Water Column

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In a nutshell:

- The quality of coastal marine waters determines the primary productivity of the ecosystem that is available to support populations of fish and shellfish.
- Conditions in the water column affect the quality of beaches for tourism, the safety of seafood, and the availability of habitat needed by several endangered species.
- Circulation patterns on the SWFS limit exchange and favor the development of algal blooms and their retention in nearshore waters for periods of weeks to months.
- Inputs of nutrients related to agriculture and development might be responsible for increasing the occurrence of harmful algal blooms in marine waters; however, this is a topic of debate among scientists.

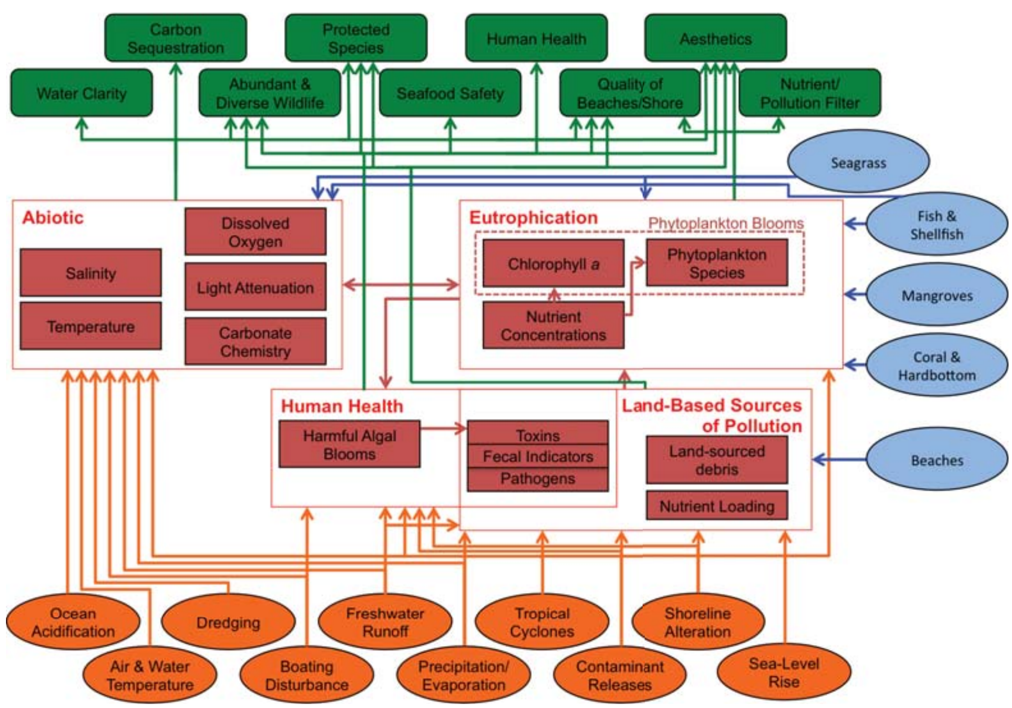
The water column of the SWFS reflects the inflow of freshwater from the Florida peninsula, the physical processes that control surface circulation, and the complex biogeochemical processes that influence the cycling and concentration of particulate and dissolved materials. The geographical limits of the domain of interest extend from the inner low-salinity waters adjacent to the coast to the outer boundary of shelf waters set by a barrier to lateral mixing known as the “forbidden zone” (Yang *et al.,* 1999; Olascoaga *et al.,* 2006). The southern boundary includes the waters offshore of the Ten Thousand Islands while the northern boundary is offshore of Charlotte Harbor. A diverse set of sources and sinks of the dissolved and particulate constituents in the water column occur at the boundaries of these shelf waters and include bottom sediments, the contiguous oceanic waters of the Gulf of Mexico, and the riverine inflows along the west Florida coast. The organisms included in this model encompass plankton (phytoplankton, zooplankton, bacteria, and other “decomposers”) but exclude the benthos and larger living resources such as invertebrates and fish. These larger organisms are incorporated into the fisheries submodel for the SWFS.

There are persistent offshore spatial gradients in physical properties (salinity) and the dissolved and particulate materials from the coast to outer shelf waters, with maximum concentrations of dissolved and particulate materials near the coastal inflows and estuaries. The constituents are modified through biogeochemical cycling in both the water column and the sediments. Residence times of dissolved and particulate matter on the shelf can be on the order of weeks to months as the flow regime constrains surface waters onshore of the convergent boundary at mid-shelf (Yang *et al.,* 1999). Thus, two of the ecosystem attributes that people care about, harmful algal blooms dominated by the toxic dinoflagellate *Karenia brevis* (Steidinger *et al.,* 1998) and "blackwater" events (Hu *et al.,* 2003), can be retained on the inner shelf and influence water quality for periods of weeks to months.

Role in Ecosystem: The Water Column Linkages to Water Quality and Fisheries

The spatial distribution and abundance of pelagic and benthic primary producers are critical components of the SWFS ecosystem. The magnitude of primary production determines the quantity of organic matter available to support higher trophic levels. The surface waters of the West Florida Shelf are oligotrophic, except for the nearshore regions in which freshwater discharge delivers nutrients in river plumes that are derived from natural and anthropogenic sources. Pelagic fish are dependent upon sufficient phytoplankton production for organic matter, but are also influenced by the species that are present. The highest levels of pelagic primary production (fish and shellfish) on the West Florida Shelf occur in blooms of the dinoflagellate *Karenia brevis* (Vargo *et al.,* 1987), a harmful algal species that producers brevetoxins. However, when these toxins accumulate in shellfish, or in the flesh of finfish, they result in Neurotoxic Shellfish poisoning (NSP) due to their neurotoxic properties (Watkins *et al.,* 2008). Consumption of fish with brevetoxins can result in the deaths of birds, fish, and marine mammals. Additionally, the release of brevetoxins in the atmosphere can lead to respiratory distress with symptoms that result in treatment within hospital emergency rooms (Hoagland *et al.,* 2009). The magnitude of nutrients required to support these blooms, as well as other pelagic primary producers, is an active area of research with societal implications.

Water quality also is a function of water clarity. The quantity and quality (spectral composition) of irradiance that penetrates the water column determines the magnitude of benthic primary production. Benthic primary producers



Water column submodel diagram for the Southwest Florida Shelf.

include seagrass and the microphytobenthos; these organisms contribute to total ecosystem production in the mid and northern segments of the West Florida Shelf (Gattuso *et al.,* 2006). However, the magnitude of primary production in benthic versus pelagic environments is not well documented for the SWFS. Given the results of model experiments for shelf waters off Tampa Bay (Darrow *et al.,* 2003), it is likely that benthic primary production is potentially equivalent to that in the water column. Nutrient inputs influence the distribution of primary production, for enhanced pelagic primary production can reduce the available light energy reaching the benthos. If phytoplankton growth is stimulated by enhanced nutrient delivery from freshwater sources, the magnitude of benthic primary production can decrease as light becomes limiting for photosynthesis on the bottom.

Attributes People Care About

The water column of the SWFS plays a major role in the attributes that people care about. The ecosystem services provided by the pelagic ecosystem are strongly linked to the water column. Among these attributes are:

- Harmful algal blooms
- Beach quality
- Water clarity
- Protected species
- Seafood safety

Harmful Algal Blooms

Harmful algal blooms occur on the SWFS almost every year (Steidinger *et al.,* 1998). Bloom initiation can occur offshore in subsurface waters below the thermocline. Cells adapted to low light conditions are transported eastward, towards the coast, in the bottom waters in response to forcing by prevailing winds. The highest cell concentrations develop nearshore adjacent to the coastal salinity fronts in response to a combination of physical, chemical, and biological processes (Walsh *et al.,* 2006). In three of the last five years (2007-2011), bloom initiation has occurred in the nearshore coastal waters adjacent to Fort Myers. Blooms were subsequently transported north by alongshore currents that responded to forcing by prevailing winds. Eventually the blooms declined, with remnants of *K. brevis* populations near Fort Myers.

Declining blooms can be exported from the SWFS. In the late fall or early winter, currents can transport the remnant populations south to the Florida Keys and eventually carry *K. brevis* to offshore waters (Walsh *et al.,* 2009; Olascoaga *et al.,* 2006). When the cells are transported offshore, they can be exported to the Florida Current and eventually be advected around the Florida Keys to the East Florida Shelf (Murphy *et al.,* 1975). Periodically, harmful algal blooms dominated by *Karenia* spp. develop along the southeast Florida coast and infrequently develop as far north as Cape Hatteras (Tester *et al.,* 1991).

Beach Quality

Tourism is the main source of income in southwest Florida, and beach quality is a major determinant of tourist visits to the area, as well as the quality of their vacation experience. An economic study of Florida's beaches was compiled with data from 2003 and revealed that over 80 percent of all tourists to southwest Florida visited local beaches (Murley *et al.,* 2006). Income from tourism in southwest Florida, from Charlotte to Sarasota counties, exceeded $15 billion, with approximately half from direct spending. If beach quality degrades, visits to beaches rapidly decline for both local inhabitants and tourists.

Water Clarity

The clarity of the water column is determined by the particulate and dissolved constituents. The oligotrophic nature of the water column implies that throughout much of the year the water is highly transparent. However, inputs of terrestrial dissolved organic matter and nutrients alter water clarity on the SWFS through the direct contribution of colored dissolved materials and the stimulation of phytoplankton growth (Bissett *et al.,* 2005). These constituents can degrade the transmission of light through surface waters and alter water clarity. Phytoplankton booms, including harmful algal blooms, are one of the features that the public identifies as responsible for altering water clarity.

Protected Species

The SWFS is one of the major regions in which manatees overwinter. In 2009, the Florida Fish and Wildlife Conservation Commission reported that there were >2400 manatees in the nearshore waters of the southwest coast, with an approximately equal number along the east coast of Florida. Many of the overwintering mammals reside near Fort Myers, particularly the Florida Power and Light power plant. When the mammals are in coastal waters, they are prone to injury from power boats. Additionally, manatees suffer when harmful algal blooms occur. A bloom of *Karenia brevis* killed over 50 mantees in 1996 (Bossart *et al.,*1998), with an additional mortality event, at reduced numbers, in 2000 (Bossart, 2001). Turtles are also found in the coastal waters of the SWFS, with nesting beaches for loggerheads in Naples and Bonita Springs beaches from May to October. The most endangered sea turtle in the world, the Kemp's Ridley, nests in the Ten Thousand Islands region and Charlotte Harbor. Radio satellite tracking studies of a few of these turtles have found that when adults migrate into coastal waters, they can remain within Florida's water throughout the year (http://www.conservancy.org/page.aspx?pid=585).

Seafood Safety

Floridians consume about 40 pounds of seafood per person annually, about twice the average per capita consumption in the United States (Degner *et al.,* 1994). Consumers are concerned about the safety of seafood, and a recent reduction in seafood following the Deepwater Horizon oil spill in 2010 illustrates how perceived effects of pollutants can alter public attitudes regarding seafood safety. The Florida Department of Agriculture surveys seafood for health risks. On the southwest Florida coast, this monitoring includes sampling the ambient seawater concentration of *Karenia brevis*, the toxic dinoflagellate responsible for NSP with symptoms of diarrhea, nausea, and vomiting. Shellfish beds are closed when cell concentrations reach 5,000 cells liter^{-1}. This management policy has been effective, with typically one to five cases diagnosed during blooms (Watkins *et al.,* 2008).

Quantifiable Attributes

Nutrient Concentrations

Nutrient and dissolved organic matter concentrations decrease from the coast to offshore waters along the southwest Florida coast. Nutrients are altered on the shelf as primary production incorporates inorganic forms into organic matter, which are subsequently recycled through decomposers, predominantly bacteria, to inorganic nitrogen and phosphorus. Rates of nutrient cycling have been assessed for both nitrogen and phosphorus in conjunction with algal blooms, particularly in the region between Charlotte Harbor and Tampa Bay, as summarized by Vargo *et al.* (2008). The anthropogenic contribution of nutrients to coastal waters has been hypothesized to enhance the frequency of harmful algal blooms along the SWFS (Brand and Compton, 2007), although the extent of the linkage between development and bloom occurrence is under debate (Vargo, 2009; Walsh *et al.,* 2009).

The nearshore distribution of salinity reflects the wind-driven circulation and input of freshwater from rivers. Liu and Weisberg (2007) mapped the salinity distribution across the shelf off Tampa Bay and Sarasota. The seasonal pattern of salinity along the coast revealed low salinities (<35.9) shoreward of the 30-m isobath in summer, with higher salinities (>36) present in winter. During the winter, the inner shelf currents are to the southeast and upwelling is favorable, while in summer downwelling occurs with currents to the northwest. Sutton *et al.* (2001) similarly found that lowest salinities were shoreward of the 30-m isobath in the midwest Florida Shelf.

In the southern region of the SWFS, the gradients in the concentrations of nitrogen and phosphorus (Rudnick *et al.,* 1999) and silica (Jurado *et al.,* 2007) have been assessed with regard to the alongshore flux from rivers to western Florida Bay. Quantifying the nutrient flux from the SWFS to western Florida Bay is important to accurately monitor the effects of Everglades restoration efforts on productivity of the bay and surface waters of the adjacent shelf (National Research Council, 2008).

Chromophoric Dissolved Organic Matter

The cycling of organic matter in the surface waters of the SWFS has been evaluated in the context of the contribution of chromophoric (colored) dissolved organic matter (CDOM) to inorganic carbon inputs (Clark *et al.,* 2004). Terrestrial sources of CDOM are decomposed in the upper water column by a combination of physical (photodegradation), biological (microbial decomposition), and chemical processes as fresher waters are mixed with saltier waters on the shelf. The most refractory matter remains in the water column as more labile material is degraded. This material contributes to the high extinction coefficients (low visibility) associated with blackwater events that originate from freshwater sources and propagate across the SWFS.

Phytoplankton Blooms

While harmful algal blooms are of major concern on the SWFS, other non-toxic species also create dense populations of high algal biomass in surface waters. Diatoms are a beneficial food source for many marine organisms, including benthic invertebrates, and are frequently present at bloom concentrations on the SWFS. Nutrient quality and quantity appear to regulate the dominant phytoplankton taxa present along the SWFS. Under conditions of low riverine inputs, northern waters have relatively low inorganic nitrogen concentrations in conjunction with cyanobacteria and dinoflagellate-dominated communities. In mid-shelf waters (Sanibel to Shark River), the nitrogen:phosphorus ratios are near that required to support plankton growth with cyanobacteria dominating. In southern waters (south of Shark River), diatoms can dominate under phosphorus-depleted conditions (Heil *et al.,* 2007).

Diatoms require silica in contrast to other phytoplankton taxa that lack frustules, the external siliceous "covering" of diatoms. The silica input to the SWFS from rivers (Juardo *et al.,* 2007) and potentially from groundwater (Brand, 2002) favor the growth of diatoms on the southern SWFS. Centric diatom blooms have developed in nearshore waters adjacent to Charlotte Harbor (McPherson *et al.,* 1990), the SWFS adjacent to the Ten Thousand Islands (Jurado *et al.,* 2007), and in the shallow regions of western Florida (Phlips and Badylak, 1996). These blooms are advected south along the shelf in the fall, creating winter diatom blooms in western Florida Bay.

Toxins

The toxic nature of *Karena brevis* blooms results from the production of a suite of polyether neurotoxins that are collectively termed brevetoxins. These high molecular-weight compounds can accumulate in shellfish and, when consumed in sufficient concentrations, produce symptoms (gastric distress) termed NSP (Watkins *et al.,* 2008). The toxins can also be transferred across the air-sea interface and then aerosolized. When the aerosolized brevetoxins are inhaled by beachgoers, they produce symptoms of rhinorrhea, coughing, and severe bronchoconstriction (Kirkpatrick *et al.,* 2004). The resulting costs associated with toxic blooms are estimated to range from 0.5 to 4 million dollars annually in visits to hospital emergency rooms in Sarasota County, Florida (Hoagland *et al.,* 2009). Medical costs associated with *K. brevis*-related respiratory illness are undoubtedly much higher for the entire west Florida coast.

Drivers of Change in the Southwest Florida Shelf

Development

The coastal counties of southwest Florida have experienced rapid population growth during recent decades. Between 2000 and 2008, for example, the population of Sarasota and Collier counties increased at a rate at, or exceeding, 10 percent. This increase has been hypothesized to have resulted in enhanced nutrient discharge to the coastal waters of the SWFS and an increase in the occurrence of harmful algal blooms (e.g., Brand and Compton, 2007). Eutrophication has been demonstrated to enhance development of harmful algal blooms in other regions (Anderson *et al.,* 2008), although the specific linkage between coastal eutrophication and harmful algal bloom occurrence on the West Florida Shelf is in debate (Walsh *et al.,* 2009; Vargo, 2009).

Climate Change

The increase in surface temperature of marine surface waters associated with the anthropogenic input of carbon dioxide to the atmosphere has several potential effects on marine ecosystems. The impact of an alteration in the carbon dioxide system in seawater will affect marine organisms that produce calcium carbonate as aragonite in skeletal structures (Andersson and Gledhill, 2011). The impact of this effect on the SWFS could potentially be in the species composition of the benthic community, although there have been no studies to address this. A second potential impact of climate change could be in a species shift in the pelagic communities, particularly in the species composition of phytoplankton. Changes in land runoff due to modification of the hydrologic cycle, coupled with altered inputs of nutrients and a warming of surface waters, have been proposed to result in changes in species in phytoplankton taxa (Paerl and Scott, 2010; Hallegraeff, 2010).

Nutrient Loading

Several sources contribute nutrients to the water column of the West Florida Shelf, including rivers, benthic communities, and bottom intrusions that originate from onshore flows from the Gulf of Mexico Loop Current. Considerable effort has been devoted to quantify the nitrogen and phosphorus inputs from these sources as they support harmful algal blooms on the SWFS. Estuaries are a major source of nutrients, in both dissolved inorganic and organic forms, that support primary production near the shore (Vargo *et al.,* 2008). In particular, dissolved organic forms of nitrogen are the major form of this essential nutrient in the rivers that flow into the West Florida Shelf coastal waters (McPherson and Miller, 1990).

Further offshore, nitrogen and phosphorus enter the shelf ecosystem from upwelling of subsurface waters in the Loop Current (Walsh *et al.,* 2006). Additional biological inputs occur from the nitrogen-fixing cyanobacteria *Trichodesmium* sp., which often blooms in summer in response to the seasonal input of iron from atmospheric dust transported westward from the Sahara (Walsh and Steidinger, 2001). When *Trichodesmium* sp. blooms, they release measurable quantities of dissolved organic nitrogen that subsequently supports primary production in the water column. Direct atmospheric inputs of nitrogen also occur through wet and dry deposition in the eastern Gulf of Mexico (Paerl *et al.,* 2002). In total, these sources can support dense algal blooms on the West Florida Shelf, although no individual nutrient source is sufficient to maintain prolonged bloom events (Vargo *et al.,* 2008).

Tropical Cyclones

Tropical cyclones occur almost annually in the Gulf of Mexico. These event-scale features can rapidly transit through the West Floria Shelf in mid to late summer. Mixing is greatly enhanced during the passage of these storms, and surface waters can be destratified with nutrients introduced into the surface layer (e.g., Ortner *et al.,* 1984). Primary production is enhanced in the wake of intense storms, although this effect is primarily observed in oceanic waters seaward of the shelf break (Chen *et al.,* 2009). In nearshore waters, the passage of intense storms can resuspend sediments and reduce the transparency of the water column (e.g., Chen *et al.,* 2009), resulting in a potential reduction in pelagic primary production in coastal waters.

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