Seagrasses of Florida: A Review

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Introduction

Seagrass communities are noted to be some of the most productive ecosystems on earth, as they provide countless ecological functions, including carbon uptake, habitat for endangered species, food sources for many commercially and recreationally important fish and shellfish, aiding nutrient cyling, and their ability to anchor the sediment bottom. These communites are in jeopardy and a wordwide decline can be attributed mainly to deterioration in water quality, due to anthropogenic activities.

Seagrasses are a diverse group of submerged angiosperms, which grow in estuaries and shallow ocean shelves and form dense vegetative communities. These vascular plants are not true grasses; however, their “grass-like” qualities and their ability to adapt to a saline environment give them their name. While seagrasses can be found across the globe, they have relatively low taxonomic diversity. There are approximately 60 species of seagrasses, compared to roughly 250,000 terrestrial angiosperms (Orth, 2006). These plants can be traced back to three distinct seagrass families (Hydrocharitaceae, Cymodoceaceace complex, and Zosteraceae), which all evolved 70 million to 100 million years ago from a individual line of monocotyledonous flowering plants (Orth, 2006). The importance of these ecosystems, both ecologically and economically is well understood. The focus of this paper will be to discuss the species of seagrass in Florida, the components which affect their health and growth, and the major factors which threaten these precious and unique ecosystems, as well as programs which are in place to protect and preserve this essential resource.

Ecological Functions and Benefits of Seagrass Communities

Seagrass beds form an abundantly productive part of the coastal ecosystem both, worldwide and in within the state of Florida. These communities support a myriad of flora and fauna by providing a physical structure to a largely barren sediment bottom. According to the Smithsonian Marine Station at Fort Pierce (2002), one acre of seagrass can sustain upwards of 40,000 fish and 50 million invertebrates.The submerged aquatic vegetation (SAV) acts as substratum for a diverse epiphytic and microalgal community, including sponges, bryozoans and forams, which serve as a main driver of the trophic system, within the near shore ecosystem (Duffy, 2006). The organisms living in the sediments and on the surface of the leaves of the seagrass beds are the base of the coastal food chain, thus drawing innumerable species of fish, invertebrates and turtles. The leaves and the detrital community also serve as a food source for the Florida Manatee (*Trichechus manatus latirostris* Harlan), noted as an endangered species in 1979 by the Endangered Species Act (FWC, 2007) and the green turtle (*Chelonia mydas* Linnaeus), listed as endangered under the Endangered Species Act in 1982. (IUCN Red List, 2015). In addition, the seagrass canopy is teeming with juvenile fish and other small organisms that utilize this habitat as shelter from predation (Zieman & Zieman,1989). Macroalgae and drift algae are often found in conjunction with seagrass meadows and they provide a home and abundant food source for many species of amphipods and decapods. According to Duarte and Chiscano (1999), seagrass acts as a carbon sink and the authors estimate that worldwide seagrass beds account for approximately 15% of the net CO_2 uptake by marine organisms, while accounting for only 1% of the marine primary production. Seagrass beds also help to clarify the water by trapping fine sediments and reducing the amount of re-suspension of sediments from wind and wave action (FWC “Importance of Seagrass”, 2015). Seagrass beds also act as sediment stablizers and reduce the effects of wave action on shoreline erosion. These factors combine to make seagrass beds a key environmental resource (Duffy, 2006).

Economic Impacts of Seagrass Beds In Florida

Seagrass beds in Florida contribute to the economy through several means, including ecotourism and the commercial fishing industry. An estimated 70% of Florida fishery species spend a portion of their lifecycle in seagrass communities thus making these communities vital to the success of the fishing industry (FWC “Importance of Seagrass”, 2015). The number rises from 70% of fish dependant on seagrass beds to 90% when ecotourism activities, such as diving, snorkeling, and fishing are factored in (FDEP “Florida Pays Tribute to the State’s Seagrasses”, 2010). Florida’s Department of Environmental Protection (FDEP) has estimated that one acre of seagrass in Florida provides an approximate economic contribution of $20,500 per year. The value is derived from the economic value of nutrient cycling as well as the commercial and recreational fisheries (Smithsonian Marine Station at Fort Pierce, 2002). In 2003, the total estimated area of seagrass within Florida was 2.25 million acres; a number which does not include unmapped deep water beds located in the Gulf of Mexico (FDEP “FACT 2010”, 2010). The Smithsonian Marine Station at Fort Pierce estimated 2.7 million acres of seagrass in 2002. This translates to an estimated economic benefit of $46 billion annually, ranging upwards to $55 billion annually contributing to the states economy. In 2000 the FDEP reported that the states seagrass beds supported a harvest of fish and shellfish with a sustained a value of $125 billion (Smithsonian Marine Station at Fort Pierce, 2002).

According to FDEP “FACT 2010” (2010), saltwater boat and non-boat fishing activities draw 17 million people annually to Florida and nature study draws 27.5 million people annually. In 2009, 84.2 million visitors contributed 65.2 billion dollars to the Florida economy (FDEP “FACT 2010”, 2010). Over half of the visitors in 2009 were attracted to resources in Florida which exist, in part, to seagrass meadows.

In addition, according to the 2014 “State of the U.S. Ocean and Coastal Economies Report”, Florida is one of the three leading states in tourism and recreation employment (Kildow et al., 2014). Approximately, 5-6% of the total employment in Florida in 2010 was attributed to the ocean economy, which is the concept that the ocean and its resources are a direct or indirect link to the economic functioning of the state (Kildow et al., 2014). These numbers make it clear the economy in Florida and the seagrass meadows within the state are linked.

An Overview of the Seven Different Species of Seagrasses Found in Florida Waters

Worldwide, there are 52 species of seagrasses documented and identified, seven of which can be found in Florida’s waters (FDEP “What are Seagrasses?”, 2013). Figures 1 and 2 show the distribution of seagrasses within the state and the regions in which the seagrass grows. It is broken down into 5 regions with South Florida containing 63% of the total seagrass, Big Bend accounting for 27%, the Gulf Peninsula accounting for 5%, the Atlantic Peninsula accounting for 3% and the Panhandle accounting for 2% of the total seagrass, based on a 1993 estimate (FDEP “FACT 2010”, 2010).

Figure 1. Seagrass Distribution in the State of Florida: (FDEP, 2014).

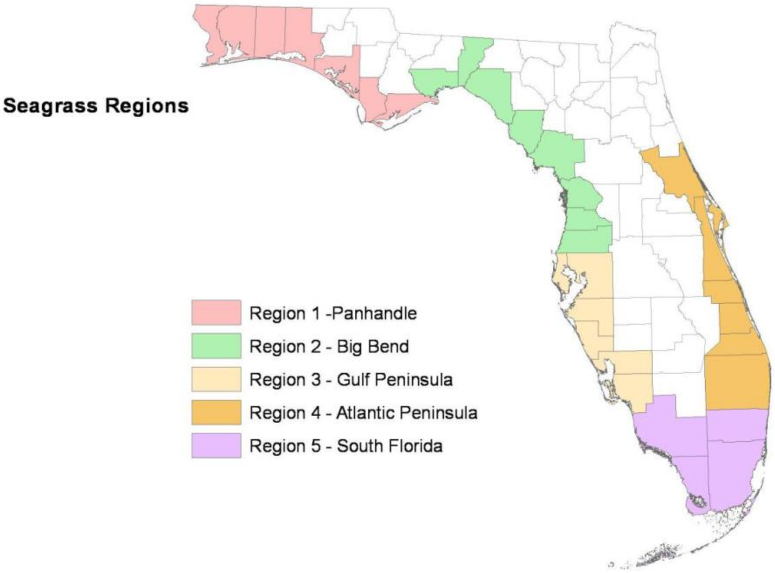

Figure 2. Seagrass Distribution Regions in the State of Florida: (FDEP, 2014).

The first of the seven species of seagrass found within the state is *Thalassia Testudinum*, also known as turtle grass (Figure 3 and Figure 4), which is the largest species of the seven seagrasses found in Florida. It has long flat, ribbon like blades which range from 10-12 mm long and 4.5-10 mm wide (FWC "*Seagrasses*", 2015). It is distributed from Venezuela through Central America to the West Indies and Bermuda to eastern Florida (Smithsonian Marine Station at Fort Pierce, 2002), and is the most abundant seagrass in Florida.

This species grows and thrives in subtidal zones with mud substrates in depths of about 10 m, however, in some waters it can be found up to 30 m deep (FWC "*Seagrasses",* 2015) It reproduces through sexual and vegetative reproduction with the latter accounting for the majority of the spread of the species within Florida (Smithsonian Marine Station at Fort Pierce ,2002).

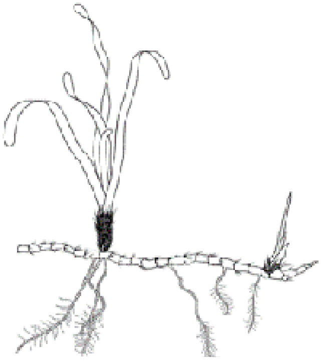

Figure 3. *Thalassia Testudinum* Drawing: (FDEP, "What are Seagrasses?", 2013).

Figure 4.*Thalassia Testudinum* (FDEP, "What are Seagrasses?", 2013).

Syringodium Filiforme (Figure 5 and 6),also known as manatee grass, has blades which are cylindrical in shape and range in length from 10–30 cm and 0.8–2 mm wide (FWC "*Seagrasses*", 2015). It is distributed throughout the Gulf of Mexico, the Western tropical Atlantic, Bermuda and Eastern Florida (FWC "*Seagrasses*", 2015). It grows in subtidal zones exclusively and can be found in waters up to 18 m deep in some locations (FWC "*Seagrasses*", 2015). It grows in muddy to sandy substratum and reproduces both sexually and asexually through rhizome elongation and branching; however, it is thought that most reproduction is vegetative (Smithsonian Marine Station at Fort Pierce, 2002).

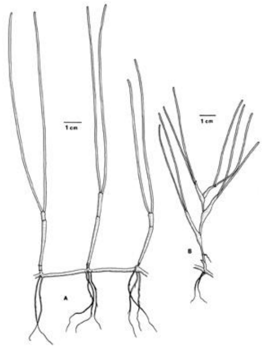

Figure 5. *Syringodium Filiforme* Drawing: (FWC "Syringodium Filiforme", 2015).

Figure 6. *Syringodium Filiforme*: (FDEP, "What are Seagrasses?", 2013).

Halodule beaudettei and the synonym *Halodule wrightii* (Figures 7 and 8*)*, more commonly known as shoal grass, has long thin and flat blades that are 3.5–32 cm long and 0.3-2.2 mm wide (FWC, "*Seagrasses*", 2015). It ranges from North Carolina hugging the coastline and extending on into the Caribbean. It can also be found in South America and places in Northwestern Africa (Smithsonian Marine Station at Fort Pierce, 2002). This species grows in lower intertidal and upper subtidal zones sometimes becoming exposed at low tide (FWC, "*Seagrasses*", 2015). It grows in all types of sediments ranging from silty mud to sand (Smithsonian Marine Station at Fort Pierce, 2002) and can be found in waters up to 12 m deep (FWC "*Seagrasses*", 2015). It reproduces mainly through vegetative propagation; however it does flower and is capable of sexual reproduction (Smithsonian Marine Station at Fort Pierce, 2002).

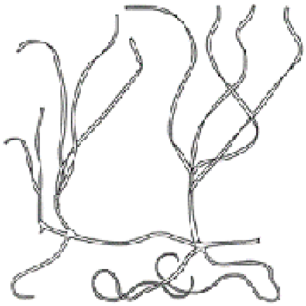

Figure 7. *Halodule Wrightii* Drawing. (FDEP, "What are Seagrasses?", 2013).

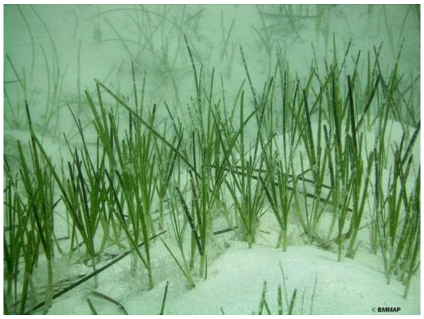

Figure 8. *Halodule Wrightii*. (Government of Bermuda, 2015).

There are three types of *Halophila* species which can be described as smaller and more delicate than the other species of seagrass in Florida, the first is *Halophila decipiens* or paddle grass, seen in Figures 9 and 10. This particular species grows in much deeper water than the previous species with maximum depths up to 85 m provided proper water quality parameters are met (FWC "*Seagrasses*", 2015). Its paddle shaped leaves are 1 - 2.5 cm long and 3 - 6mm wide (FWC "*Seagrasses*", 2015). This species is distributed throughout the West Indies and the Indo-Pacific as well as Southeastern Florida and in the Gulf of Mexico as well as the continental shelf in Cuba (Smithsonian Marine Station at Fort Pierce ,2002). *Halophila decipiens* reproduces through sexual and asexual reproduction and is defined as monoecious (producing both male and female flowers) (Smithsonian Marine Station at Fort Pierce, 2002).

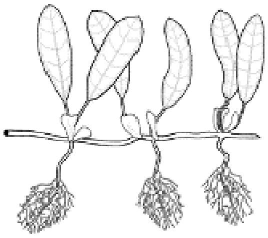

Figure 9. *Halophila Decipiens* Drawing: (FDEP, “What are Seagrasses?”, 2013)

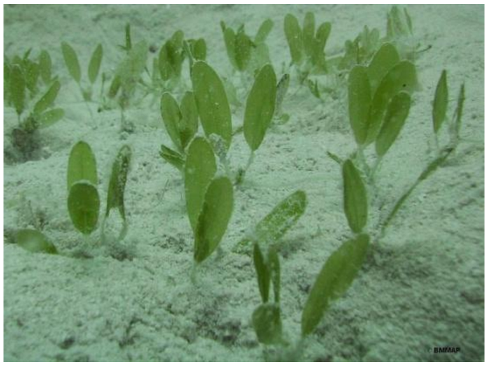

Figure 10. *Halophila Decipiens*: (Government of Bermuda, 2015).

The next species of *Halophila* is *Halophila engelmannii* (Figure 11 and 12), more commonly known as star grass. The blades of this species range from 1 – 3 cm long and 3 – 6 mm wide. The long elliptical shape and serrated edges make the seagrass distinguishable. Leaves appear in groups of 4 - 8 attached to a short petiole (FWC “*Seagrasses*”, 2015). It can grow in a wide variety of substratum from mud to sand and shelly sand and grows from maximum depths of 90 m all the way to the low tide line (FWC “*Seagrasses*”, 2015). It is distributed throughout Florida and the Bahamas as well as Texas and the West Indies (Smithsonian Marine Station at Fort Pierce, 2002). This species is dioecious, with each individual containing only male or female parts and it reproduces sexually as well as asexually (Smithsonian Marine Station at Fort Pierce, 2002).

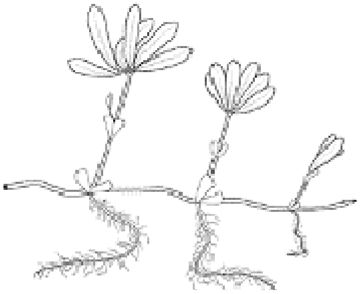

Figure 11. *Halophila Engelmannii* Drawing: (FDEP, “What are Seagrasses?”, 2013).

Figure 12. *Halophila Engelmannii in foreground,* mixed with Syringodium Filiforme: (Yarbro and Carlson, 2011).

The final species of *Halophila* found in Florida is *Halophila johnsonii* (Figure 13 and 14), commonly referred to as Johnson's seagrass. Its status is threatened under the endangered species act, mainly due to its limited range. It is found only in Southeastern Florida from the Sebastian Inlet to Biscayne Bay, with the largest patches being documented in the Lake Worth Inlet (NOAA Fisheries, 2013). This species is the rarest species of its genus and has been designated as critical habitat by NMFS (National Marine Fisheries Service) (NOAA Fisheries, 2013). To be classified as a critical habitat you must meet both of the two following criteria as quoted by NOAA Fisheries "Critical habitat is defined as specific areas: within the geographical area occupied by the species at the time of listing, if they contain physical or biological features essential to conservation, and those features may require special management considerations or protection; and outside the geographical area occupied by the species if the agency determines that the area itself is essential for conservation."(NOAA Fisheries, 2015). Another factor which likely contributes to its "threatened" status is the fact that this species only reproduces asexually, limiting its means of reproduction to one, whereas most seagrasses have two means of reproduction (NOAA Fisheries, 2013).

Halophila Johnsonii grows in coastal lagoons in the intertidal zone and is found in substrate ranging from muddy to sandy (FWC, "*Seagrasses*", 2015). Its leaves, which occur in pairs of two with a short 1 - 2 cm long petiole, are 0.5 – 2.5 cm long and 1 - 4mm wide with a brown midrib and a pointed tip (FWC, "*Seagrasses*", 2015).

Figure 13. *Halophila Johnsonii* Drawing:(FDEP, "What are Seagrasses?", 2013)

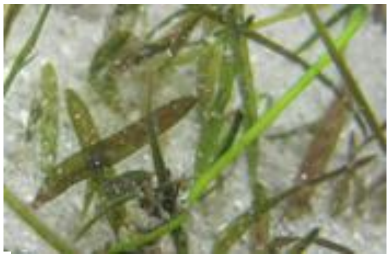

Figure 14. *Halophila Johnsonii*: (NOAA Fisheries, 2013.)

The seventh species of seagrass found in the waters of Florida is *Ruppia Maritima* (Figure 15 and 16), also known as widgeon grass. *Ruppia Maritima* is not considered a true seagrass, but rather it is identified as a submerged macrophyte (Koch et al., 2006). Widgeon grass has long thread-like leaves which taper off into a point reaching a maximum of 20 cm long and less than 1mm wide (FWC "*Seagrasses*", 2015). This species is unique as it can exist in a vast spectrum of substrate types. It is distributed worldwide in temperate and subtropical latitudes with a range of 69 degrees north and 55 degrees south (FWC "*Seagrasses*", 2015). It is generally found in shallow waters ranging from 2-5m deep (FWC, "*Seagrasses*", 2015).

Reproduction in *Ruppia Maritima* occurs through either sexual or asexual reproduction. Another factor which makes this species unique is its production of spores which are hydrophobic and therefore float on the surface of the water (Smithsonian Marine Station at Fort Pierce, 2002). Sexual reproduction is thought to be the primary reproductive device for the species (Smithsonian Marine Station at Fort Pierce ,2002).

Figure 15. *Ruppia Maritima* Drawing:(FDEP "What are Seagrasses?", 2013).

Figure 16. *Ruppia Maritima*: (Government of Bermuda, 2015).

Factors that Affect Florida Seagrass Health and Growth

Seagrass productivity is affected by physiological processes as well as several biotic and abiotic factors, which work together synergistically to impact and guide plant metabolism (Lee et al., 2007). Lee et al. (2007) identified three main factors which govern this process: underwater irradiance**,** temperature, and nutrients. This paper will discuss the three stated above, as well as a fourth essential component to the growth and health of seagrasses namely, salinity.

I. Light (Underwater Irradiance)

Light is an essential requirement for any member of kingdom plantae and this is no different for seagrasses. Light can become attenuated in the water column through absorption and scattering. Light scattering does not remove it from the water column all together, but it increases the odds that the light will become absorbed by particles in the water through the mechanism of lengthening the path that the photon must travel, thus effectively removing it from use by seagrasses. (Smithsonian Environmental Research Center. "Chapter IV- Factors Contributing to Water Column Light Attenuation", 2015). It is extremely important to have light and a specific light spectra reach plants in order to satisfy their oxygen demand. However, light can be attenuated in the water column by many factors, including turbidity, the presence and concentration of chlorophyll a in the water, and color (Gallegos and Kenworthy, 1996). The depths to which seagrasses can grow are affected by light penetration. The maximum depth is defined as the ecological compensation depth (ECD) wherein the overall carbon balance becomes negative (C respiration exceeds C assimilation) and the seagrass bed becomes unsustainable (Gallegos & Kenworthy, 1996).

Underwater irradiance can be reduced by anthropogenic and natural perturbations. As exemplified by the Lambert-Beer equation, light is reduced with increasing depth due to absorption and scattering, based on the properties of the material through which the light is traveling. Suspended dissolved solids, phytoplankton in the water column and the water itself contribute to reduced light penetration (Lee et al. 2007). As reported by Steward et al. (2006), the three main factors responsible for light attenuation were turbidity, color and chlorophyll a, in that order. Each species of seagrass has a different light requirement. However, the minimum light requirement for seagrasses is much higher than that of macroalgae and phytoplankton, with a 2 - 37% surface irradiance (SI) requirement versus a 1 - 3% surface irradiance factor respectively (Lee et al., 2007). Surface irradiance is measured as m-2 s-1. Table 1 shows the minimum light requirements of various seagrass species throughout the world.

Table 1. Light Requirements for Seagrasses. Lee et al. (2007).

Species	Location	Latitude	Minimum Light Requirement %	Source
Ruppia Maritima	Brazil	32°S	8.2	Dennison et al. (1993)
Halodule Wrightii	Laguna Madre, USA	27°21'N	18	Dunton (1994)
Halodule Wrightii	Laguna Madre, USA	27°21'N	15-20	Burd and Dunton (2001)
Halodule Wrightii	Indian River Lagoon, USA	27°30'N	24-37	Kenworthy and Fonseca (1996)
Halodule Wrightii	Indian River Lagoon, USA	27°30'N	20	Steward et al. (2005)
Halodule Wrightii	Corpus Christi Bay, USA	27°49'N	18	Dunton (1994)
Halodule Wrightii	Corpus Christi Bay, USA	27°49'N	20	Czerny and Dunton (1995)
Halodule Wrightii	San Antonio Bay, USA	28°15'N	18	Dunton (1994)
Halodule Wrightii	Florida, USA	25°-30°N	17.2	Dennison et al. (1993)
Halophila Decipiens	Cuba	23°N	8.8	Dennison et al. (1993)
Halophila Decipiens	St. Croix, USA	17°N	4.4	Dennison et al. (1993)
Halophila Engelmannii	Cuba	23°N	23.7	Dennison et al. (1993)
Syringodium Filiforme	Cuba	23°N	19.2	Dennison et al. (1993)
Syringodium Filiforme	Florida, USA	25°-30°N	18.3	Dennison et al. (1993)
Syringodium Filiforme	Florida, USA	25°-30°N	17.2	Dennison et al. (1993)
Syringodium Filiforme	Indian River Lagoon, USA	27°02'N	24-37	Kenworthy and Fonseca (1996)
Thalassia Testudinum	Puerto Rica	18°N	24.4	Dennison et al. (1993)
Thalassia Testudinum	Cuba	23°N	23.5	Dennison et al. (1993)
Thalassia Testudinum	Florida Bay, USA	25°N	13	Fourquerean and Zieman (1991)
Thalassia Testudinum	Corpus Christi Bay, USA	27°49'N	20	Czerny and Dunton (1995)
Thalassia Testudinum	Corpus Christi Bay, USA	27°49'N	>14	Lee and Dunton (1995)
Thalassia Testudinum	Florida, USA	25°-30°N	15.3	Dennison et al. (1993)

Light requirement variation can be attributed to physiological and morphological adaptations and adjustments to local light regimes (Lee et al., 2007). Figure 17 illustrates the mechanisms different species use to adapt to varying light levels. Some species might exhibit a higher chlorophyll concentration in lower light conditions or less below-ground biomass, in order to reduce the oxygen demand by the roots. Some species may adapt by producing a fewer amount of leaves to reduce the amount of self shading (Ralph et al., 2007). It is noted that species with a well developed stem above the ground have a lower light requirement than those that have a rosette type arrangement (Lee et al., 2007). Leaf shape also plays a role in the ability of the plant to efficiently capture light and it is suggested by Lee et al. (2007) that elliptical or paddle shaped blades, such as found with *Halophila* species, are better at harvesting light than species with long, thin blades. It is no surprise that the *Halophila* species are typically found in deeper waters.

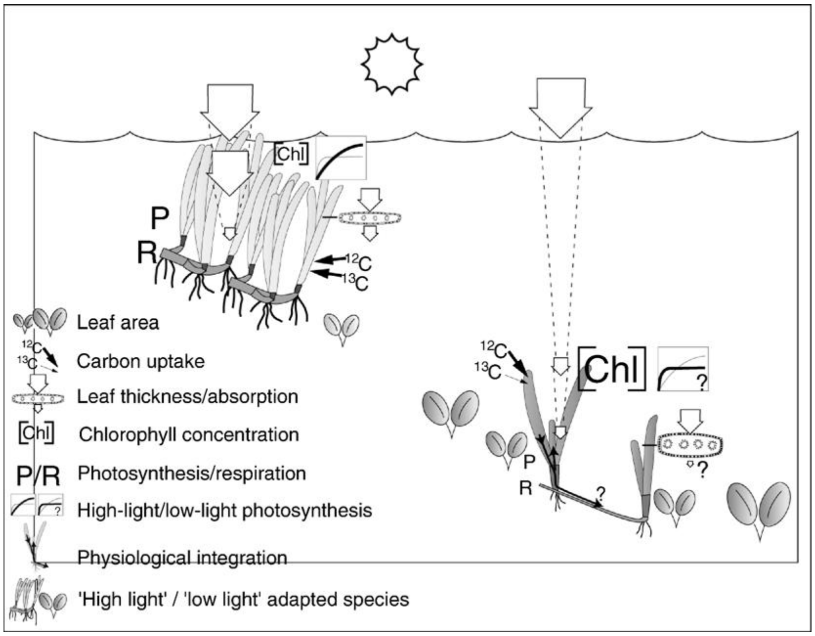

Figure 17. Conceptual Model of Possible Seagrass Adaptations to Varying Light Regimes: (Ralph et al., 2007)

In addition, seagrasses are rooted in anoxic sediments a majority of the time, so plant-available oxygen is more limited, which in turn, places a higher requirement for photosynthetically active radiation (PAR) (Gallegos & Kenworthy, 1996). The PAR denotes a spectral range of solar radiation (400 to 700 nm), which is the visible spectrum and for which photosynthesis occurs. Seagrasses have the highest photosynthetic efficiency in the red and blue spectra, while they demonstrate low photosynthetic effieciency in the green and yellow regions of the spectrum (Chartrand et al., 2007). Suspended particles in the water column can remove the red and blue photons, while allowing the less useful green and yellow photons to pass through (Chartrand et al., 2007).

A. Turbidity

Turbidity is a relative measure of water clarity and how much material is suspended in the water column. These measurements can help to give you an estimate of the total suspended sediments (TSS) in the water column. Turbidity is determined by the amount of light scattered by the suspeneded particles and not a direct measurement of the amount of suspended sediments in the water column. Suspended sediments is an umbrella term for several sediment types including clay, silt, algae, plankton and other microscopic organisms and soluble colored organic compounds or tannins (USGS, 2015).

Turbidity may be caused by natural processes or anthropogenic disturbances. Increased runoff due to a wet season, El Nino or a hurricane, may increase turbidity, due to the extra volume of water carrying suspended solids into neighboring water bodies. These precipitation events re-suspend sediments in the water column, as well. Sources of anthropogenically induced turbidity can be point and non-point sources. Examples include, dredging and filling operations, farming activities, releases of sewage, and construction activities, to name a few. These activities not only lead to increased loads of suspended solids entering the water body but also sediment resuspension (Lee et al., 2007). Changing land-use and increasing rates of development along Florida's coastline leads to increased runoff coming from the land, because it cannot infiltrate the ground and impervious surfaces.

Figure 18 illustrates causes of natural light attenuation, such as phytoplankton, turbidity, dissolved organic matter, epiphytes, and sediment resuspension, as well as anthropogenically induced causes of turbidity. The lower pane in the figure (future prediction) represents the illustrator's view of light attenuation and related seagrass losses if conditions do not change.

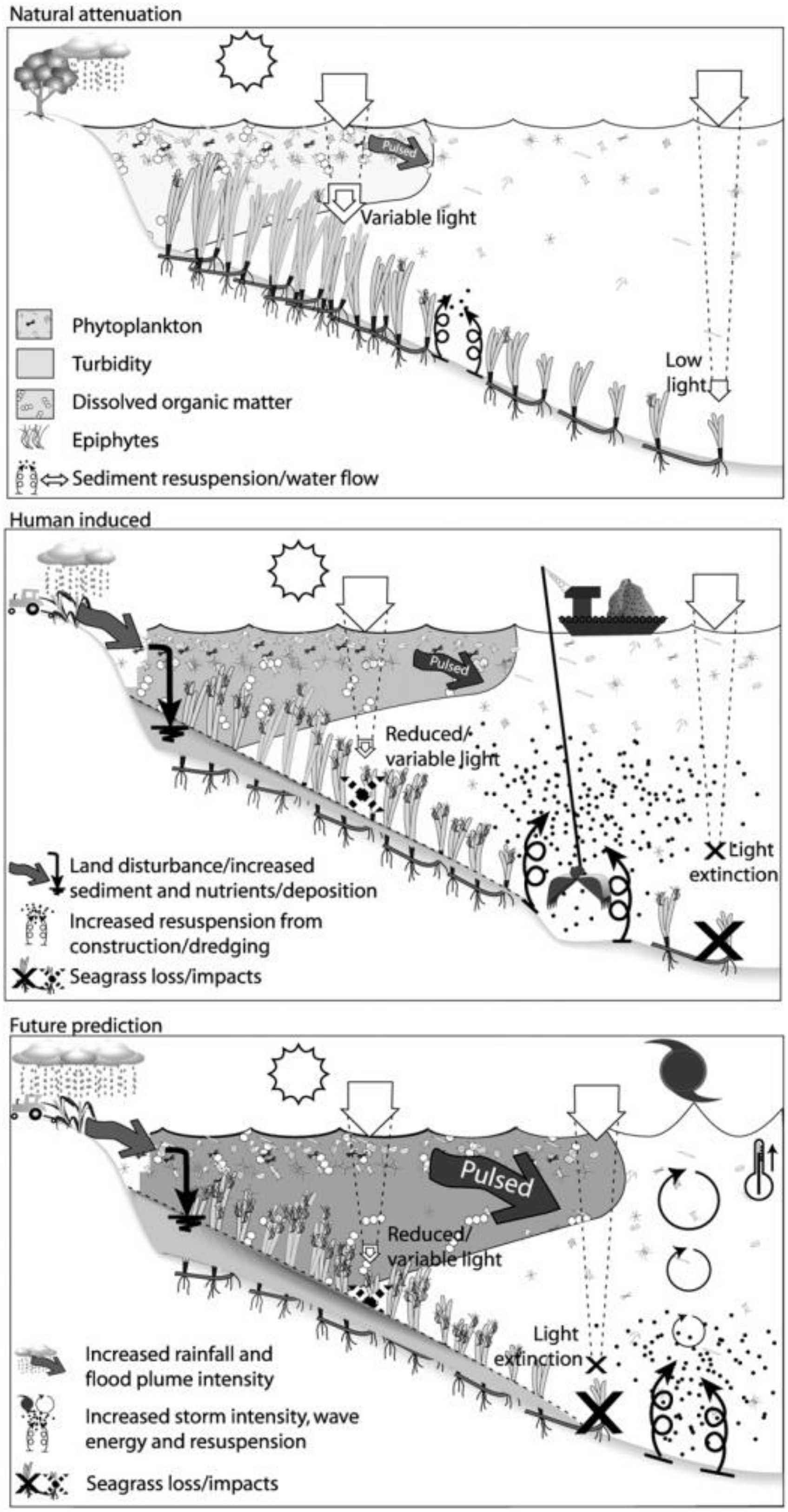

Figure 18. Causes of Natural Light Attenuation versus Human Induced Light Attenuation: (Ralph et al., 2007).

B. Color

Color is directly associated with turbidity. Many factors can result in a color change to the water, which in turn, can affect underwater irradiance. Among these factors are tannins and dissolved organic carbon (the remains of degraded plant and animal material). When these factors are present they tend to give the water a brownish or blackish hue (Wilson, 2010). Metallic ions, such as iron and manganese, can also color the water with a reddish color (Wilson, 2010). Other sources of color change can derive from algal blooms, humus and peat, lawn and landscape runoff and industrial wastes (Wilson, 2010). As anthropogenic activities increase and land development continues, this problem will persist.

C. Chlorophyll A

The amount of chlorophyll in the water can also help one to understand the relationship between turbidity and underwater irradiance. Phytoplankton in the water column contributes to the absorption of light. This absorption rate can vary, based on depth, composition of the water, and species of plankton. However, it is still a factor to diminishing light irradiance (Smithsonian Environmental Research Center. “Chapter IV Factors Contributing to Water Column Light Attenuation”, 2015). Large algal blooms can severely diminish light, as well as compete for oxygen, and can result inmassive seagrass bed die offs.

D. Epiphytic Shading

A final factor to be considered when looking at light and photosynthetic productivity is epiphytic shading. Epiphytes adhere to the blade of the grass leaving less area for light absorption (Smithsonian Environmental Research Center. “Chapter IV Factors Contributing to Water Column Light Attenuation”, 2015). Epiphytic growth is thickest at the tops of the leaves as this portion was the first to grow, thus allowing more time for epiphytes to colonize (Smithsonian Environmental Research Center. “Chapter 11 Seagrass Communities”, 2015). Seagrass blades in general have a higher turnover rate, which helps to the combat the problem of epiphytic shading, with most leaves lifespan ranging from 11 to 100 days, depending on the species (Smithsonian Environmental Research Center. “Chapter 11 Seagrass Communities”, 2015).

II. Temperature

The second major factor affecting the growth of seagrass is temperature. Light and temperature are closely related (part of the electromagnetic spectrum), making it somewhat difficult to distinguish individual effects. Seagrass growth is seasonal, with most growth in spring and summer, and little to no growth during fall and winter (Lee et al., 2007). According the Lee et al. (2007) the optimal temperatures for tropical and subtropical species of seagrass is between 23°C and 32°C; however, it is noted that some species behave differently under varying temperatures, an occurrence which can be explained by the physiological differences among seagrass species. For example, in *Thalassia Testudinum*, leaf productivity increased with increasing temperatures, with no obvious high temperature growth cap. However, it was shown that for other species, as temperatures rose in the summer, productivity and biomass decreased, indicting high temperature growth inhibition (Lee et al., 2007).

One way of determining optimal temperature ranges is to look at photosynthesis-irradiance (P-I) curves. It is shown that respiration and the photosynthetic rate increased with increasing water temperature (Lee et al. 2007). Furthermore, the optimum temperature for photosynthesis can vary, based on the amount of underwater irradiance. An overarching trend seems to appear, indicating that as the amount of underwater irradiance decreases so does the optimal temperature for photosynthesis. This of course means that as underwater irradiance increases, so does the optimal temperature for photosynthesis (Lee et al. 2007). This indicates that a plant which is exposed to low light conditions will have a lower optimal temperature for photosynthesis and it is likely that plants at higher temperatures need more light to maintain optimal productivity (Lee et al. 2007).

Respiration rates increase much more rapidly than that of photosynthesis, with increasing temperature. This leads to an overall net reduction in photosynthesis (Lee et al.,2007). Higher temperatures may also lead to increased growth of epiphytes and algae within the meadows, leading to increased shading of the bed and therefore less surface space for light absorption (Bjork et al., 2008). It is worth noting that as temperatures increase due to climate change, seagrass regimes and distributions will change and the long-term sustainability of these beds will be determined by their ability to adapt to these changes.

III. **Salinity**

A third abiotic factor affecting the health and growth rates of seagrass meadows in Florida, is salinity. Salinity is affected by local and seasonal storms, as well as freshwater releases from control structures and canals. Overall, seagrass can exist in a wide range of salinities, starting from 5 practical salinity units (PSUs), which is equivalent to parts per thousand (ppt) (Bjork et al., 2008). The upper range is a subject of debate and much like the other factors discussed previously, salinity tolerances vary among species.

Among the seven species of seagrass found in Florida, *Halodule* seems to tolerate the widest range of salinities (Zieman & Zieman, 1989). The Smithsonian Marine Station at Fort Pierce (2002) suggests an optimal range for *Halodule* in Florida of 12.0 - 38.5 ppt. However, they also gathered information from a study in Texas which reported that Halodule was not only the most abundant seagrass in salinities ranging from 1.0 - 60.0 ppt, but that it was the only species which survived in salinities of 45.0 ppt and higher. Organisms which can tolerate a wide range of salinities are known as euryhaline.

Another euryhaline species is *Syringodium Filiforme*. Although this species cannot withstand extended periods of low salinity it can survive through short intervals of lowered salinity (Smithsonian Marine Station at Fort Pierce, 2002). The optimal range of salinities for this species is between 20.0 – 25.0 ppt, as reported by the Smithsonian Marine Station at Fort Pierce (2002).

On the other side of the spectrum, *Thalassia Testudinum* does not tolerate extreme fluctuations in salinity and begins to show health decline as salinities fall below 20 ppt (Smithsonian Marine Station at Fort Pierce, 2002). The optimal range of salinities for this species is 25.0 - 38.5 ppt (Smithsonian Marine Station at Fort Pierce, 2002).

Among the *Halophila* species, *Halophila johnsonii* seems to display the greatest tolerance of a wide variety of salinities, while *H. decipiens* is defined as stenohaline; organisms that tolerate can only within a very narrow salinity range (Smithsonian Marine Station at Fort Pierce, 2002).

Ruppia Maritima has been reported in the field within a wide range of salinities from 0 - 60ppt (Koch et al., 2006), although more studies are needed in order to establish an optimal range, as available information varies widely for this species.

Table 2 provides the results of an experimental study conducted by Koch et al. (2006) to test the upper salinity limits of various species of seagrasses. The first experiment was to quickly raise the salinities in a closed environment to try and emulate a point source event such as exposure to sewage effluent. Experiment two raised salinities slowly to try and imitate the conditions of a shallow estuary or basin experiencing high rates of evaporation. Finally, they raised the salinity in the environment at a moderate rate and tested how *Halophila johnsonii* reacted to this parameter.

Table 2. Various Seagrass species reactions to rising saline levels. Adapted from (Koch et al., 2007)

Species	Threshold	Range	Survival	Rate	Parameters	Reference
Pulsed Experiments						
Thalassia Testudinum	40	5 – 45	45	Pulsed	Leaf elongation	Lirman and Cropper (2003)
Thalassia Testudinum	40	0 – 70	50	Pulsed	Seedling growth, survival	Kahn and Durako (2006)
Thalassia Testudinum	45	36 – 70	70	Pulsed	Leaf growth, O2 prod.	Koch et al. (2006)
Halodule Wrightii	35	5 – 45	45	Pulsed	Leaf elongation	Lirman and Cropper (2003)
Ruppia Maritima	40	0 -40	40	Pulsed	Quantum yield, osmolality	Murphy et al. (2003)
Syringodium Filiforme	40	5 -45	45	Pulsed	Leaf elongation	Lirman and Cropper (2003)
Slow Rate Salinity Increase						
Thalassia Testudinum	60	28 – 74	74	0.75 psu d-1	Growth, chlorophyll content	McMillan and Moseley (1967)
Thalassia Testudinum	50	0 – 70	70	0.66 psu d-1	Seedling growth, survival	Kahn and Durako (2006)
Thalassia Testudinum	60	36 – 70	70	1.0 psu d-1	Growth, quantum yield, O2 prod.	Koch et al. (2006)
Halodule Wrightii	65	36 – 70	70	1.0 psu d-1	Growth, osmolality, quantum yield	Koch et al. (2006)
Halodule Wrightii	70	28-74	74	0.75 psu d-1	Growth, chlorophyll content	McMillan and Moseley (1967)
Ruppia Maritima	70	28-74	74	0.75 psu d-1	Growth, chlorophyll content	McMillan and Moseley (1967)
Ruppia Maritima	55	36-70	70	1.0 psu d-1	Growth, osmolality, quantum yield	Koch et al. (2006)
Syringodium Filiforme	45	28-74	60	0.75 psu d-1	Growth, chlorophyll content	McMillan and Moseley (1967)
Moderate Rate Salinity Increase						
Halophila Johnsonii	30	0-60	50	10 psu d-1	Growth, photosynthesis	Fernandez- Torquemada et al. (2005)

Table 3 shows the upper limits of salinities where tropical seagrasses have been reported to grow worldwide.

Table 3. Upper ranges of salinities for seagrasses which have been reported growing in the field: Adapted from (Koch et al., 2006).

Species	Salinity range (psu)	Locations and conditions	Reference
Thalassia Testudinum	15 - 40	2 year (1969 - 1970) Biscayne Bay, Fl.	Zieman (1975)
Thalassia Testudinum	50->60	Chronic hypersaline period (1989-1990) central Florida Bay, Fl	Zieman et al. (1999)
Thalassia Testudinum	28-54	Hypersaline conditions (2004 - 2005), Florida Bay, Fl	Koch (unpublished data)
Halodule Wrightii	35-62	Extensive beds, salinities recorded 1996-1997, Baffin Bay, TX	Cotner et al. (2004)
Ruppia Maritima	0 ->60	A very wide range of salinities observed for this species based on review	Kantrud (1991)

This study seemed to indicate that seagrasses are capable of living in hypersaline environments, given that the salinities rose gradually whereas they were less likely to survive if the salinities were pulsed. (Koch et al., 2006).

When species are exposed to salinities outside of their ideal range (either high or low), deleterious effects start to take place and mortality may occur (Crigger et al., 2005). This is not all due to salinity; however, salinities beyond acceptable ranges may elicit a complex set of reactions, which have an indirect effect on the health and fitness of seagrasses, such as excessive carbon drain due to osmoregulation activities within the plant, and an increased O_2 demand, in order to meet respiratory requirements (Koch et al., 2006). Hydrology, anthropogenic changes to land use, depth of the water, evaporation rates, drought and rain events all affect salinity levels in a given body of water and thus influences the seagrass community comoposition. Climate change will also play a role in the dynamic salinity regimes, as precipitation and drought events become more extreme.

IV. <u>Nutrients</u>

Nutrients are essential for plant growth and productivity. The rates of nutrient uptake are dependent upon two things. First, uptake rates will fluctuate among species as the physiology and age of the plant changes. Second, uptake rates are dependent upon the level of nutrients in the water column and the sediment pore water (Nayar et al., 2012). While nitrogen accounts for only 1 - 4% and phosphorus only 0.1-1.0% of the dry weight tissue of seagrass, they are still the two most growth-limiting nutrients in seagrass

(Duarte, 1990). In general, seasgrasses which grow in sandy or organic sediments tend to be N-limited while seagrasses, which grow in carbonate sediments, tend to be P-limited (Burkholder et al., 2007). Mechanisms for which seagrasss can take up nutrients and the effects of too many or too few nutrients in the water column and sediment pore water will be covered in the next section.

A. Nitrogen Uptake

Seagrasses are capable of assimilating nitrogen through above-ground and below-ground tissues (Lee et al., 2007). One source of organic nitrogen is seagrass leaf litter, as well as the decomposition of other organic matter in the water column (Lee et al., 2007). The main inorganic forms of nitrogen available to seagrasses are NO_3- (nitrate) and NH_4+ (ammonium) in the water column, as well as ammonium in the sediment pores (Lee et al., 2007). The assimilation of nitrate is more energetically costly to the plant because nitrate must be reduced to ammonium in order for the plant to assimilate it. This process depends upon stored carbon in order to breakdown the nitrate into a more useful form, which can lead to declines in carbohydrate levels (Touchette & Burkholder, 2000). Ammonium on the other hand, can be assimilated directly, and therefore is the preferential form of inorganic nitrogen for seagrasses (Lee et al., 2007). Some of the available ammonium is a product of dinitrogen fixation from the surrounding eubacteria and cyanobacteria communities found within the beds (Touchette & Burkholder, 2000). Some studies have shown that a majority of the ammonium and nitrate uptake is through the leaves of the plant, therefore most of the nutrients used come directly from the water column (Touchette & Burkeholder, 2000). Lee et al. (2007) suggests that since seagrass leaves have been exposed to low nutrient contents they may have developed an ability to take up nutrients at very low concentrations, however below ground tissues are capable of assimilating inorganic nitrogen as well if the water concentrations become too low (Touchette & Burkholder, 2000.)

B. Phosphorus Uptake

The main source of phosphorus is PO_4^{3-} (phosphate), which like N, is found in both, the water column and the sediment pore waters (Lee et al., 2007). As with N, phosphate can be absorbed through above- and belowground tissues. Even so, most phosphate uptake is likely via the roots, because PO_4^{3-} has an extremely short residence time in the water column (Burkholder et al., 2007).

One way in which phosphate can become biologically unavailable to the seagrass is through its affinity to form calcium phosphate complexes in water (Burkholder et al., 2007). In addition, epiphytic colonizations can restrict P availability to host plants by blocking access to the water column (Touchette & Burkholder, 2000). Although information on this varies as some studies have shown that the leaves of the plant have a higher uptake affinity than the roots of the plant.

C. Seagrass Response to Eutrophication

It is well documented that seagrasses are N- and P- limited in oligotrophic (i.e., low nutrient) waters, where supplying N and P increased biomass, shoot size and productivity (Lee et al., 2007). Current trends demonstrate increasing nutrient concentrations in the water column (eutrophic condition). Elevated levels of nutrients can have adverse and deleterious effects on seagrass beds and in many cases, can cause mortality. The major cause of eutrophication or cultural eutrophication, is due to increased human habitation of coastal zones and urbanization, leading to nutrient runoff. Sewage and stormwater runoff are two of the major players which contaminate water bodies (Dillon et al., 2008). Farming practices and improper fertilizer application also contribute to this problem. In the St. Lucie estuary, the Indian River Lagoon and the Lake Worth Lagoon, releases from Lake Okeechobee also negatively impact the seagrass beds found within their waters (Crigger et al., 2005 and Lapointe et al., 2012).

One way elevated nutrient concentrations in the water column effect seagrass beds is through stimulation of phytoplankton, epiphyte and macroalgae growth, which can effectively block light from reaching the grass (Lee et al., 2007). Between the years 2009 and 2011, 31,916 acres of seagrass were destroyed in the North Indian River Lagoon, due to a series of harmful algal blooms (HAB's), induced by enriched nutrient loads. (Yarbro & Carlson, 2015). This is just one case of the hundreds documented worldwide. Nutrient excesses can also lead to a buildup of organic matter that may promote sediment anoxia and sulphide toxicity (Cabaco et al. 2013). A third and final way elevated nutrient regimes negatively impact seagrass beds is through direct nutrient toxicity, which has been documented in some seagrass species (Cabaco et al., 2013). These effects have been observed worldwide, but they have been more pronounced in estuaries and embayments with poor flushing, due to reduced tidal action leading to concentrated nutrient loads (Burkholder et al., 2007). Figure 19 shows a conceptual model of increasing nutrients over time and the effects to the biomass of several major primary producer groups. In shallow and deep water systems, as the amount of nutrients increase, there is a slight increase in seagrass biomass, followed by a sharp decline. In shallow water systems, as nutrient concentrations increase, macroalgae biomass begins to rise very rapidly and become the dominant primary producer, while in deep water systems, phytoplankton becomes the dominant primary producer.

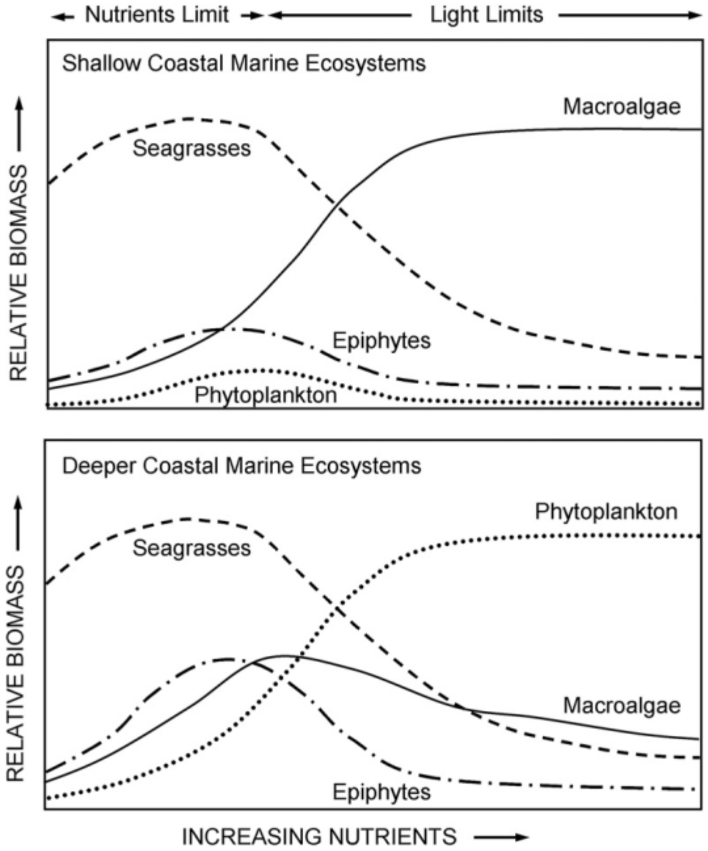

Figure 19. A conceptual model of nutrient enrichment in shallow and deep water systems: (Burkholder et al., 2007).

Nutrient enrichment acts as a positive feedback cycle as it sets in motion a chain of events that negatively impacts seagrass beds. An increase in nutrient loading decreases the plant's photosynthetic capability, which can lead to seagrass die-off. This, in turn, results in a proliferation of barren ground and increases the likelihood of sediment re-suspension in the water column. Sediment resuspension further reduces photosynthesis and also increases nutrient concentrations in the water column, resulting in enhanced growth of macroalgae and phytoplankton communities, which leads to increased rates of respiration and ultimately hypoxia in the water column and anoxia in the sediments (Burkholder et al., 2007). As sediments become anoxic, bacteria and microorganisms in the sediments must rely on alternative electron acceptors, such as sulfate, which can lead to sulfide toxicity to plants (Burkholder et al., 2007). Figure 20 below demonstrates this process graphically.

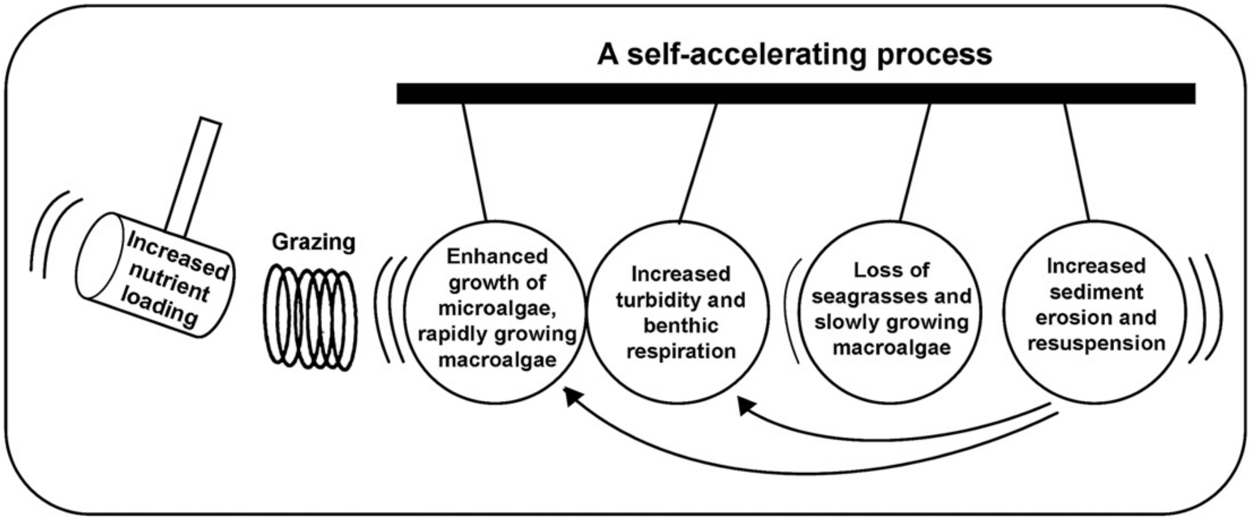

Figure 20. A Graphic Representation of the Effects of Nutrient Enrichment: (Burkholder et al., 2007).

Natural and Anthropogenic Threats to Seagrasses

To review, Florida is home to seven seagrass species. Good water quality is essential for maintaining healthy seagrass beds. Factors that affect water quality include, light availability, temperature, salinity, and nutrient availability. If even one of these factors is negatively impacted, it can lead to positive feedback loops of continued declining water quality, thereby endangering seagrass health.

Any event that reduces water quality is a threat to seagrass beds. These events can be natural disturbances or human induced disturbances. Among natural threats are storm events, such as hurricanes, grazing events by aquatic herbivores, and disease. However, it is quickly becoming clear that anthropogenic or human-induced events, such as dredging, increased run-off, sewage disposal, aquaculture, boating (propeller scarring and grounding), and fishing activities (trawling) are the most prominent causes of seagrass habitat loss. Climate change, agriculture, and the maintenance of non-native commercial and private landscapes have also been identified as indirect anthropogenic causes of seagrass decline.

In an effort to conserve Florida's wildlife, the Florida Fish and Wildlife Commission (FWC) initiated a Statewide Wildlife Action Plan (SWAP) which created a list of threats to various habitats throughout Florida and then ranked these threats as low, medium, high, and very high. These ratings were then converted to a numeric scale of 1 to 4 so that the relative stress to a habitat could be calculated. The stressors numeric values were then summed and habitats were assigned overall values representing the threat level. This metric makes more clear which habitats are most in danger. Final values were influenced by how many individual habitats were affected by the threats and how often they received ratings of 3 and 4. Of the 14 habitat types addressed, Submerged Aquatic Vegetation, which includes seagrass and algae, was considered to be at a high threat level. Thirty individual threats were identified to affect this category, the highest of any habitat type. Table 4 shows the threats and threat levels to various habitats in Florida, as reported by the Florida Department of Environmental Protection (FDEP) FACT 2010 Report (2010). Direct your attention to the column labeled Submerged Aquatic Vegetation to see the specific threats which affect seagrass beds.

Table 4. Threats to Various Habitat Types in Florida: (FDEP “FACT 2010”, 2010)

	Sources of Stress	Habitat Category Stress Levels by Source														Overall Stressor Rating		
		Annelid Reef	Beach/ Surf Zone*	Coastal Strand*	Bivalve Reef	Coastal Tidal Stream	Coral Reef	Inlet	Mangrove Swamp	Hard bottom	Pelagic	Salt Marsh	Submerged Aquatic Vegetation	Subtidal Unconsolidated Sediment	Tidal Flat	Number of Habitats Affected	Percentage of Habitats Rated 3/4	Average Stressor Rating (all Habitats)
1	Coastal development	3	4	4	3	4	4	3	4	0	0	4	4	3	4	12	100%	3.67
2	Mining and drilling	0	4	0	0	3	3	0	0	0	0	0	0	0	0	3	100%	3.33
6	Dams/Release of water	2	3	0	3	4	3	3	3	2	0	3	3	3	3	12	83%	2.92
8	Dredging channels/shipping	3	3	2	3	4	3	3	3	3	1	3	4	2	2	14	71%	2.79
5	Light pollution	0	3	3	0	0	0	3	0	0	0	0	0	0	0	3	100%	3.00
4	Parasites/pathogens	0	0	0	0	0	4	0	3	3	0	0	2	0	0	4	75%	3.00
3	Climate change	3	4	3	0	3	4	0	3	2	0	3	3	0	2	10	60%	3.00
7	Stormwater management	1	2	0	4	4	4	2	2	2	3	3	4	3	3	13	62%	2.85
9	Harmful algal blooms	0	3	0	3	0	3	2	3	2	3	0	4	0	2	9	67%	2.78
10	Shoreline hardening	1	3	4	0	4	3	3	3	2	0	2	3	0	2	11	64%	2.73
11	Roads, bridges, causeways	0	4	3	3	2	3	2	3	1	0	3	3	2	3	12	67%	2.67
12	Disrupting sediment	2	3	0	0	0	2	3	0	3	0	3	3	0	2	8	63%	2.63
13	Beach nourishment	3	3	2	3	3	3	3	2	2	0	3	2	2	3	13	62%	2.62
14	Invasive plants	0	3	2	0	3	3	2	3	2	0	2	3	0	0	9	56%	2.56
15	Nutrient loads (all sources)	0	3	1	3	3	4	0	3	0	2	0	3	1	0	9	67%	2.56
16	Chemicals & toxins	0	2	0	0	3	3	0	3	2	0	2	2	3	3	9	56%	2.56
17	Industrial operations	3	3	0	1	3	2	2	3	2	1	3	3	3	4	13	62%	2.54
18	Invasive animals	0	3	2	3	3	0	2	3	2	2	0	3	1	3	11	55%	2.45
19	Recreational activities	1	4	3	1	2	2	3	2	0	0	0	4	2	3	11	45%	2.45
20	Surface water withdrawal	0	0	0	3	3	0	2	2	0	0	3	3	1	2	8	50%	2.38
21	Losses of keystone species	0	3	1	0	0	3	0	0	2	3	0	2	0	0	6	50%	2.33
22	Large industrial spills	0	2	0	0	3	2	2	2	0	0	2	2	0	3	8	25%	2.25
23	Groundwater withdrawal	0	0	0	0	2	0	0	2	0	0	0	3	0	2	4	25%	2.25
24	Fishing pressure	0	2	0	1	2	4	2	2	2	2	0	3	0	0	9	11%	2.22
25	Vessel/Boating impacts	1	2	0	1	2	3	3	2	2	1	2	4	1	2	13	23%	2.00
26	Aquaculture operations	0	2	0	0	0	0	0	3	0	1	0	2	0	0	4	25%	2.00
27	Noise pollution	0	2	0	0	2	0	2	3	0	1	0	0	0	0	5	20%	2.00
28	Utility corridors	2	2	0	0	2	2	2	2	1	0	2	2	0	0	9	0%	1.89
29	Fish & Wildlife mgmt.	0	2	1	1	0	0	0	3	2	1	3	0	0	0	7	29%	1.86
30	Fishing gear impacts	1	2	0	0	2	3	2	2	2	1	0	2	2	1	11	9%	1.82
31	Solid waste	0	2	0	0	2	2	0	2	2	0	0	1	1	2	8	0%	1.75
32	Aquarium trade	0	1	0	0	0	3	0	0	1	0	0	2	0	0	4	25%	1.75
33	Thermal pollution	0	0	0	0	2	0	0	2	0	0	0	2	1	0	4	0%	1.75
34	Military activities	0	0	2	0	0	2	2	0	0	0	1	0	0	0	4	0%	1.75
35	Placement of artifical reefs	1	0	0	0	0	2	0	2	2	1	1	2	0	0	7	0%	1.57
	Number of Stressors	14	29	14	15	25	27	22	29	23	14	19	30	16	20	**AVERAGE & SD**		2.42
	Overall Habitat Rating	1.93	2.72	2.36	2.40	2.80	2.93	2.41	2.59	2.00	1.64	2.53	2.77	1.94	2.55	2.40	0.38	0.50

Management and Protection Policies

The need for protection and preservation of these highly productive ecosystems is paramount. The Federal and State government recognized this need and created programs in order to work toward this goal. Several programs have been established, such as the Surface Water Improvement Act (SWIM). Established in 1987, the SWIM goal is to manage critical water bodies at a level “that provides aesthetic and recreational pleasure for the people of the State; that provides habitat for native plants, fish, and wildlife, including threatened or endangered species; and that attracts visitors and accrues other economic benefits.”(U.S. Fish and Wildlife Service, 2014). In addition, the National Estuary Program (NEP) was established under the Water Quality Act of 1987, with goals of enhancing coastal resources through improved water quality (U.S. Fish and Wildlife Service, 2014). In the 1960’s Florida started to create aquatic preserves aimed to protect submerged aquatic vegetation throughout the state. Another program put in place is the Coastal Zone Management Program (CZM). This program is a unique partnering of coastal state governments and the Federal government with similar goals of protecting coastal resources through proper planning and management. (U.S. Fish and Wildlife Service, 2014). The National Estuarine Research Reserves (NERRS) is another program that protects lands through preservation and publich education. Carried out by the National Oceanic and Atmospheric Administration (NOAA) this program seeks to protect the spectrum of estuaries across the United States and manages them to maintain their natural beauty. (U.S. Fish and Wildlife Service, 2014). Together, these programs help to raise awareness and maintain this precious resource.

Conclusions

On a national scale, the inherent value of these ecosystems is overwhelmingly important. Their functioning as nurseries for commercially-important fish, their protection of the shoreline by anchoring sediments, and their function as a carbon sink, make this habitat irreplaceable. While there have been some steps taken to protect this natural resource, more needs to be done. Increased turbidity, lower salinities, higher temperatures and higher nutrient loads are all cause for concern and need to be the focus for coastal zone land managers, as we move into the future. The economic and biological benefit of this resource speaks for itself. Florida cannot afford to lose these productive ecosystems.

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