoff from these lands is advected into the Florida Keys (Lapointe *et al.,*2004).

## Wastewater Discharge

The discharge of wastewater into the Florida Keys marine environment would likely be due to non-point source contamination through the leaching of injection wells or septic systems. Evidence has already been found that the direct injection wells load viral contaminants into the nearshore (Paul *et al.,* 1997). In addition to pathogen loading, wastewater discharge may load nutrients. On the northern section of the Florida reef tract, wastewater discharge has been found to increase nitrogen loading and cause macroalgal overgrowth of coral reefs (Lapointe, 1997).

### Climate Change

The emission of greenhouse gases, including $CO_2$, provides a double dose of stress to the Florida Keys ecosystem. First, the increase in $CO_2$ concentrations is causing a decrease in the aragonite saturation state of seawater and lowering the pH, which is commonly referred to as ocean acidification. This decrease can have detrimental effects on calcifying organisms, including the coral reefs of the Florida Keys (Manzello *et al.,* 2008). However, the exact magnitude and direction of this effect on different components of the ecosystem is unclear given the variety of responses between different organisms and the gradual nature of acidification over several generations allowing organisms to adapt (Hendriks *et al.,* 2010). Secondly, according to the IPCC (2007) report, the increase in $CO_2$ is likely resulting in warmer ocean temperatures and changing rainfall patterns. These changes to rainfall and temperature will affect the health of organisms living in the water column.

## Mechanisms of Change

The primary mechanisms by which these drivers bring about change in the Florida Keys water column is through phytoplankton blooms, a loss of grazers, disease, and organismal physiology.

### Phytoplankton Blooms/Nutrient Loading

In addition to reducing water clarity, increased eutrophication associated with increased nutrient concentrations can negatively impact benthic habitats through overgrowth by less desirable macroalgae. Recent investigations of Florida Keys coral reefs have observed an increase in diversity and abundance of macroalgae, possibly as a result of anthropogenic nutrient loading (Lapointe *et al.,* 2004). Macroalgae are detrimental to the health of the corals and are not as aesthetically pleasing to divers. A healthy seagrass community is a byproduct of good water quality and natural nutrient concentrations. Seagrass beds in the Florida Keys have been observed to increase macroalgal abundance in correlation with increased nitrogen concentrations (Collado-Vides *et al.,* 2007).

Increasing nutrient concentrations will also likely increase phytoplankton concentrations and favor more ecologically damaging phytoplankton species (Livingston, 2007; Boyer *et al.,* 2009). In adjacent waters, blooms of picoplanktonic *Synechococcus* have occurred after increased nutrient loading (Rudnick *et al.,* 2007). These *Synechococcus* blooms have been implicated as the causative agent in a cascade of ecological disturbances that included a massive loss of sponge populations. These blooms have also coincided with hypoxic conditions (Madden and McDonald, 2009), which affect the health of fisheries, dolphins, sea turtles, manatees, and whales by restricting their habitat and influencing the size of prey populations (Zhang *et al.,* 2009).

Although phytoplankton blooms are a natural phenomenon in some upstream waters of the Florida Keys, increased nutrient loading by altering freshwater QQTD and land-use changes can increase the frequency, magnitude, duration, and spatial extent of phytoplankton blooms. These increases can lead to blooms being advected into the Florida Keys and potentially damaging the ecosystem and reducing the quantity and quality of ecosystem services. As mentioned, an increase in phytoplankton blooms negatively impacts all other aspects of the marine ecosystem and likely poses the most immediate, severe threat to the Florida Keys water column.

### Loss of Grazers—Food Web alterations

As discussed in the fisheries driver, removing the largest of marine predators causes food web changes that can ultimately decrease grazing upon phytoplankton (Shackell *et al.,* 2010). By decreasing grazing upon phytoplankton, blooms of phytoplankton can become more intense without an increase in nutrient loading. The loss of grazers, specifically benthic sponges, has been implicated as a major contributor to phytoplankton blooms in north-central Florida Bay (Peterson *et al.,* 2006).

### Disease

Disease to both humans and marine life as a result of increased pathogen and toxin concentrations in the water column could be a major source of degradation to the Florida Keys water column. In fact, it is not even the incidence of disease as much as the perception that the water is safe for swimming, diving, and consumption of its marine life.

### Physiology

Changing the salinity, temperature, and aragonite saturation state of the water column will affect the health of marine organisms by changing the efficiency of their physiological processes. The impact of ocean acidification on marine organisms is highly variable, although it appears unlikely that effects will be dramatic in the short term (Hendriks *et al.,* 2010). However, changes due to temperature increases could be more pronounced because many organisms in the Florida Keys are already living near their thermal maximums (Manzello *et al.,* 2007).

## Status and Trends

The FIU/SERC data has been extensively examined for trends (Boyer and Briceno, 2010). There were several trends that were consistent throughout the Florida Keys from the Dry Tortugas to northern Key Largo. Total organic carbon had a consistent decreasing trend throughout the Florida Keys. Salinity had a consistent increasing trend that was more pronounced on the northern edge of the Keys in the back country and sluiceway (Figure 2). This increase in salinity could affect physiology because most organisms do not prefer salinities greater than the adjacent coastal ocean (Serrano *et al.,* 2010).

Trends in nutrient and chlorophyll-a concentrations, likely indicators of eutrophication (Boyer *et al.,* 2009), are less clear. Chlorophyll-a had no significant increases and, in fact, had significant decreases in many areas of the Florida Keys, particularly on the oceanside. However, total phosphorus, the limiting nutrient to phytoplankton in some adjacent systems (Fourqurean *et al.,* 1993; Boyer *et al.,* 1997), was increasing in most of the Florida Keys, and dissolved inorganic nitrogen, another potentially limiting nutrient (Lapointe, 1997), had no net clear trend as $NO_3$ decreased and $NH_4$ increased. These may indicate the increase in total phosphorus is localized and not affecting phytoplankton biomass. However, dissolved oxygen was generally decreasing, especially in the back country and sluiceway, which is a typical response to eutrophication. If concentrations drop low enough, the result is unfavorable habitat conditions for many organisms.

Figure 2. Map of sluiceway and back country (Florida Bay).

There was also a net decrease in light attenuation, which reflects an increase in water clarity. This is beneficial to benthic primary producers because it means more light is reaching the benthos and providing more energy for benthic primary producers. It is also beneficial for ecosystem services, as most divers and many fishermen prefer or require clear water to effectively conduct their activity.

## Topics of Scientific Debate and Uncertainty

A primary research need is understanding how altered nutrient loading affects water quality and thus habitats and fish. Specifically, understanding the impact of human development on the ecosystem needs to be quantified. Replacing one square mile of pristine coastline with impermeable developed land has negative impacts on water quality, but there is a need to better quantify this impact for use in management strategy evaluations. Understanding these relationships improves modeling accuracy and thus increases our ability to evaluate management plans accurately prior to their adoption. Accurate quantification of nutrient and toxin loading from septic tanks would allow managers to decide whether conversion to sewer systems would significantly improve water quality prior to implementing this action.

Another primary research need is to develop an understanding of the causes of shifts in phytoplankton communities. There is significant research on the factors that determine phytoplankton type in the open ocean, but much less for coastal waters such as the Florida Keys. The type of phytoplankton that dominates the system affects the entire trophic web. Small, cyanobacterial phytoplankton support fewer large zooplankton and thus less energy is available to fish populations. Moreover, cyanobacteria can "clog" sponges and cause them to senesce (Phlips *et al.,* 1999). This loss of hardbottom habitat triggers a cascade of negative ecological effects that affect the commercially important Caribbean spiny lobster among other species (Butler *et al.,* 1995). Improved research should focus on being able to determine the factors that lead to a dominance of cyanobacteria over other phytoplankton types. This would allow managers to actively try to avoid these conditions and thus maintain a healthier phytoplankton community.

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