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An Evaluation of the Seagrass Habitat in North Biscayne Bay, Florida, in Relation to a Changing Environment and Urbanization in the Port of Miami Harbor Basin 2005-2011

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HALMOS COLLEGE OF NATURAL SCIENCES AND
OCEANOGRAPHIY

An Evaluation of the Seagrass Habitat in North Biscayne Bay, Florida, in Relation to a Changing Environment and Urbanization in the Port of Miami Harbor Basin 2005-2011.

By

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Abstract

Seagrass habitats in South Florida are exceptionally valuable. They play an important ecological role in the coastal environment by stabilizing sediment, providing habitat for other species and supporting a whole food web. The availability of light and nutrients in aquatic ecosystems are the driving factors behind seagrass distribution. Water quality has been known to influence the abundance, distribution and composition of seagrass beds. South Florida has extensive diverse coastal communities. Throughout its human development dramatic changes have occurred in its natural ecosystems. In South Florida, many examples of seagrass habitat loss are documented, with a variety of contributing factors. The present research investigates the spatial and temporal patterns in benthic vegetation of the North Biscayne Bay marine basin, located just south of the heavily urbanized Port of Miami. The area has been altered significantly through dredging projects to widen and deepen the channels around the port facilities in order to accommodate larger vessels. This study focuses primarily on environmental and physical conditions that are likely to alter the distribution of seagrass. The availability of light and nutrients in aquatic ecosystems are the driving factors behind seagrass distribution and therefore one may expect seagrass degradation if any drastic changes occurred in these parameters.

Project data used were collected from the South Florida Fish and Invertebrate Assessment Network project (FIAN), an element of the greater Everglades Restoration Program. Additional Environmental and physical data were obtained from the South Florida Water Management District (SFWMD) and the National Ocean and Atmospheric Administration (NOAA). The FIAN Port of Miami (POM) study location is dominated by three species of seagrass: *Thalassia testudinum*, *Syringodium filiforme*, and *Halodule wrightii*. Analysis has shown that over the seven-year period, 2005 - 2011 the state of the seagrass has been fairly stable with minor perturbances ($p > 0.05$). There are some seasonal fluctuations evident in seagrass cover-densities, but minimal change was observed between the spring and fall ($p > 0.05$). *Syringodium* is the dominant species, followed by *Thalassia* and *Halodule* within the POM. Environmental and physical conditions from FIAN (salinity, temperature, sediment depth, turbidity, etc.) varied between years and seasons; however, most measurements remained in the ideal range for seagrass growth. Water depth, sediment depth, and turbidity were significant predictors of seagrass occurrence in the POM; however, water depth was the only major predictor of seagrass cover-density. The available environmental and physical data from the SFWMD showed minimal changes in the environmental and physical measurements across available sample years and are in the ideal range for seagrass. Turbidity has improved since the completion of the port construction and major weather disturbances (hurricanes) in 2005. Minimal changes were detected during the seven year study period (2005-2011) within the seagrass habitat of the heavily urbanized region of POM.

Keywords: FIAN, SFWMD, NOAA, Deep Dredge, Panama Canal, environmental, physical, natural, anthropogenic

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1.0 Introduction

Coastal communities have some of the densest human populations and are more vulnerable to environmental impacts. South Florida is home to a rising coastal population and has many valuable natural resources, including the seagrass communities. Human population expansion and the increasing anthropogenic inputs to the coastal waters are perceived as the dominant cause of the world-wide decline in seagrasses habitat (Short and Wyllie-Echeverria 1996). Major epicenters for seagrass loss are adjacent to areas of dense human populations and most of the declines appear to be related to human activities, many of which impact the light available for plant photosynthesis (Kemp 2000). The habitat that remains reflects the influence of the surrounding urban environment.

Anthropogenic seagrass losses have been attributed to many direct and indirect causes. Most such losses result from human activities that increase inputs of nutrients and sediment into the coastal zone (Short and Wyllie-Echeverria 1996), reducing water clarity. Coastal development involving dredge-and-fill activities can impact seagrass meadows in two ways: through direct physical impact (e.g. removing the plants and the underlying sediments or by killing the plants by covering them with a thick layer of fill material) or through indirect effect (e.g. reduced water clarity by increased turbidity) (Lewis 1977; Janicki et al. 1995; Yates et al. 2011). Despite the recognition of seagrass beds as some of the world’s most productive and valuable ecosystems, anthropogenic losses of these habitats continue at an alarming rate (Short and Wyllie-Echeverria 1996). Over the past century, anthropogenic and natural disturbances have dramatically influenced the coasts in Miami, Florida. The amount of seagrass habitat that remains is dependent on stable environmental and physical conditions for growth; however, with construction activities for human expansion in the Port of Miami (POM) and the threat of extreme weather events, the potential for seagrass habitat loss exists.

1.1 Seagrass Natural History

Seagrasses are a mixed group of clonal flowering plants which grow submerged in shallow marine and estuarine environments, exhibiting a low taxonomic diversity with about 60 species worldwide (Green and Short 2003; Peterson and Fourqurean 2001). Seagrasses are not true grasses and are more closely related to lilies but they appear grass-like with shoots of three to five leaf blades attached to a horizontal stem and thick roots and rhizomes that allow them to anchor themselves into the bottom sediment (McKenzie 2008). They come in a variety of shapes and sizes depending on species, but both the leaves and stems of seagrasses contain air channels for transport of water, food and absorption of gases (McKenzie 2008). The strong root structure allows seagrasses to withstand strong currents and waves, especially during storm events (GMP 2004). The structure of these plants, as well as the height of the canopy and the extent of the meadow, is influenced by a number of ecological factors (Björk et al. 2008).

Seagrasses can reproduce both sexually and asexually (Ewanchuk and Williams, 1996). Most seagrass stands begin as seedlings that spread through vegetative rhizome expansion and new shoot production until they form clonal patches, beds and, eventually, meadows (Björk et al. 2008). The life span of seagrass modules is scaled to their size, with small species having short leaf life spans and larger species having longer leaf life spans (Hemminga and Duarte 2000). Seagrasses continually produce new leaves, roots and rhizomes, leaving the old plant material to enter the detrital food web (Björk et al. 2008). This steady-state condition can be maintained over long periods, leading to long-lived seagrass meadows (Hemminga and Duarte 2000).

1.1.2 Environmental Constraints for Seagrasses

Seagrasses are able to tolerate a wide range of climates (GMP 2004) and are present in all U.S. coastal states, with the exception of Georgia and South Carolina, where a combination of freshwater inflows, high turbidity, and large tidal amplitude restricts their occurrence (Thayer et al. 1997). Many environmental variables influence the growth and survival of each seagrass species. The consensus among studies revealed that light, depth, sediment characteristics salinity, temperature, and nutrient concentrations were among the most important variables that produced a response in a measured seagrass indicator (Kirkman 1996, Dennison et al.1993; Livingston et al. 1998; Koch 2001, and Fourqurean et al. 2003; Wilson and Dunton 2012**)**. The various combinations of these parameters will permit, encourage or eliminate seagrass from a specific location (McKenzie 2008).

Light is a critical factor controlling seagrass productivity and spatial distribution because the amount of light that reaches the submerged plants dictates the daily growth and seasonal productivity (Björk et al. 2008). Light requirements are greater for seagrasses (Duarte 1995) because of their extensive below-ground roots and rhizomes that they must support (Duarte 199l**)**. Limited light can stress the plants and result in a reduction of below-ground biomass, reduced carbohydrate content of rhizomes, loss of tissue nutrients and other growth issues (Coles and McKenzie 2004). Water depth and turbidity (the amount of suspended particles in the water) are major factors influencing the amount of light available to seagrasses. Turbidity measures water clarity and expresses the degree to which light is scattered and absorbed by molecules and particles suspended in the water (Radke et al. 2003). Increased turbidity and lowered light transmission can adversely impact an ecosystem, limiting the distribution and depth at which species can grow (Abal and Dennison 1996). Suspended sediment that causes turbidity can precipitate and accumulate and smother communities. The depth distribution of seagrasses is largely determined by light penetration, restricting their range to depths less than 70 m (Short et al. 2007), although some species have been reported at a maximum of 90 m (Hemminga and Duarte 2000). In areas near large river discharges or in areas of development, seagrass depth limits are reduced by significant light attenuation (Björk et al. 2008). Distribution may even be limited in some shallow water habitats due to cloudiness and low irradiances levels (Björk et al. 2008). In more turbid waters, seagrasses may produce elongated leaves so that they can reach the light closer to the surface and may form less dense canopies in order to avoid self-shading (Short et al. 1995; Collier et al. 2008). Seagrass species are mostly confined to sandy or muddy sediment where their roots can penetrate (Hemminga and Duarte 2000) and their placement and development has also been found to correlate with sediment depth (Zieman et al 1989; Hall et al. 1999). Colonizing seagrasses (e.g., *Halodule*) are better suited to mobile sediments than some of the larger species (McKenzie 2008).

Each species of seagrass can tolerate different ranges of salinity. In general seagrasses can survive a range of salinities from 5-60 ‰ (parts per thousand, ppt equivalent to practical salinity units, PSU) (McMillan and Moseley 1967, Walker 1989), with some species having the ability to tolerate both lower and higher salinities ranging from 0 -140 ‰ (Björk et al. 2008). Water temperature can also influence the health and growth rate of seagrasses (McKenzie 2008). Temperature tolerances vary widely for individual species, but seagrasses have been found to withstand temperatures as low as -6 °C (Eelgrass in Alaska is known to tolerate encasement in ice during winter) and brief readings as high as 40.5 °C (Phillips and Meñez 1988). Temperature also controls the pH and the dissolved carbon dioxide (CO2) in the water column, which can influence seagrass growth.

Seagrasses require nutrients such as inorganic carbon (C), nitrogen (N) and phosphorus (P) for growth (McKenzie 2008). Coastal waterways obtain nutrients from terrestrial, atmospheric and oceanic sources, but human activities often enrich the waters too much (McClelland and Valiela 1998). High nitrate and ammonium concentrations in the water column may also limit seagrass growth (Burkholder et al. 1992; Van Katwijk et al. 1997). A compilation of data on the nutrient environment of seagrass meadows world-wide shows that in seagrass beds the average water column has an ammonium concentration of 3.1 uM, a nitrate concentration of 2.7 uM, and an average phosphate concentration of 0.35 uM (Hemminga 1998). High levels of chlorophyll-a in a system often indicate turbid, poor water clarity with low levels suggesting higher water clarity and good conditions for seagrass (McPherson and Miller 1994; Tomasko et al. 2001). Too high nutrient levels in the water column can cause excessive algal growth and organic matter loading to the bottom waters, which in turn can cause an increase in bacterial decomposition of the organic matter and consume oxygen, depleting the water column of dissolved oxygen (DO) (Clement et al. 2001) and potentially creating hypoxic and anoxic conditions (Hypoxia = DO < 2 mg/L, and anoxia = DO < 0.1 mg/L) (Vitousek et al. 1997). These conditions can cause negative impacts to aquatic life ranging from mortality to chronic impairment of growth and reproduction (USEPA 2001). In estuaries and coastal waters, low DO is one of the most widely reported consequences of nitrogen and phosphorus pollution and one of the best predictors of a range of biotic impairments (Bricker et al. 2003).

1.1.3 Natural Impacts to Seagrasses

Natural changes in weather patterns and storm events cause mixing in the water column and can increase the amount of nutrient input into an ecosystem. Seasonal changes in the environment can alter the amount of light penetration and other habitat conditions that influence the growth of seagrass. Seasonal changes in temperature affect the capacity of water to hold DO, with colder waters having the ability to hold more DO than warm waters (US EPA 2006). Solar heating can cause layering, with the dramatically warmer surface layer becoming isolated from the colder bottom layer (US EPA 2006). Stratification in salinity often results from colder denser salt water intruding at depth, while warmer less dense fresh water sits at the surface. However, storms, tides, and wind can cause mixing and eliminate the layering caused by salinity and temperature differences (US EPA 2006). Gradual changes that come with seasonality allow organisms to acclimate, whereas rapid shifts may cause shock and adversely affect their distribution and abundance (US EPA 2006).

Over the next century, the predicted changes in global climate will alter many of the factors that shape the coastal ecosystem of South Florida (RECOVER 2014). Climate change could cause sea level rise, increases in temperature, changes in precipitation patterns, and changes in the intensity and/or frequency of extreme events (ICLEI 2010). This could lead to a rapid loss and substantial changes to the benthic communities along the coasts (Wanless et al. 1994). Studies done by the Organization for Economic Cooperation and Development (OECD) identified Miami–Dade as the county with the highest amount of vulnerable assets exposed to potential coastal flooding, with costs projected at around $3.5 trillion (Nicholls et al. 2007). As the climate changes, the composition and distribution of biota that occur in the coastal ecosystem will shift (Scavia et al. 2002).

1.1.4 Anthropogenic Impacts to Seagrasses

Anthropogenic seagrass losses have been attributed to many direct and indirect causes, with most such losses resulting from human activities that increase inputs of nutrients and sediment into the coastal zone (Short and Wyllie-Echeverria 1996), thereby reducing water clarity. Although dredging and filling activities are strictly regulated, localized turbidity impacts can occur in connection with dredging, coastal construction, or vessel traffic (Hefty et al. 2001). The resuspension of sediments and the introduction of nutrients from runoff and pollutants from damaged structures (e.g. landfills, water treatment plants and ports/marinas) can affect the water quality (Tilmant et al. 1994; Davis et al. 2004). Physical damage can also occur from vessel groundings and scarring of the bottom with propellers. Direct and indirect impacts to the seagrasses in Florida have been attributed mainly to increased urbanization and coastal development, which in turn have brought about sewage pollution, eutrophication, sedimentation and destructive motor vessel activity (Littler et al. 1989; Sargent et al. 1995; Hall et al. 1999; Carruthers et al. pers. comm. 2007; Short et al. 2010b; Short et al. 2010c; BBAP 2012). The major consequence of all these activities is reduced water clarity and quality as well as physical destruction of habitat. Decreases in seagrass populations reported in Florida Bay were mostly attributed to environmental change (e.g. changes in water clarity, light attenuation and salinity) and anthropogenic-induced damage to the habitat with the introduction of pollutants, coastal development and motor vessel damage (Littler et al. 1989; Sargent et al. 1995; Hall et al. 1999).

1.1.5 Ecological Role and Economic Importance of Seagrasses

Seagrasses are keystone components of coastal ecosystems throughout the world where they contribute to productivity, carbon budget, and sediment stability, as well as provide essential habitat to a large number of associated organisms (Zieman 1972; Davis and Dodrill 1989; Holmquist et al. 1989; Thayer et al. 1997; Walker et al. 2001; Fourqurean et al. 2002; Lirman and Cropper 2003; Lirman et al. 2008). With the many physical, chemical and biological services they offer, seagrasses are essential to the marine environment. The structural components of seagrass leaves, rhizomes, and roots modify currents and waves, trapping and storing both sediments and nutrients, and effectively filtering nutrient inputs to the coastal ocean (Hemminga and Duarte 2000). They protect the coast from erosion by trapping and stabilizing the marine sediments, raising the sea floor at rates of around 0.04 inch per year (Duarte et al. 2007). These habitats act as nutrient sinks and play a significant role in global carbon and nutrient cycling (Hemminga and Duarte 2000). Blue carbon is the carbon captured by living organisms in the oceans and represents more than 55% of the green carbon (Nellemann et. al 2009). This carbon is stored in the form of sediments from mangroves, salt marshes and seagrasses (Nellemann et. al 2009). Seagrasses cover less than 0.5% of the entire seafloor and are responsible for capturing and storing up to some 70% of the carbon permanently stored in the marine realm (Nellemann et. al 2009). Current studies suggest that mangroves and coastal wetlands trap carbon at an annual rate two to four times greater than mature tropical forests and store three to five times more carbon per equivalent area than tropical forests mainly due to the fact that the blue carbon is stored in the soil, not in above-ground plant materials (Murray et al. 2011). The carbon from these habitats can remain stored for millennia, rather than decades or centuries as with terrestrial plants (Nellemann et. al 2009).

The seagrass habitats help support the thriving, multimillion-dollar recreational fishery industry (Dawes et al. 2004). Nearly all of the commercially and recreationally valuable estuarine marine animals depend on seagrasses for parts or all of their life cycles (Kikuchi and Peres 1977; Thayer et al. 1978; Kikuchi 1980; Ogden 1980; Thayer and Ustach 1981; Phillips 1984). In 1997, the economic value of global seagrass habitats was estimated at $19,004 per hectare per year, generating an annual value of $3.8 trillion. However, this value did not include fisheries, climate regulation, habitat, recreational and cultural values, or erosion control (Costanza et al. 1997; Unsworth and Cullen-Unsworth 2010). Seagrasses are a highly significant part of the Florida coastal economy and provide millions of acres of habitat, supporting both commercially and recreationally important fisheries species and bring in millions of dollars annually from out-of-state and resident recreational boaters and fishermen (Bell 1993; Milon and Thunberg 1993; Virnstein and Morris 1996; Virnstein 1999; Wingrove 1999; Thomas and Stratis 2001). In Florida, more than 70% of recreational and commercially important fish, shellfish and crustacean species spend part of their lives in seagrass beds (FFWCC 2003). In 2000, FDEP estimated that each acre of seagrass in Florida had an economic value of approximately $20,500 per year, creating a statewide economic benefit of 55.4 billion dollars annually (Hill 2002). In 2010, an estimated $5 million of commercial harvest came from crab, shrimp, lobster, and fish species that were supported by seagrass communities in Miami-Dade County (Sweeney 2011). Protecting the species targeted by commercial fisheries and the habitats on which these species depend helps to ensure both a productive ecosystem and economy (BBAP 2012).

1.2 South Florida Seagrass Species

Seven species of seagrasses are commonly found in southern Florida waters: *Thalassia testudinum* (turtle grass), *Syringodium filiforme* (manatee grass), *Halodule wrightii* (shoal grass), *Halophila decipiens* (paddle grass), *Halophila engelmannii* (star grass), *Halophila johnsonii* (Johnson's seagrass), and *Ruppia maritima* (widgeon grass) (Figure 1) (Sweeney 2011; Fourqurean et al. 2002; Hemminga and Duarte 2000; Sargent et al. 1995; Eiseman and McMillan 1980). *Thalassia testudinum, S. filiforme,* and *H. wrightii* each have a tropical to subtropical distribution and are the three most abundant species of seagrasses found in Florida's near-shore waters (Zieman and Zeiman 1989). Sixty percent of Biscayne Bay bottom substrate is thought to be covered by *T. testudinum, S. filiforme,* and *H. wrightii*, leaving the rest of the substrate bare sand or hard bottom (Browder et al. 2005; Lirman and Cropper, 2003). Given the occurrence of these three seagrasses in South Florida, they are the primary focus of this study; however, other species will be discussed.

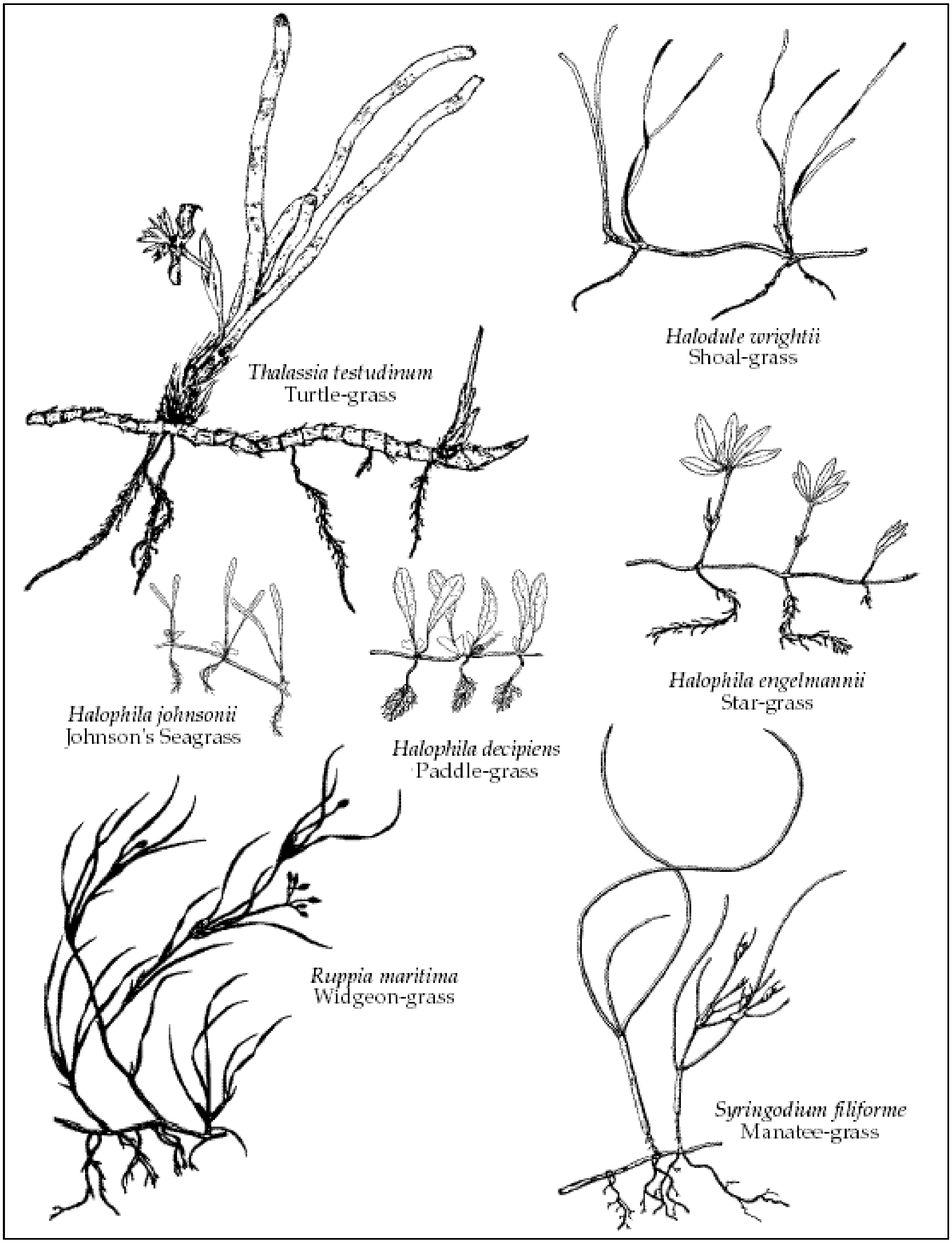

Figure 1. Seagrass species occurring in Florida (from Sargent et al. 1995, based on drawings by Mark D. Moffler).

1.2.1 *Thalassia testudinum*

The seagrass *Thalassia testudinum,* commonly known as turtle grass, is the most abundant and thought to be one of the most important habitat-forming seagrass species in Florida because it creates extensive dense grass beds (Short et al. 2010d). It gets its name from the endangered Green Sea Turtle which depends on the grass for its diet (GMP 2004; Short et al. 2010d). It has the largest and most complex rhizome and root systems and is distinguished by its deep-green broad ribbon like leaves (Whitfield et al. 2004; GMP 2004). The blades are normally over 1 cm wide and range from 10 to 75 cm long (Phillips and Meñez 1988; Fonseca 1994; GMP 2004). It grows in dense, extensive stands, creating expansive meadows, and generally prefers mud or sand substrate for colonization. Their thick rhizomes can be found penetrating to depths of 20 cm below the surface (Phillips and Meñez 1988; Fonseca 1994; GMP 2004; Short et al. 2010d). It can be long-lived and is extremely resilient to storms and disturbances; however, it has very slow rhizome expansion rates which can slow the regrowth process of this species following a disturbance event (Whitfield et al. 2004). Individual shoots of the plant have been found to live for over 10 years, enduring seasonal temperature changes and powerful tropical storms (Phillips and Meñez 1988; Fonseca, 1994; GMP 2004).

From the two methods of plant increase and dispersal used by *T. testudinum,* sexual reproduction was found to be secondary to rhizome elongation and clonal growth (Phillips 1960; Zieman 1972; Les 1988; Gallegos et al. 1993; Schlueter and Guttman 1998). *Thalassia testudinum* plays an important role in sediment production and is very important in the prevention of coastal erosion (Zieman 1982; UNESCO 1998; Hemminga and Duarte 2000; Green and Short 2003; Larkum et al. 2006). It can be found in low density in oligotrophic areas (low nutrients) and is replaced by other species when there are continuous high nutrient inputs (Fourqurean and Rutten 2004). Because *T. testudinum* is a major habitat-forming species that cannot be replaced functionally by another species, it is suggested that its available habitat should be closely monitored (Van Tussenbroek et al. 2006; Short et al. 2010c).

1.2.2 *Syringodium filiforme*

Syringodium filiforme, manatee grass, is common, locally dominant seagrass and a major habitat forming species that occurs in the western tropical Atlantic from Florida (USA) to Venezuela, including the Gulf of Mexico and the Caribbean Sea, as well as Bermuda (Short et al. 2010c). Manatee grass is an important food source for many marine animals including manatees (Zieman 1982), and is named after the endangered marine mammals. It is distinguished by its cylindrical leaf blades which are approximately 1-3 mm wide and ranging from 10 to 40 cm in length (Phillips and Meñez 1988; Littler et al. 1989; Fonseca 1994; GMP 2004). The blades are flexible and are able to withstand high current velocities (Littler et al. 1989), but are also very brittle and broken pieces are often found floating in large rafts along the coast after a storm event (Phillips 1960). The leaf length is affected by the depth of the water and the overall leaf length was found to be greater in deeper waters (Phillips 1960). This species creates a shallow but dense rhizome matrix and has a tall, dense leaf canopy, which makes this grass an ideal nursery for many other species (Sargent et al. 1995). The elongated blades from these plants can trap suspended particulates in the water column, increasing water clarity and improving the quality of the water by incorporating pollutants into their biomass and the surrounding sediments (Sargent et al. 1995).

In South Florida *S. filiforme* is a major habit forming species and is often found growing together with *T. testudinum* and *H. wrightii* (Green and Short 2003; Short et al. 2010c), but can also form large monospecific stands down to 18 m (Phillips and Meñez 1988; Fonseca 1994; GMP 2004). Rhizome elongation and new branch production are primarily responsible for the dispersion of this species (Phillips 1960). The flowering of *S. filiforme* plants in Florida is actually very rare, so it is assumed that for the most part it does not use sexual reproduction in this region (Phillips 1960). Rhizomes have been reported to extend into the water column, presumably using this as a means of reproduction (Phillips and Meñez 1988; Fonseca 1994; GMP 2004).

1.2.3 *Halodule wrightii*

Halodule wrightii, commonly known as shoal grass, is a seagrass species with a disjoint global and predominantly tropical distribution, with the main part of its range in the Atlantic Ocean and others found in the eastern tropical Pacific and the Indian Ocean (Short et al. 2010b). It has fine blades with a bidentate tip (Phillips 2006). The blades grow to between 5 and 40 cm in length and their width can range from 1 to 3 mm (Phillips and Meñez 1988; Fonseca 1994; GMP 2004). Large continuous meadows are predominant on shallow shoals and flats, with the grass often exposed at times of low tide (Phillips and Meñez 1988; Fonseca 1994; GMP 2004).

Halodule wrightii is a common species in Florida and usually found mixed with other seagrass species (like *T. testudinum* and *S. filiforme*) (Short et al. 2010b). It is fast growing and has a high turnover rate (Sargent et al. 1995; Short et al. 2010b). Shoal grass is highly tolerant to a range of environmental conditions and is considered a pioneer species that can replace less tolerant species under conditions of habitat deterioration, eutrophication, and increased turbidity (Short et al. 2010b). It is usually an early colonizing species but studies in Florida Bay show that with increased nutrient levels, it can become the dominant species locally as it is able to out-compete *T. testudinum* for light resources (Fourqurean et al. 1995).

1.2.4 *Halophila species*

Three species of *Halophila* have been recorded in South Florida waters; *H. decipiens, H. engelmannii*, and *H. johnsonii*. *Halophila* seagrasses are generally restricted to low light environments such as deeper water, under docks, as an understory plant and in shallow turbid waters (Fourqurean et al. 2002). These three species are able to tolerate a wide range of conditions such as low light intensities and higher levels of turbidity , which allows them to thrive in environments which are not suitable for other seagrass species (Fourqurean et al. 2002; GMP 2004; Short et al. 2010a). These plants are relatively small, just a few cm in height, with shallow root structures that are easily dislodged. *Halophila* are also known as pioneer species and are one of the first species to settle on disturbed sites and available substrate.

1.2.5 *Ruppia*

The final species of seagrass found in Florida is *Ruppia maritima*, or widegeon grass. Fourqurean et al. (2002) found that *R. maritima* was restricted to areas closer to freshwater sources. This species is found to have a high tolerance for low and variable salinity so they are more prevalent in areas with canal discharges (Lirman et al. 2008).

1.3 Algae: Benthic and Epiphytic

Associated with seagrass beds are characteristic benthic and epiphytic algae, which attach themselves to sediments, rocky outcroppings, and the seagrasses themselves (FMNH 2015). Algae are important to consider because they may contribute significantly to the structure and function of the seagrass community (Heijs 1987, Verheij and Erftemeijer 1993, Jupp et al. 1996, Sidik et al. 2001). Typical (common) benthic macroalgae observed in Florida include several species of Red algae (*Rhodophyta*), Green algae (*Chlorophyta*), and Brown algae (*Phaeophyta*). There are also several types of Calcareous-green algae (*Calcareous-Rhodophyta*) that produce calcium carbonate, which eventually becomes incorporated into the surrounding sediments (FMNH 2015). Seagrasses provide sufficient surface area on which hundreds of species of epiphytic algae could attach. The epiphytes cover the tips of the seagrass blades, rather than the bases, in order to receive more sunlight for photosynthesis, subsequently reducing seagrass growth as a result of shading. Eventually the epiphytes will become part of the detritus, along with the seagrass blades as they break off and decompose (FMNH 2015). Research on drift algae-epiphyte-seagrass interactions suggest that temporary, moderate cover of macroalgae may benefit seagrass by reducing epiphyte loads if the epiphyte cover negatively impacts the seagrass (Irlandi et al. 2004). While a moderate amount of nutrient input may increase seagrass growth, dramatic or prolonged increases in available nutrients can be harmful, creating excessive epiphyte growth and algae blooms that result in reduced light availability to the seagrasses (FMNH 2015).

Algae blooms are controlled by physical, chemical, and biological factors (Brush and Nixon 2010). Bloom events are considered an indicator of degraded conditions in an area, and these events can highlight how sensitive a system is to both human and natural disturbances (RECOVER 2014). According to Qiuying and Dongyan (2014), seagrass decline caused by algae blooms is becoming a more common phenomenon in the temperate and tropical regions across the world, through direct and indirect impacts. Competition for living space and resources are the most direct impacts associated with algae blooms, while the result of the bloom (e.g., light reduction, hypoxia, and decomposition) can lead to significant indirect impacts on the seagrass beds (Qiuying and Dongyan 2014). Short-term disturbances from algae blooms are tolerable because the seagrass beds can usually recover, but long-term events can lead to a significant decrease in seagrass biomass (Qiuying and Dongyan 2014).

1.4 Study Site: Port of Miami, North Biscayne Bay, FL

1.4.1 Physical Environment

The Port of Miami (POM) is the southernmost major port on the Atlantic Coast of the USA (USACE 2004). It is an island facility (NOAA 2012) situated on 520-acres of land mass that was created through beneficial reuse from the combination of the three manmade spoil disposal islands (Dodge, Lummus and Sam's Islands) within the Northern portion of Biscayne Bay in South Florida (CDMP 2011). The North Bay extends from the Broward/Miami-Dade County line, south to the Rickenbacker Causeway (Corcoran et al. 1984; Hale 1993) and only represents about 10% of the entire bay area (Ecosummary Biscayne Bay 2002). The POM is located in the southernmost portion of this region (see Figure 2). The POM basin is bounded to the north by the Fisherman’s Channel adjacent to the busy commercial shipping harbor of Port of Miami, to the west by the most densely populated area of the state, the City of Miami, including the Miami River, to the east by Miami Beach and Fisher Island, and to the south by the Rickenbacker Causeway (CDMP 2011; Caccia and Boyer 2005; Ecosummary Biscayne Bay 2002). Channels and turning basins adjacent to the port provide ship access to the cargo-handling and cruise passenger facilities. The vessels enter and exit through the Government Cut Channel, which is federally maintained. The channel branches at the Fisher Island Turning Basin to run along the north (Main Ship Channel) and south (Fisherman’s Channel) sides of the port (CDMP 2011) (Figure 3). Land surrounding the Port of Miami is essentially fully developed, except for Virginia Key, and the diverse terrestrial and marine habitats in the area include beaches, mangroves, seagrass beds, hardbottom and reef communities, rock/rubble bottom, and unvegetated bottom (USACE 2004).

Water depth in the basin is generally shallow, except for the channel leading into the port which measured around 500 ft wide and 42 ft deep before new dredging began in 2013. The bay bottom is characterized in most areas by a thin layer of sand and mud sediment less than six inches (15.2 cm) in depth (USACE 2004), but near Miami Beach, sediment thickness is increased up to 40 in (101.6 cm) (USACE 2004). The tidal range in the bay is relatively small, approximately one meter, with salinities ranging from 30 to 40 ‰ (McNulty et al. 1962) and annual water temperature fluctuations ranging from 18 to 31°C (McNulty et al. 1962; Maciá 2000). Salinity within the bay is influenced by precipitation, freshwater inputs from land, canal, and groundwater sources, and tidal influx of oceanic water (Alleman et al. 1995; Wang et al. 2003; Lirman and Cropper 2003; Lirman et al. 2008). Because it is a shallow water lagoon, the bay experiences sudden changes in salinities throughout the year from both natural and anthropogenic factors (Serafy et al. 2003; Lirman et al. 2008).

The natural weather patterns in South Florida determine the amount of rainfall over the year. There are two distinct seasons, the dry and wet season represented by spring and fall collections, respectively. The dry season, December through May, has milder air and water temperatures and significantly lower precipitation typically resulting from frontal passages (Sutula et al. 2003; Tabb et al. 1962). The wet season lasts from May through November, during which time there is an increased amount of rainfall from frequent tropical storms and thunderstorms (Sutula et al. 2003). The wet season is also characterized by the hurricane season; the passage of hurricanes can dramatically increase precipitation in some years. Hurricanes and tropical storms can change the sediment dynamics, salinity, water quality, nutrient fluxes, vegetative cover and biotic community structure (Davis et al. 2004; Tilmant et al. 1994). Droughts are also a natural part of the climate variability in South Florida, but the duration, extent, severity, and reoccurrence intervals can impact the coastal ecosystems (Gilbert et al. 2012; Petes et al. 2012). They can alter species composition, distribution, abundance and health due to changes in salinity, water quality, and freshwater influx (Gilbert et al. 2012). Water management practices have greatly altered the impact of seasonal rainfall on the wetlands and estuaries of South Florida, but the regional patterns still contribute to the balance between fresh and salt water in the transition zones (Jiang et al. 2011, McIvor et al. 1994, Shomer and Drew 1982).

The port experiences a certain level of chronic turbidity and sedimentation due to erosion, daily outflow from the Miami River, and daily ship and tug activity in addition to the natural sources of turbidity from runoff, and wind or tide-driven shifting of shallow sediments (USACE 2004). The POM basin, within North Biscayne Bay, holds a significant environmental and economic importance to South Florida. This region is continually impacted by human activities and the habitat has been mornitored by many different agencies including the South Florida Fish and Invertebrate Assessment Network (FIAN). North Biscayne Bay has the distinction of being an aquatic preserve and as such, no impact can occur without state permit under the condition that any damage is mitigated by planting an equivalent amount of seagrass at the same site or a nearby already damaged site (Thorhaug 1980). In 1980, The Biscayne Bay Aquatic Preserve was established, under Ch. 18-18, F.A.C (USACE 2004) for the purpose of preserving and enhancing the natural waterways of Biscayne Bay, so that future generations can enjoy its biological and aesthetic values (Kardys et. al 2012). Within the aquatic preserve is the Bill Sadowski Critical Wildlife Area (BSCWA), located just south of the Port of Miami and next to Virginia Key (Figure 3). BSCWA was established in 1990 by the Florida Game and Fresh Water Fish Commission (now called the Florida Fish and Wildlife Conservation Commission) to protect important habitats including the shallow submerged seagrass and hardbottom habitats, intertidal mudflats, and coastal mangrove wetlands in the Biscayne Bay area of Virginia Key (USACE 2004). The protected area covers about 700 acres and is closed to boating year-round, except for authorized channels that are excluded from the aquatic preserve due to their status as Federal navigation channels (USACE 2004). The boundaries are marked on-site with buoys (USACE 2004) (see Figure 2).

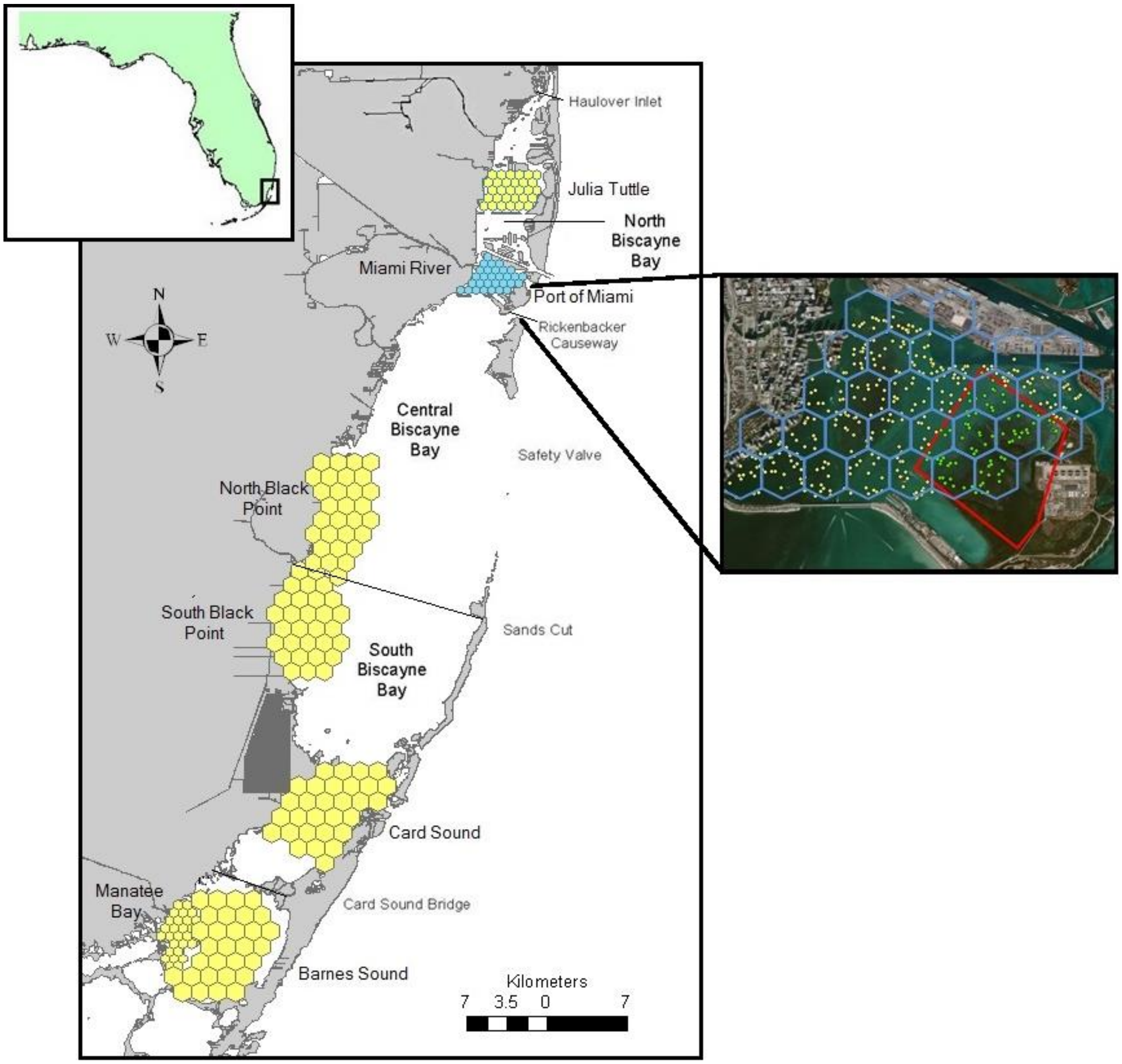

Figure 2. Study area located in North Biscayne Bay on the southeast coast of Florida. The regions of Biscayne Bay sampled in the FIAN project are highlighted in yellow and blue. The Port of Miami (POM) study area, highlighted in blue, is enlarged to show the 30-cell hexagonal grid used in FIAN. Area bounded in red in the insert is the Bill Sadowski Critical Wildlife Area (BSCWA), which is designated as a no-entry zone.

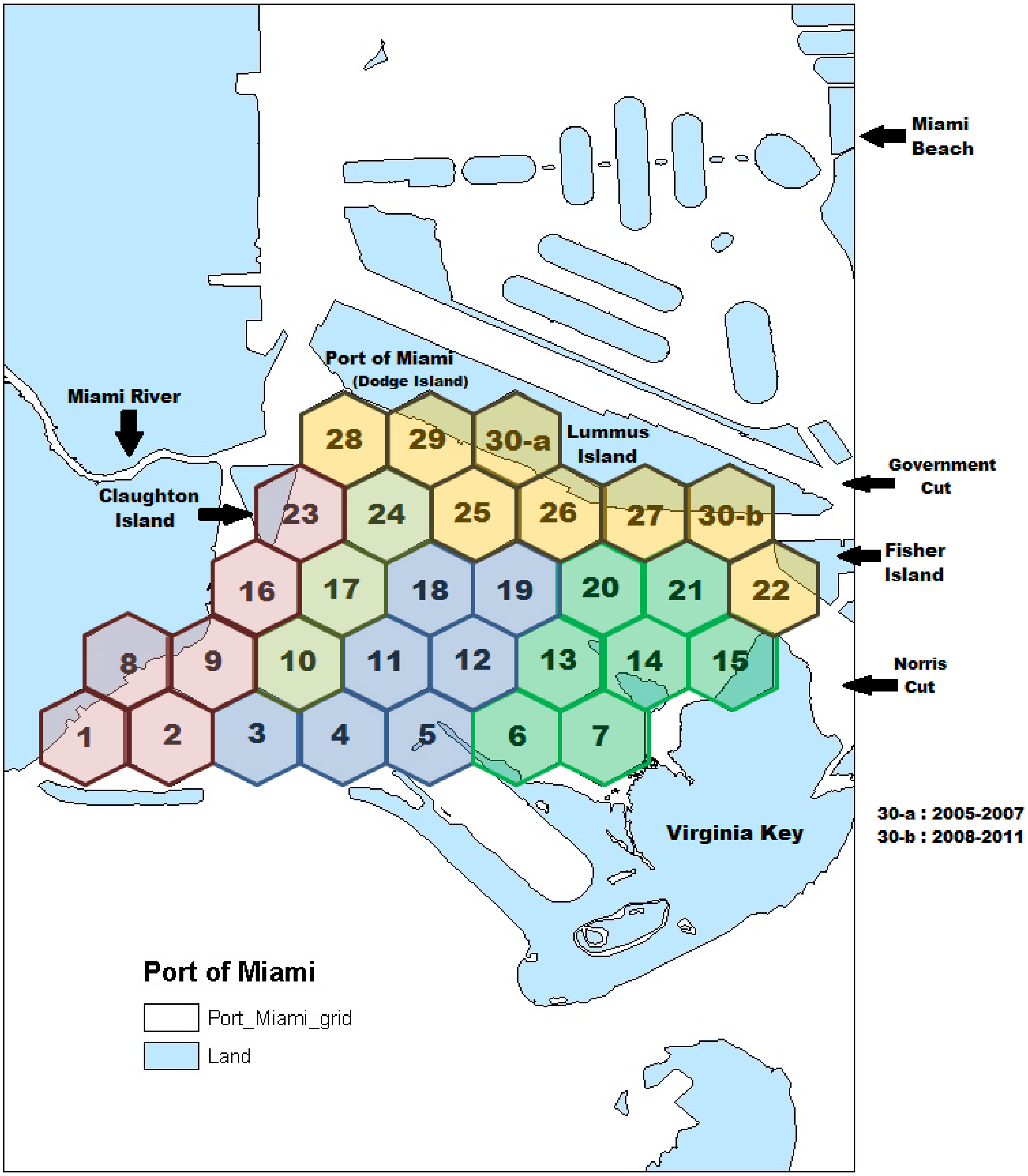

Figure 3. Map of the POM FIAN sample location boundaries and significant land marks within the Port of Miami. The 30-cell hexagonal grids highlighted by location type: Miami City East Coast (red), East Coast Grass patch (dark green), No Entry Zone Virginia Key Grass patch (light green), Channel through center of basin (blue), and the channel and Cuts South of Port Islands (yellow). Site 30 was relocated from 30-a to 30-b in 2008 due to the large amount of land within the grid.

1.4.2 Miami Port Economic Importance to South Florida

The Port of Miami is one of the most significant economic generators for South Florida and is owned and operated by the Seaport Department of Miami-Dade County (CDMP 2011). It is on the list of top 10 cargo container ports in the United States and is the largest container port in Florida (USACE 2007). The Port of Miami has the dual distinction of "Cruise Capital of the World" and "Cargo Gateway of the Americas" (USACE 2007) because it is among an elite group of ports in the world that caters to both cruise ships and containerized cargo (CDMP 2011). The Port of Miami has more than 35 shipping lines calling on over 100 countries and over 254 ports (USACE 2004).

The total economic impact of the Port of Miami operations on the nation is estimated at more than $8 billion per year with more than 45,000 jobs directly or indirectly attributable to the Port operations (USACE 2004). To facilitate the efficient movement of goods and passengers, the port also utilizes the local, regional, and inter-regional transportation network components consisting of roads, railway lines, and channels (USACE 2004). With Miami-Dade County's population estimated at 2.5 million people as of 2010 (BBAP 2012) the value of the shipping port on the economy becomes even greater. The harbor and surrounding area is of great importance to the recreational, social, economic, and cultural life of South Florida (Caccia and Boyer 2005). Historical population trends in Florida have shown that Miami-Dade County has continuously had the largest population since 1970 (FDH 2012).

1.4.3 Port Expansion: 2012 Deep Dredge Project

To meet future challenges in Miami-Dade County and the South Florida region, the Port of Miami will continue its sustainable growth through the development of the cargo, cruise and commercial entities (CDMP 2011). The Deep Dredge, Panama Canal project was proposed to accommodate larger ships in the Port of Miami (Miami-Dade 2012). Under the management of the U.S. Army Corps of Engineers (USACE), the harbor entrance channel was widened from 500 to 800 feet and deepened from 42 feet to 50/52 feet (2011b), allowing the port to become the only global logistic hub south of Virginia capable of handling the bigger post-Panamax vessels (Miami-Dade 2012). Miami-Dade invested over $1 billion in capital infrastructure projects to transform the port. The dredging of the port began in August 2013 and was completed in July 2015, for the June 2016 opening of the expanded Panama Canal (Miller et al. 2016).

Direct and indirect impacts to the seagrasses in Florida have been attributed mainly to increased urbanization and coastal development, which in turn has created sewage pollution, eutrophication, sedimentation and destructive motor vessel activity (Littler et al. 1989; Sargent et al. 1995; Hall et al. 1999; Carruthers et al. pers. comm. 2007; Short et al. 2010a; Short et al. 2010b; BBAP 2012). The major consequence of these activities is reduced water clarity and quality as well as physical destruction of habitat. The resuspension of sediments and the introduction of nutrients from runoff and pollutants from damaged structures (e.g. landfills, water treatment plants and ports/marinas) can affect the water quality (Tilmant et al. 1994; Davis et al. 2004). Physical damage can also occur from vessel groundings and scarring of the bottom with propellers. Monitoring and protection of the region has been extensive in POM over the years with the hope of preventing further damage to the marine habitat. The dredging project is expected to place additional stress on adjacent seagrasses only over the short-term (USACE 2004). From past field observations and assessment of historic aerial photography, the dredging is not expended to have a long-term negative impact on the seagrass beds outside the limits of the direct and indirect impacts of construction (USACE 2004). The new dredging is expected to only impact the seagrass habitats immediately adjacent to dredging activities and they may experience direct loss and reduced functional values (USACE 2004). Increased turbidity and sedimentation are expected to have indirect impacts in areas where they occur over seagrasses (USACE 2004).

1.5 Study Objectives & Hypotheses

In South Florida, natural disturbances, combined with the consistently growing coastal population demands and an economy based on marine-related tourism have created the need to monitor and protect the seagrass community (Collado-Vides et. al 2007). Dredge and fill activities in Miami have altered areas of Biscayne Bay with channels too deep for seagrass growth (Hefty et al. 2001). Despite the development that has taken place, there still are areas with abundant submerged aquatic vegetation consisting of seagrass and macroalgae species and mangrove fringe forests (Sweeney

2011). The bay is highly productive and supports many protected, threatened and endangered species including the Florida manatee (*Trichechus manatus latirostris*), the smalltooth sawfish (*Pristis pectinata*), five species of sea turtle, bottlenose dolphins, the American crocodile, (USACE 2007; Caccia and Boyer 2005) and Johnson's seagrass (*Halophila johnsonii*) (BBAP 2012). Loss of these benthic-vegetated habitats could result in loss of species richness and abundance (Bloomfield and Gillanders 2005).

Water quality and the health of seagrass communities have been linked in many locations around the world; as water quality has deteriorated, seagrass communities have been lost (Cambridge et al. 1986; Orth and Moore 1983). It is important to document the habitats and environmental conditions in order to understand how they may be changing. Humans have placed increasing pressure on seagrasses and the concern is that these habitats might not be able to sustain themselves (Lirman et al. 2008). At the current rate of human population growth, it is projected that Florida will lose the ability to sustain its estuarine environments within the next 20 years (Montague and Odum 1997). In order to protect the Port of Miami seagrass community from future human impacts, management and mitigation of dangers to the ecosystem are imperative.

The focus of this study is to analyze a potential link between significant changes in seagrass composition, cover-density and distribution and documented environmental changes within the Port of Miami. Spatially and temporally explicit environmental data are essential for determining possible causes of change within the seagrass beds (Greenawalt-Boswell et al. 2006). Comparing seagrass quadrat surveys with water quality and environmental data is useful to describe the conditions in which each species is found and will allow for future comparisons (Greenawalt-Boswell et al. 2006). This study focuses on the seagrass community and the environmental and physical measurements documented in the North Biscayne Bay region, within the sample basin of the Port of Miami (POM), using data collected in the South Florida Fish and Invertebrate Assessment Network (FIAN) project, 2005-2011, an element of the greater Everglades Restoration Program (RECOVER 2004; 2006; Robblee and Browder 2012). Seagrass, algae and associated environmental and physical measurements collected in FIAN are coupled with data available from other environmental agencies. The primary objectives are: 1) to characterize the seagrass community (e.g., species composition, cover-density, and distribution); and 2) to characterize the environmental and physical conditions (e.g., surface and bottom salinity and temperature, turbidity, sediment depth, and water depth) observed in POM; 3) to determine if there are relationships between the seagrass community and the environmental and physical conditions in POM; and 4) to evaluate if the natural and/or anthropogenic changes documented during the study period have influenced the seagrass habitat in POM.

Hypothesis 1: There are short and long term temporal and spatial changes evident in the seagrass composition, cover-density, and distribution within the Port of Miami.

The Port of Miami, within North Biscayne Bay, has been influenced by development in Miami and expansion of the major shipping port within the last century. Areas with high human activity are prone to more drastic and frequent changes than other less populated areas. This can alter water quality within a system and impact the benthic habitat. The seagrass habitat in Port of Miami will be assessed to evaluate whether there has been a decline in seagrass composition, cover-density, or distribution over time.

Hypothesis 2: There are short and long term temporal and spatial changes evident in the environmental and physical conditions in the Port of Miami.

A natural cycle of weather events occur in South Florida, creating two distinct seasons (dry and wet). The amount of rain and storm activity can be severe some years and can in turn cause changes to the environmental and physical conditions (e.g. water depth, sediment depth, temperature, salinity, and turbidity) within the coastal habitats. The extent of these environmental and physical changes in the system will be assessed.

Hypothesis 3: Changes in the environmental and physical conditions within the Port of Miami relate with changes in the composition, density and distribution of the benthic community.

Short and long-term changes in quality of the water within a system can impact the benthic habitat. Trends/associations between the seagrass and environmental and physical data will be assessed within the basin.

Hypothesis 4: Natural and anthropogenic influences have caused changes to the seagrass habitats within the Port of Miami over time.

Seagrass communities in North Biscayne Bay have been highly variable because of habitat modifications that have been taking place since the early 1900s (Caccia and Boyer 2005). Human activities and development, as well as natural events, stress the nearshore coastal marine environments in South Florida. Areas with high levels of human activity are at greater risk for unnatural habitat disturbances.

2.0 Materials and Methods

Data used for this study come from an existing data set developed in the South Florida Seagrass Fish and Invertebrate Network, FIAN (Robblee and Browder 2012) (see Table 2). Data are located on the USGS Benthic Database maintained by Everglades National Park. As a Monitoring and Assessment Plan project, FIAN is part of RECOVER, the Restoration, Coordination and Verification Program of the Comprehensive Everglades Restoration Plan (CERP) (RECOVER 2004; USACE and SFWMD1999).

2.1 FIAN Data

The FIAN project sampled 19 basins in three regions of South Florida: Biscayne Bay, Florida Bay, and the Lower Southwest Mangrove Coast. For this study of Port of Miami, data from one of the nineteen FIAN locations (POM) are used in analyses (Figure 2). To assess changes between sampling years and season, samples were collected at the end of the spring (dry season Apr/May) and fall (wet season Sept/Oct) from 2005 through 2011, for a total of fourteen collections. Using a geographic information system (GIS), a grid of 30 equal-sized cells was superimposed over the basin (Figure 3) to encompass the observable or expected gradients of physical and environmental conditions and vegetation characterizing the location. The sample grid-cells only encompassed waters that were accessible to a shallow-draft boat (Robblee and Browder 2012). Within each cell a single randomly located point was sampled. This method allowed FIAN the ability to randomly, but quasi-evenly, sample the environmental and habitat gradients present in an area and still create an accurate representation of the entire basin. The grid-cell size sampled in the Port of Miami covered a total of 1060.5 hectares (10,605,000 m^2) across the basin. A total of 420 samples were collected for analysis in the basin during the 7 years of FIAN.

2.1.1 Seagrass Community Vegetation Sampling

A Garmin GPSMAP492 GPS was used to locate each sampling sample site and the latitude and longitude coordinates were recorded. The vegetation observations and sediment composition were recorded by a free-diving researcher. A modified Braun-Blanquet cover-abundance method was used to quantify the seagrass and algae in a 0.25 m^2 quadrat at each site (Braun-Blanquet 1932; Mueller-Dombois and Ellenberg 1974; Fourqurean et al. 2002). This method involves classifying all vegetative species present and assigning an abundance code for each species present (Braun-Blanquet 1932). This allows for large areas to be sampled in a short time (Wikum 1978), while still accurately representing the overall vegetation composition. Braun-Blanquet is a useful tool for establishing baseline data for assessment of environmental impacts (Wikum 1978). Replicate quadrats were sampled at each individual site within a basin, and a cover-abundance rating from 0 to 5 was assigned to each vegetative group: 0 = no species present, 0.1 = individual or solitary stem, 0.5 = sparse covering, 1 = 0-5% cover, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, and 5 = 75-100% (Robblee 2009; Collado-Vides et al. 2007) (Table 1). Canopy height was measured in conjunction with Braun-Blanquet cover/abundance because it provided a simple and quick measure of the physical structure of the grass community (Robblee and Browder 2012). For this study, the mean of all replicate samples per site were used for analyses.

FIAN underwent several modifications in order to better monitor the habitat and optimize resources. After the 2005 and 2006 collections, the number of quadrat replicates increased from three to six at a sample site. Greater numbers of samples increase precision and provide a more accurate picture of the habitat and distribution of species (Braun-Blanquet 1932). In 2007 it was determined that broad plant groupings could provide an estimate of overall habitat (nearly comparable to other more time consuming methods). Therefore, beginning with the fall 2007 collections, estimation of cover/abundance was expanded to include the three aggregate plant groupings: all-vegetation, all-seagrass and all-algae. With the earlier collections spring 2005 through spring 2007, aggregate plant groupings were not observed and therefore could not be calculated from the available cover/abundance scores of the individual species. With Braun-Blanquet cover/abundance estimates, averaging is only appropriate by species and scores are not additive between groups. Due to the ordinal scale, once averaged, abundance cannot be converted back to a cover/abundance index score. The estimate of overall habitat could only be measured for nine of the fourteen collections (fall 2007 through fall 2011). Also, the sampling grid for site 30 was relocated in 2008 due to the majority of the grid cell positioned over the channel. Site 30 was moved to a similar, nearby location, closer to Government Cut and the marine environment (See Figure 3). A total of 2159 quadrats and 420 sites were sampled over the 14 collections (one quadrat was not sampled in the fall of 2010).

2.1.2 Environmental and Physical Measurements

At each site, water depth, sediment depth and texture, and water quality (salinity, temperature, and turbidity) were measured, the seabed flora composition and cover were measured, and animal abundance and species composition were estimated (shrimp, crabs and fish). Fauna will not be discussed in this study. Grid-cells were grouped into location type: vicinity to coastline, channels, shallow areas, and no entry zones (Figure 3). Temperature and salinity at the surface and bottom were recorded using a WTW 330i Conductivity Field Meter. A water sample was taken in clear water from just below the surface upon arrival and was stored on ice to quantify turbidity that was measured later in the laboratory using an HF Scientific DRT-15CE portable turbidimeter. Water depth was recorded using a 3-m long polyvinyl chlorine (PVC) pole marked with 1-cm increments. Sediment depth was measured at each site by a diver using a 3-m long, 1.2-cm diameter PVC pole marked with 1-cm increments (see Table 1). Tides were recorded for each sampling location based on tide charts from NOAA. Water depths are biased by sampling restrictions in shallow water areas that limit access by boat to periods of relatively deep water; no restrictions apply in deep waters (Robblee and Browder 2012).

Table 1. Measurement and method for biotic and environmental and physical measurements used to characterize sampling locations in FIAN (Robblee and Browder 2012).

Method	N	Description
Braun-Blanquet Cover/Abundance		
Cover/abundance Estimate	3/6	Cover of seagrass and algae by species; plant groupings (0.25m^2 quadrat), Scores by species: .1 = individual, .5 = sparse, 1 = 0-5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, 5 = 75-100%.
Canopy Height	6	Maximum height (cm)
Sediment Texture	6	Estimate by feel/appearance: M = mud, SM = sand/mud, MS = mud/sand, S = sand, CS = coarse shell, R = rubble, HH = *Halimeda* hash, combinations of these, etc.
Associated Habitat Data		
Sediment Depth	1	Probe, sediment surface to bedrock (cm).
Water Depth	1	Depth when sampled (cm).
Associated Environmental Measurements		
Surface Salinity	1	WTW 315i and 330i Conductivity Meters (psu)
Bottom Salinity	1	WTW 315i and 330i Conductivity Meters (psu)
Surface Temperature	1	WTW 315i and 330i Conductivity Meters (^{o}C)
Bottom Temperature	1	WTW 315i and 330i Conductivity Meters (^{o}C)
Water Turbidity	1	DRT 15C Turbidity meter (NTU)

2.1.2.1 Other Agency Data

In order to determine other possible influences on water quality within the POM basin, data were collected from the South Florida Water Management District (SFWMD) corporate environmental database, DBHYDRO, which stores historical and up-to-date environmental data for 16 counties and many environmental agencies. The Department of Environmental Resource Management (DERM) and the Southeast Environmental Research Center (SERC) of Florida International University (FIU) each held water quality monitoring contracts to support the District’s management of the Biscayne Bay region, and subsequently the POM basin since 1978 (BBS Plan 2006). Only data sampling that coincides with the USGS FIAN sampling period (2005-2011) and variables associated with seagrass distribution were used in this study (refer to Table 2).

Between June 24, 1996 and September 22, 2008, SERC-FIU collected water quality monitoring data for the Biscayne Bay water quality monitoring network project (BISC), which included station BISC130, located near Dodge Island in POM (see Figure 4). SFWMD eventually discontinued the project. In 2008 DERM was chosen as the lead agency for water studies in Biscayne Bay and has been collecting data from October 2009 until present day from the monitoring station BB22, located midway between the Miami Marine Stadium and NOAA slip at Dodge Island (see Figure 4). There is a gap in the data from October 2008 until October 2009 while the project was switching agencies. The various parameters between monitoring agencies that did not display a continuous record or were measured in different formats were deemed incompatible for data comparison and excluded from this study. For example, ammonia was measured by both agencies, but DERM measured it as total ammonia and FIU-SERC as dissolved ammonia (RECOVER 2014). All data from SFWMD were collected on a monthly basis. Weather data for the time period was obtained from the National Oceanic and Atmospheric Administration (NOAA) station located at Virginia Key, Miami, Florida. Sufficient data available over the record period from the other monitoring agencies are listed in Table 2.

Figure 4. Location of SFWMD monitoring sites BB22 (DERM) and BISC130 (SERC-FIU) and the NOAA Weather Station located in the North Biscayne Bay region within the POM basin

Table 2. Environmental and physical measurements from all agencies used in this study to characterize the POM sampling location.

Agency	Sample Years	Location	Variables
FIAN	2005-2011	30 monitoring hexagonal grid sites in the POM basin (see Figure 3)	seagrass and algae cover-density (#/m^2) canopy height (cm) sediment depth (cm) and texture water depth (cm) turbidity (NTU) water temperature (^{o}C) salinity (‰)
SFWMD		Center of POM basin (see Figure 4)	water temperature (^{o}C) salinity (‰) turbidity (NTU) dissolved oxygen (DO) (mg/L) pH (field units) Chlorophyll-a (CHL-A) (mg/M^3) organic-carbon (OC) (mg/L) nitrate plus nitrite (NOx) (mg/L) total phosphate (P) (mg/L)
DERM BB22	1979-1996, 1998-2003, 2009-present	Lat. 25.4522553 Long. -80.1027368	
SERC-FIU BISC 130	1996-2008	Lat. 25.454799 Long. -80.101801	
NOAA	2005-2011	Virginia Key, Miami (see Figure 4)	rainfall (in) air temperature (^{o}C)

2.2 Data Analysis

FIAN data were grouped by grid-cell, season, year, and vegetation type. Statistical analyses were conducted using IBM SPSS Statistics 20 (2011) and Microsoft Excel (2010). Maps created using habitat variables including average canopy height, cover/abundance of the four seagrass genera, *Thalassia*, *Halodule*, *Syringodium* and *Halophila*, and average cover/abundance of four algal groups, red, brown, green, and calcareous (Robblee and Browder 2012), were analyzed for noticeable changes among sampling collections.

The presence/absence of grass and algae were also calculated across years and between seasons for total quadrats (N = 2169) and sites (N = 420) sampled over the study period (2005-2011). General linear models were used to detect annual and seasonal variations in vegetation (seagrass and algae) occurrence in FIAN data.

For purposes of this study, the replicate quadrats from Braun-Blanquet surveys were averaged to give an overview of vegetation groups present at each of the 30 sample sites within the basin. Seagrass canopy height measurements were averaged from the quadrat replicates for each site as well. Cover-density for vegetation groups at each FIAN sample site were calculated from the ranked abundance codes using the following formulas based on Braun-Blanquet (1965) methodology (Robblee 2005):

Cover-Density = sum of B-B scale values/ total # of quadrats

Nonparametric tests were used to analyze the calculated Braun-Blanquet vegetation data due to the ordinal nature of the ranked vegetation abundance codes. Kruskal-Wallis tests were used to compare the calculated FIAN vegetation cover-density data and the seagrass canopy heights across years and between the 30 sample sites; to test for seasonal effects a Mann-Whitney U test was used.

For the FIAN physical and environmental measurements, mean sediment depth, water depth, turbidity, and surface and bottom temperature and salinity measurements were calculated for each sample site for annual and seasonal comparison. For surface and bottom temperature and salinity measurements, independent samples t-tests were used to determine any significant difference in the water column. General Linear Models were also constructed to determine potential temporal (annual/seasonal) effects of all physical and environmental factors within the sample basin. A *post hoc* analysis was used to identify specific years for which differences have been observed. Spatial variation between the thirty FIAN sample sites within the POM basin was determined by a One-way ANOVA. Visual inspection of site location and data measurements were compared.

Environmental data collected for the SFWMD from other agencies were averaged for the sample period and graphed for comparison with data from this study. One-way ANOVAs were used to determine any significant temporal variation between the available sample years for each variable. Related variables were also compared with NOAA weather data for the region during the sample period.

Spearman’s rank correlation coefficient (Spearman’s rho) was used to evaluate a potential relationship between vegetation and environmental and physical measurements (sediment, temperature, salinity, turbidity, and water and sediment depth). Multiple linear regression models were used to evaluate temporal effects (sampling years and seasons), physical and environmental factors (depth, sediment, temperature, salinity, and turbidity), and algae on the benthic community of seagrass (cover-density, occurrence, and canopy height) during the collection period. Four main models were constructed for the (vegetation) seagrass cover-densities: 1. Effects of year and season on benthic community, 2. Effects of physical and environmental factors (depth, sediment, temperature, salinity, and turbidity) on benthic community, 3. Effects of physical and environmental factors, year and season on benthic community, and 4. Effects of algae, physical and environmental factors, year and season on benthic community.

3.0 Results

3.1 FIAN Seagrass Community Measurements

Four genera of seagrass, *Syringodium, Thalassia, Halodule and Halophila,* were observed in the POM basin. Twenty-eight genera of algae were observed consisting of: 6 genera of green algae, including *Avrainvillea*, *Anadyomene, Batophora* and *Caulerpa*; 11 genera of Rhodophyta, red algae, including *Laurencia and Gracilaria*; two genera of Phaeophyta, brown algae, including *Sargassum* and *Dictyota*; and five genera of Chlorophyta, green algae, including *Rhipocephalus*, *Acetabularia*, *Halimeda*, *Udotea* and *Penicillus*. In FIAN some algae were not identified to species but rather lumped by genera in an “Other” group (e.g. Red Other, Green Other, Brown Other, Calcareous-green Other).

Seagrasses were present at 91.7% of the 420 sites and 77% of the 2159 quadrats sampled over the collection period. *Syringodium filiforme* was the most abundant seagrass species within the sample location, present at 66.4% of monitoring sites. *Thalassia testudinum* and *H. wrightii* were the second most abundant seagrasses, present at 52.4% and 50% of the sites, respectively. The *Halophila* genera, with three species (*H. engelmanni*, *H.decipiens*, *H. johnsonii*), was rarely present and found to only be in 7.6% of sites (see Table 3). *Ruppia maritima* was not documented in any samples.

Mixed seagrass beds were identified at 57% of the sites consisting of *Syringodium-Thalassia-Halodule* (20%), *Syringodium-Thalassia* (18%), *Syringodium-Halodule* (11%), and *Thalassia-Halodule* (8%). Homogenous beds for *Syringodium* occurred at 17% of the sites; whereas *Thalassia* (5%) and *Halodule* (11%) were rarely monospecific and were often mixed with the *Syringodium* (Table 4).

Syringodium measured the tallest average canopy height, 38.6 ± 16.3 cm, followed by *Thalassia*, 27.6 ± 11.3 cm, and *Halodule*, 16.6 ± 8.2 cm. The *Halophila* species were the shortest, measuring an average of 3.6 ± 2.1 cm. The average seagrass canopy height was calculated to be 29.96 ± 16.97 cm over the sample period.

Algae species were present at 90.5% of the 420 sites and 64.6% of the 2159 quadrats sampled over the collection period. Red and calcareous-green algae were the most abundant types of algae, present at 61.4% and 60% of the 420 monitoring sites, respectively. Green algae were the third most abundant type, followed by brown algae as the least abundant type (Table 3).

Table 3. FIAN Percentage of each vegetation genera present at sample sites and quadrats over the study period. Dominance ranks are listed for all vegetation present. Total Sites n = 420, total quadrats n = 2159.

Vegetation Groups	(n) sites present	% sites present	(n) quads present	% quads present	Dominance Rank
Halodule	210	50%	570	26.4%	5
Halophila	32	7.6%	67	3.1%	8
Syringodium	279	66.4%	1049	48.6%	1
Thalassia	215	52.4%	628	29.1%	4
Seagrass Total	385	91.7%	1662	77%	-
Red algae	258	61.4%	758	35.1%	2
Green algae	157	37.3%	312	14.5%	6
Brown algae	45	10.7%	93	4.3%	7
Calcareous algae	256	61%	713	33%	3
Algae Total	380	90.5%	1394	64.6%	-

Table 4. FIAN Frequency of sites within the POM basin with mixed or monospecific seagrass beds and no grass present. (S = *Syringodium*, T = *Thalassia*, H = *Halodule*)

Grass Mix	# Sites Present	Frequency
S+H	46	11.0%
S+T	76	18.1%
T+H	32	7.6%
S+T+H	85	20.2%
S	71	16.9%
T	22	5.2%
H	46	11.0%
No grass	42	10.0%

From 2005 to 2011 the occurrence of seagrass among the 30 sample sites increased by 10%, the occurrence of algae increased by 8%, and the total occurrence of vegetation increased by 2%. Results of a general linear model showed seagrass occurrence did not significantly vary over years or between seasons ($p > 0.05$). However, algae occurrence showed a significant annual ($F_6 = 2.465$, $p = 0.024$) (Figure 5) and seasonal ($F_1 = 2.465$, $p = 0.018$) variation (Appendix 4). A greater percentage of algae were present in the sample sites during the spring (dry) season (93.81%), than in the fall (wet) season (87.14%). Across sample years, the greatest variation in algae occurrence was observed between the 2006 and 2007 collections; the lowest occurrence of algae within sample sites was documented in 2006, followed by the highest occurrence in the 2007sampling year (see Figure 5).

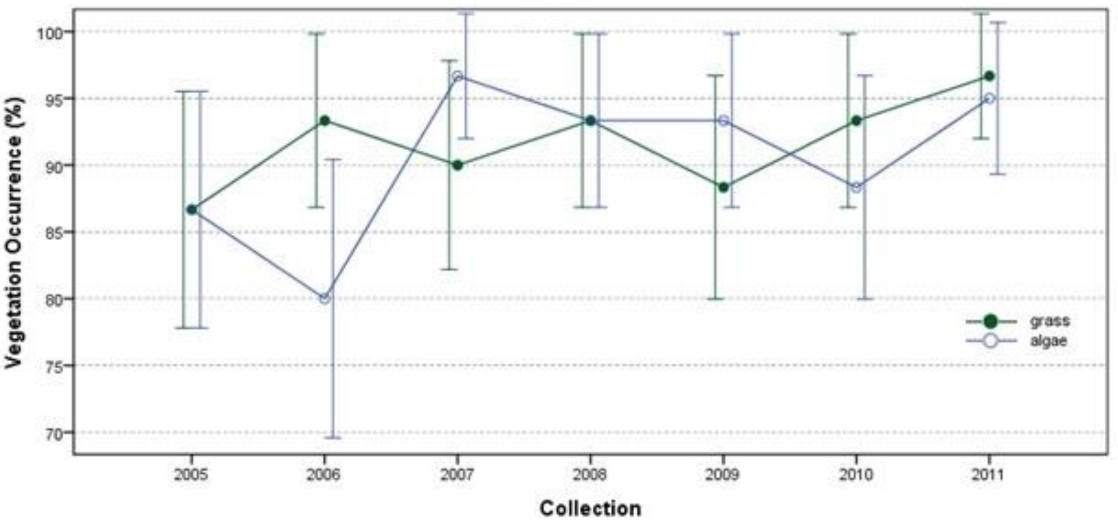

Figure 5. Mean annual seagrass and algae frequency of occurrence among the 30 sample sites measured in the Port of Miami basin over the 2005-2011 sampling period with 95% CI error bars.

Results from Mann-Whitney U tests showed seagrass cover-densities did not vary significantly between seasons for any species, $p > 0.05$ (Table 5). Generally, *Syringodium* (Figure 6A) and *Halodule* (Figure 6C) cover-densities were higher during the fall season, and *Thalassia* (Figure 6B) cover-density was higher during the spring season. Significant seasonality was observed in seagrass canopy height measurements for *Thalassia* ($Z = 6462.5$, $p = 0.002$) and *Halodule* ($Z = 6877$, $p < 0.001$), but not for *Syringodium* or the average seagrass canopy height, $p > 0.05$. Overall, taller canopy heights for all seagrass species and taller average seagrass canopy height (Table 5) were observed during the fall season (Figure 7).

Cover-density differed between all algae groups, except brown algae ($p > 0.05$). The spring sampling season measured greater red algae cover-density, while the fall measured higher green and calcareous algae cover-densities (Table 5).

Table 5. Mann-Whitney U test of significance for seasonal differences of canopy height, average canopy height (cm) and cover-density (#/m^2) among the four seagrass and four algae groups between seasons in POM.

Vegetation Canopy Height and Cover-Density Measurements between Seasons (dry/wet) Mann-Whitney U Test						
Measure	Season	N	range	mean +/- SD	*U(Z)*	*p*
Canopy Height						
Average Seagrass	spring	192	1.0 - 93.33	28.62 ± 16.14		
	fall	191	1.0 -101.2	31.31 ± 17.7	19987.5	0.127
Halodule	spring	97	4.0 - 27.0	13.31 ± 5.1		
	fall	99	4.5 - 44.0	19.81 ± 9.34	6877	0.000
Halophila sp.	spring	9	1.0 - 7.0	2.98 ± 2.21		
	fall	16	1.0 - 7.0	3.9 ± 2.07	92.5	0.251
Syringodium	spring	138	7.0 - 93.33	37.43 ± 15.08		
	fall	137	8.0 - 101.2	39.68 ± 17.42	10288	0.205
Thalassia	spring	97	3.0 - 45.0	24.62 ± 8.86		
	fall	106	5.0 - 61.17	30.33 ± 12.57	6462.5	0.002
Cover-Density						
Halodule	spring	210	0.00 - 5.00	0.52 ± 0.86		
	fall	210	0.00 - 5.00	0.63 ± 1.02	22482.5	0.710
Halophila sp.	spring	210	0.00 - 2.50	0.02 ± 0.19		
	fall	210	0.00 - 3.00	0.10 ± 0.44	23141.5	0.056
Syringodium	spring	210	0.00 - 5.00	1.36 ± 1.41		
	fall	210	0.00 - 5.00	1.37 ± 1.49	21996.5	0.965
Thalassia	spring	210	0.00 - 5.00	0.68 ± 1.09		
	fall	210	0.00 - 5.00	0.59 ± 1.00	21999	0.965
Red Algae	spring	210	0.00 - 3.98	0.83 ± 0.81		
	fall	210	0.00 - 3.00	0.21 ± 0.44	8781.5	0.000
Green Algae	spring	210	0.00 - 1.50	0.10 ± 0.26		
	fall	210	0.00 - 2.67	0.21 ± 0.43	26497	0.000
Brown Algae	spring	210	0.00 - 1.67	0.06 ± 0.22		
	fall	210	0.00 - 0.75	0.03 ± 0.11	21671	0.571
Calcareous Algae	spring	210	0.00 - 2.83	0.22 ± 0.40		
	fall	210	0.00 - 2.50	0.38 ± 0.51	25708.5	0.002

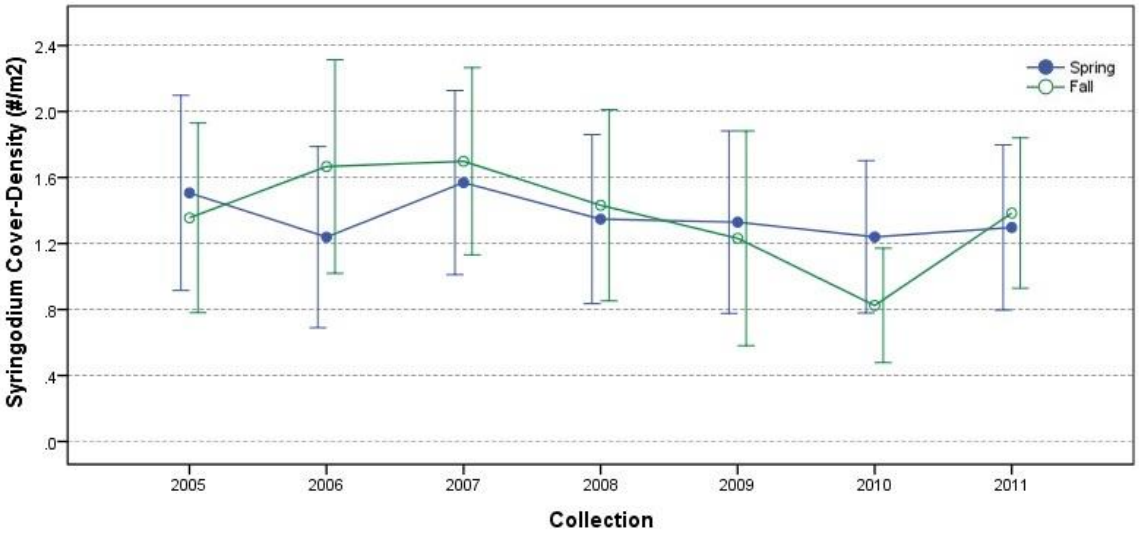

Figure 6A.

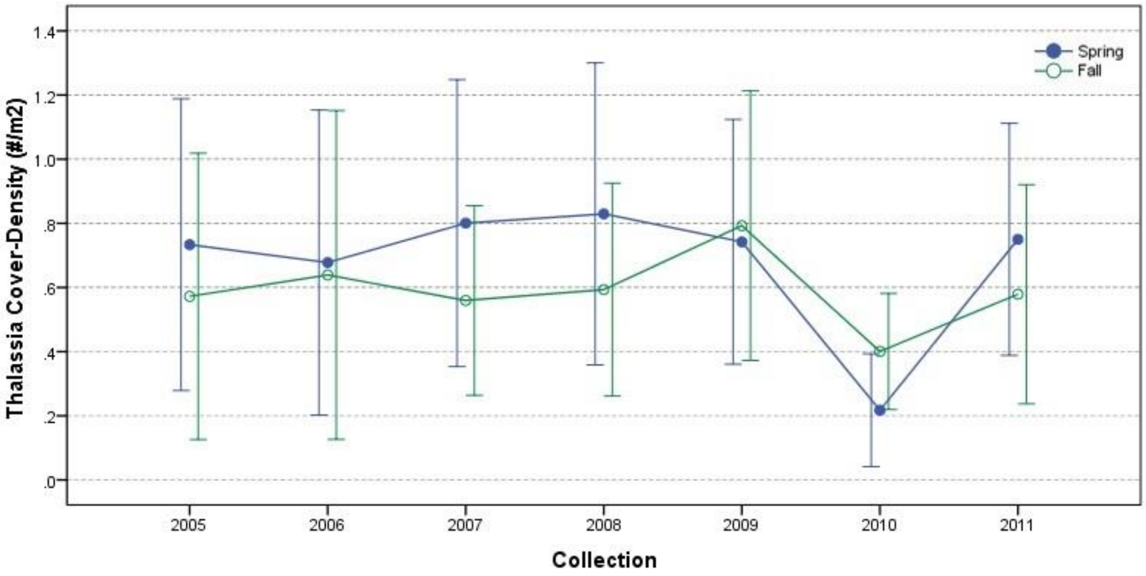

Figure 6B.

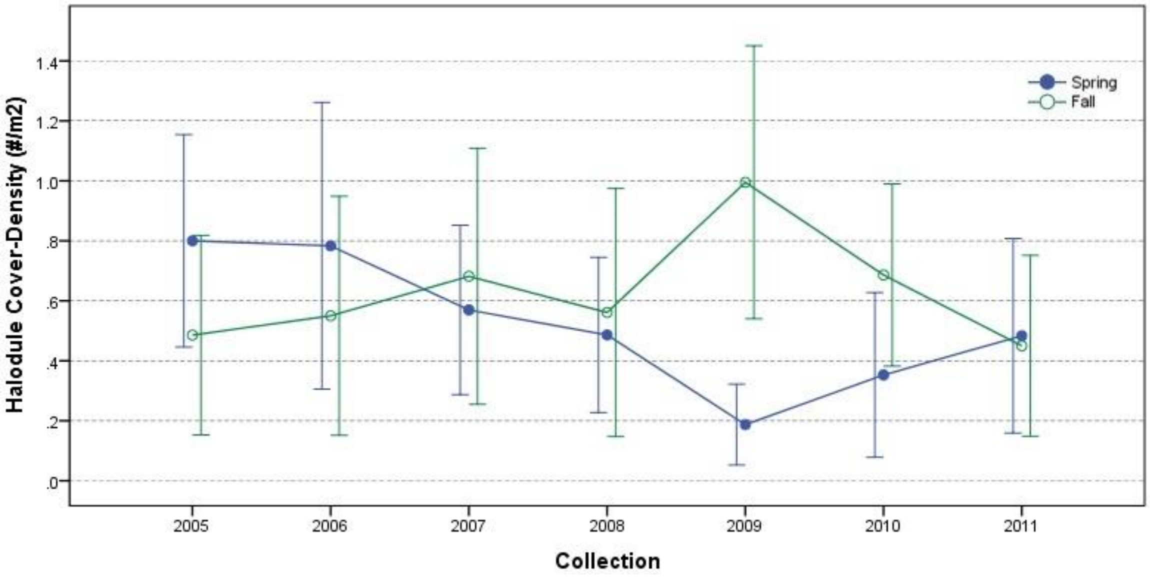

Figure 6C.

Figures 6A-C. Mean seasonal seagrass species cover-densities; A) *Syringodium*, B) *Thalassia*, C) *Halodule*, measured in the Port of Miami basin across the 2005-2011 sampling period with 95% CI error bars.

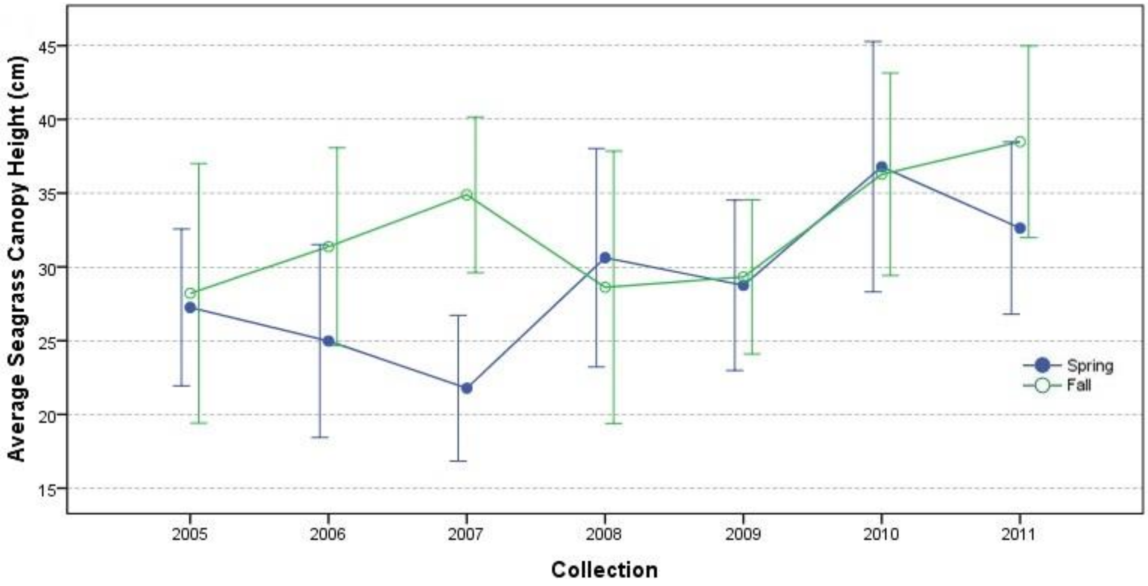

Figure 7. The annual mean average seagrass canopy height measured in the Port of Miami basin across the 2005-2011 sampling period with 95% CI error bars.

Kruskal Wallis H-tests showed no significant variations in seagrass cover-densities between the seven sampling years, ($p > 0.05$); however, there was significant annual effect on canopy height for *Syringodium*, *Halodule*, and the average canopy height (Table 6). *Thalassia* canopy height tended to fluctuate over the years, $F_6 = 11.717$, $p = 0.069$ (Figure 9). Since *Halophila sp.* canopy heights were measured at only 6% of the sample sites and they are relatively short grasses, no further analysis was done for this group. No major change was documented in seagrass cover-density (Figure 8), but canopy height did show some significant variations between collection years (Figure 9 and Figure 10). Algae cover-densities showed an annual effect for calcareous ($F_6 = 17.925$, $p = 0.006$) and brown algae groups ($F_6 = 27.992$, $p \leq 0.000$), but not in red or green algae (Table 6). Significant changes between years for brown algae can be attributed to the low occurrence of species within the group (Figure 11).

Table 6. Kruskal Wallis test of differences in seagrass canopy height (cm) and vegetation cover-densities (#/m^2) among years (2005-2011).

Vegetation Canopy Height and Cover-Density Measurements among Collection Years (1-7) Kruskal-Wallis						
Measure	N	range	mean +/- SD	*F*	df	Sig.
Canopy Height						
Average Seagrass	383	1-101.2	29.96 ± 16.97	15.623	6	0.016
Halodule	196	4-44	16.59 ± 8.2	12.984	6	0.043
Halophila sp.	25	1-7	3.57 ± 2.12	3.285	6	0.772
Syringodium	275	7-101.2	38.55 ± 16.29	17.167	6	0.009
Thalassia	203	3-61.2	27.6 ± 11.3	11.717	6	0.069
Cover-Density						
Halodule	420	0-5	0.58 ± 0.94	4.078	6	0.666
Halophila sp.	420	0-4.5	0.07 ± 0.41	7.216	6	0.301
Syringodium	420	0-5	1.37 ± 1.45	4.800	6	0.570
Thalassia	420	0-5	0.63 ± 1.05	9.841	6	0.131
Red Algae	420	0-3.98	0.52 ± 0.72	6.397	6	0.380
Green Algae	420	0-2.67	0.16 ± 0.36	9.802	6	0.133
Brown Algae	420	0-1.67	0.04 ± 0.17	27.992	6	0.000
Calcareous Algae	420	0-2.83	0.30 ± 0.46	17.925	6	0.006

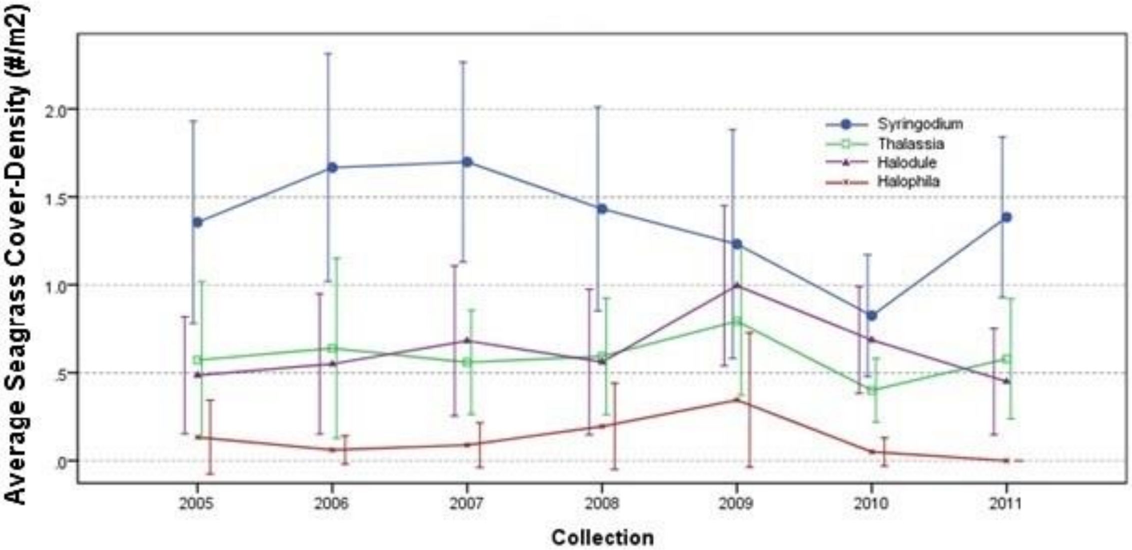

Figure 8. Mean annual seagrass species cover-densities (*Syringodium, Thalassia, Halodule*, and *Halophila sp*.) measured in the Port of Miami basin across the 2005-2011 sampling period with 95% CI error bars.

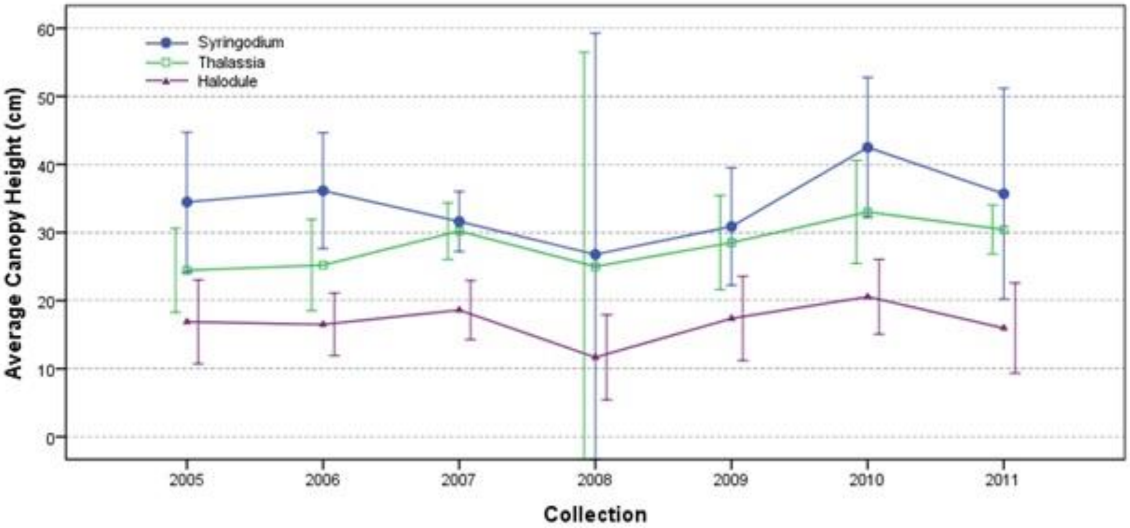

Figure 9. Mean annual seagrass species canopy heights (*Syringodium*, *Thalassia*, and *Halodule*) measured in the Port of Miami basin across the 2005-2011 sampling period with 95% CI error bars.

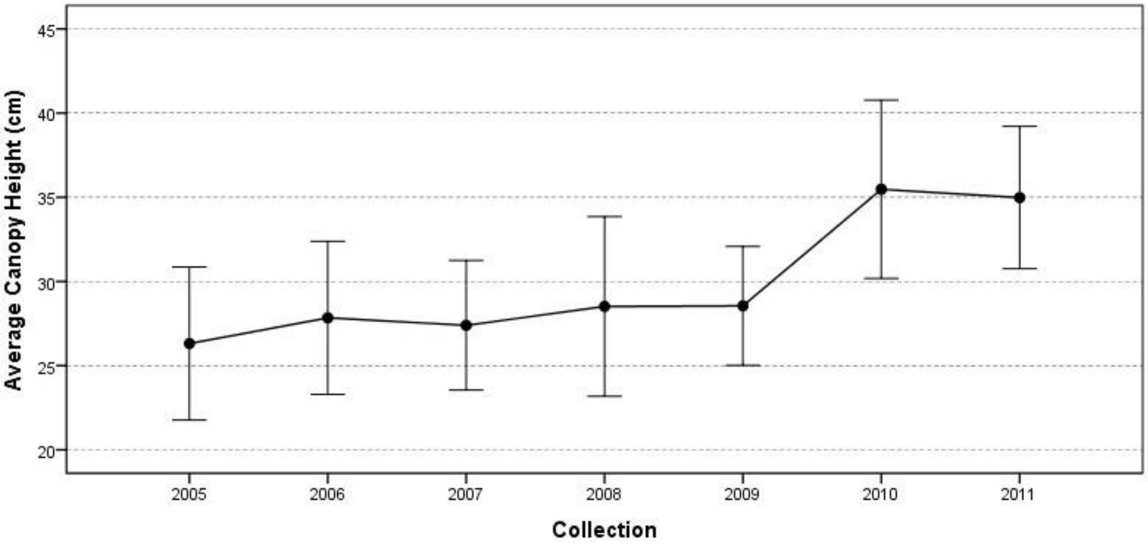

Figure 10. The annual mean average seagrass canopy height measured in the Port of Miami basin across the 2005-2011 sampling period with 95% CI error bars.

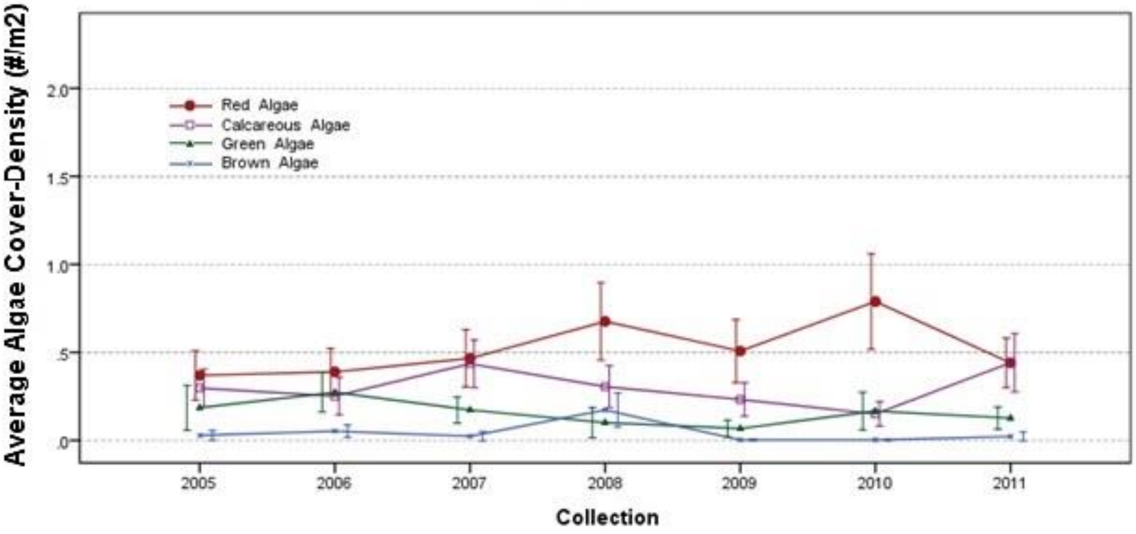

Figure 11. Mean annual algae group cover-densities (#/m^2) (red, calcareous, green, and brown) measured in the Port of Miami basin across the 2005-2011 sampling period with 95% CI error bars.

The seagrass community varied across the POM basin (see Figure 3). Results from the Kruskal Wallis H-tests showed spatial effects on the average seagrass canopy height, all seagrass cover-densities, and on green and calcareous algae cover-densities, $p < 0.05$ (Table 7). Red and brown algae cover-densities showed no significant variation between the thirty sample sites within the POM basin at $p > 0.05$. Seagrass distribution within the POM basin can be attributed to habitat differences due to location within the basin (Table 15, Appendix 3). Sample sites located in the shallow, protected areas yielded the tallest average canopy heights and the highest seagrass cover-densities. Locations within channels had some of the shorter average canopy heights and the lowest seagrass cover-densities (Table 8, Appendix 4 and Appendix 5).

Table 7. Kruskal Wallis test on average seagrass canopy height (cm) and vegetation cover-densities (#/m^2) between collection sites (1-30) within the Port of Miami basin.

Vegetation Cover-Density Measurements between Collection Sites (1-30) Kruskal-Wallis						
Measure	N	range	mean +/- SD	F	df	Sig.
Canopy Height						
Average Seagrass	383	1-101.2	29.96 ± 16.97	140.925	29	0.000
Cover-Density						
Halodule	420	0-5	0.58 ± 0.94	71.182	29	0.000
Halophila sp.	420	0-4.5	0.07 ± 0.41	56.575	29	0.002
Syringodium	420	0-5	1.37 ± 1.45	144.831	29	0.000
Thalassia	420	0-5	0.63 ± 1.05	113.669	29	0.000
Red Algae	420	0-3.98	0.52 ± 0.72	23.898	29	0.734
Green Algae	420	0-2.67	0.16 ± 0.36	66.363	29	0.000
Brown Algae	420	0-1.67	0.04 ± 0.17	27.799	29	0.529
Calcareous Algae	420	0-2.83	0.30 ± 0.46	109.407	29	0.000

Table 8. Seagrass cover-densities (#/m^2) mean, standard deviation, minimum and maximum by site (1-30) and location type within the Port of Miami basin (refer to Figure 3).

Seagrass Cover-Density	Site	**Location**	Mean	Std. Deviation	N	Hi/Low
Syringodium	**17**	East Coast Grass patch	3.32	0.85	14	max
	5	Channel in center of basin	0.10	0.36	14	min
	25	South of Port Islands	0.10	0.23	14	min
Thalassia	**7**	Virginia Key Protected Area Grass patch	3.13	1.85	14	max
	29	South of Port Islands	0.02	0.09	14	min
Halodule	**15**	Virginia Key Protected Area Grass patch	1.83	1.79	14	max
	19	Channel in center of basin	0.00	0.00	14	min

3.2 Environmental and Physical Conditions in Port of Miami, 2005-2011

Water depth, sediment depth, turbidity, surface and bottom temperature and salinity measurements were taken at each site within the POM basin. Observed water depths ranged from 44 cm to 605 cm over the basin, averaging 213.14 ± 79 cm (Figure 12C). Sediment texture was measured at 2147 of the 2159 quads sampled and 89.8% of the quadrats contained a combination of mud and/or sand substrate. The sediment depth averaged about 130.28 ± 84.1 cm and ranging from 4 cm to over 300 cm in the basin (Figure 12D). Turbidities were generally low over all fourteen collections, averaging 2.58 ± 1.76 NTU (Figure 12E).

Average water column values could not be used for salinity because an independent samples t-test determined there was a significant difference between the surface and bottom measurements ($t(420) = -2.815$, $p < 0.001$). Temperature measurements did not show a significant difference within the water column ($t(420) = -0.368$, $p = 0.923$), but due to the relationship between temperature and salinity, both surface and bottom measurements were used instead of the averages for temperature and salinity. Surface salinity was lower overall and ranged between 12.60 and 39.10‰ (33.07 ± 3.46‰), while bottom salinity ranged between 25.60 and 38.40‰ (33.65 ± 2.53‰) (Figure 12B). Surface temperature was slightly lower overall and ranged between 20.80 and 32.50 °C (27.41 ± 2.64 °C), while bottom temperature ranged between 21.90 and 32.50 °C (27.48 ± 2.86 °C) (Figure 12A). Salinity and Temperature patterns were typical of South Florida inshore water (see Appendix 3).

The combined General Linear Model for annual and seasonal effect (year*season) on environmental and physical measurements indicated variables such as water depth, turbidity, salinity, and temperature are significantly different over time, but not sediment depth (see Table 9). A significant seasonal effect was seen with water depth, salinity, temperature, and turbidity ($p < 0.05$) (see Table 9 and Figures 13A-E). The fall (wet) season measured higher water depths (Figure 13C) and temperatures (Figure 13A), while the spring season had higher salinity measurements (Figure 13B). Differences in water depth between seasons can be attributed to tide level and proximity to the deeper channels within the basin. In both the spring and fall collections, bottom salinity was greater than surface salinity (Figure 13B).

There was a significant annual effect on all environmental and physical variables over the sample period ($p < 0.01$) (see Table 9). Annual differences were revealed through the Tukey *post-hoc* tests (see Figures 12A-E). Between sample years 2006 and 2007, the most significant differences in salinity were measured (Figure 12B). 2006 measured the lowest and 2007 the highest salinities over the study period. The most significant changes in temperature were observed between 2009 and 2011, with 2010 measuring the lowest and 2011 measuring the highest temperatures over the study period (Figure 12A). The water depth and sediment depth measurements varied between most sample years. The most significant variation in water depths were measured between 2007 and 2008 (Figure 12C). Sediment depth measurements differed most significantly between the 2007-2008 and 2010-2011 sampling years (Figure 12D). From 2008 to 2009 the most significant decrease in turbidity was measured (Figure 12E).

Table 9. Summary of a General Linear Model of FIAN environmental and physical variables by Year*Season. Temperature (°C), salinity (‰), turbidity (NTU), sediment depth (cm), and water depth (cm).

General Linear Model - Tests of Between-Subjects Effects - Year * Season

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[h]
Year	Water Depth	120399.965	6	20066.661	3.460	.002	.049	20.759	.945
	Sediment Depth	298846.221	6	49807.704	7.766	.000	.103	46.597	1.000
	Turbidity	411.790	6	68.632	35.600	.000	.346	213.603	1.000
	Surface Temperature	532.337	6	88.723	149.625	.000	.690	897.748	1.000
	Bottom Temperature	500.542	6	83.424	300.604	.000	.817	1803.622	1.000
	Surface Salinity	425.324	6	70.887	12.342	.000	.155	74.055	1.000
	Bottom Salinity	253.374	6	42.229	15.073	.000	.183	90.436	1.000
Season	Water Depth	43886.735	1	43886.735	7.567	.006	.018	7.567	.784
	Sediment Depth	8557.452	1	8557.452	1.334	.249	.003	1.334	.211
	Turbidity	9.016	1	9.016	4.677	.031	.011	4.677	.578
	Surface Temperature	1708.849	1	1708.849	2881.850	.000	.877	2881.850	1.000
	Bottom Temperature	1891.629	1	1891.629	6816.169	.000	.944	6816.169	1.000
	Surface Salinity	1566.779	1	1566.779	272.798	.000	.403	272.798	1.000
	Bottom Salinity	936.840	1	936.840	334.384	.000	.453	334.384	1.000
Year * Season	Water Depth	97834.420	6	16305.737	2.811	.011	.040	16.868	.883
	Sediment Depth	51846.078	6	8641.013	1.347	.235	.020	8.084	.528
	Turbidity	100.100	6	16.683	8.654	.000	.114	51.924	1.000
	Surface Temperature	421.919	6	70.320	118.589	.000	.638	711.536	1.000
	Bottom Temperature	416.989	6	69.498	250.425	.000	.788	1502.551	1.000
	Surface Salinity	688.847	6	114.808	19.990	.000	.229	119.938	1.000
	Bottom Salinity	349.920	6	58.320	20.816	.000	.236	124.896	1.000

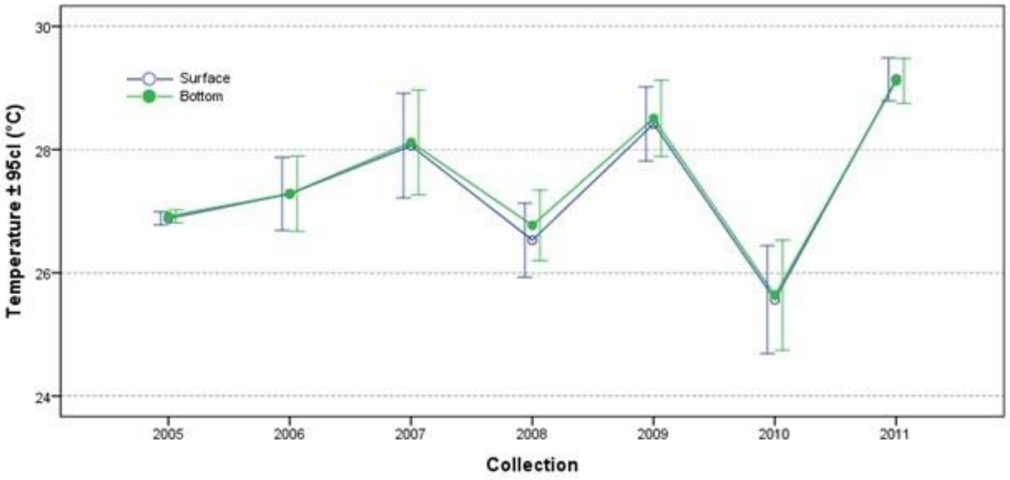

Figure 12A.

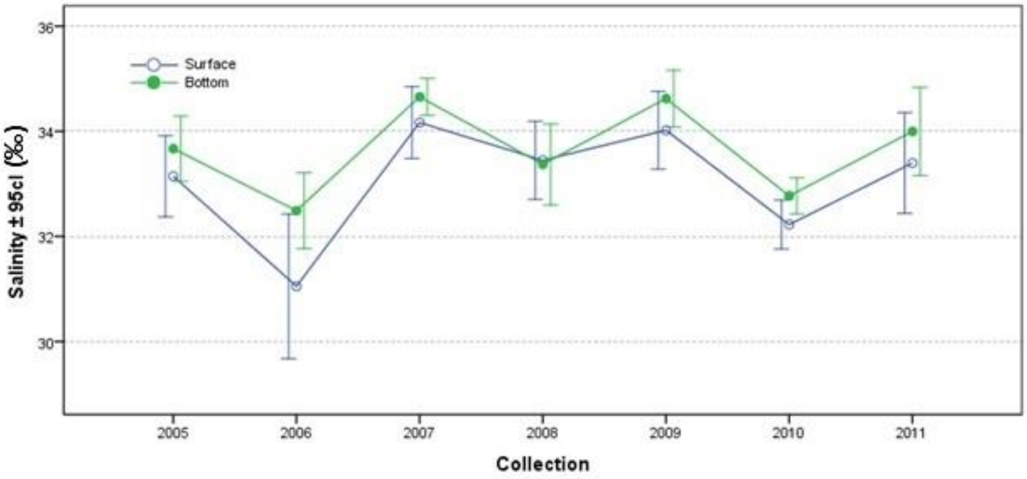

Figure 12B.

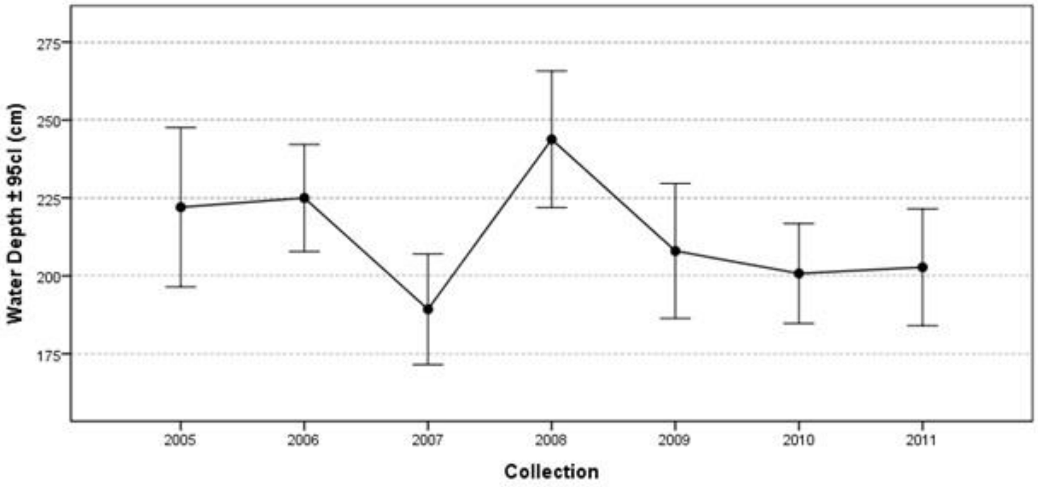

Figure 12C.

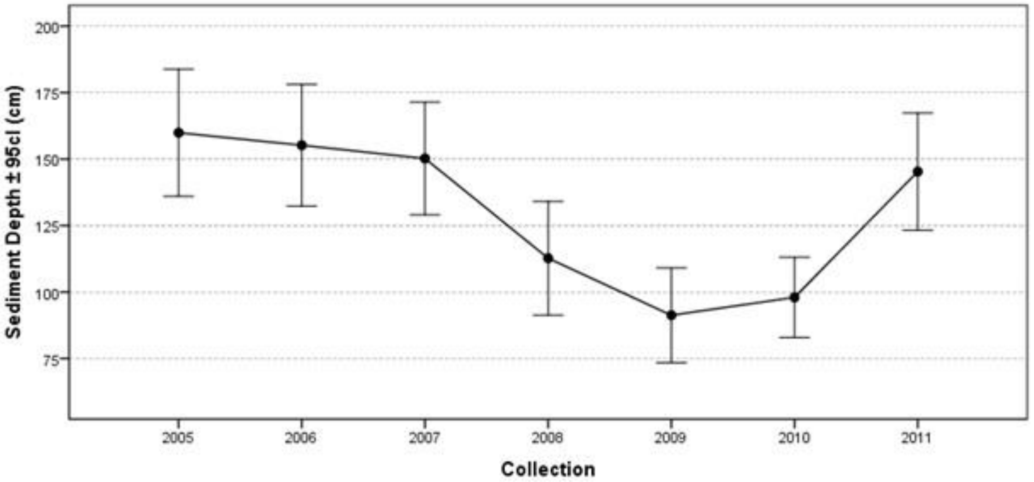

Figure 12D.

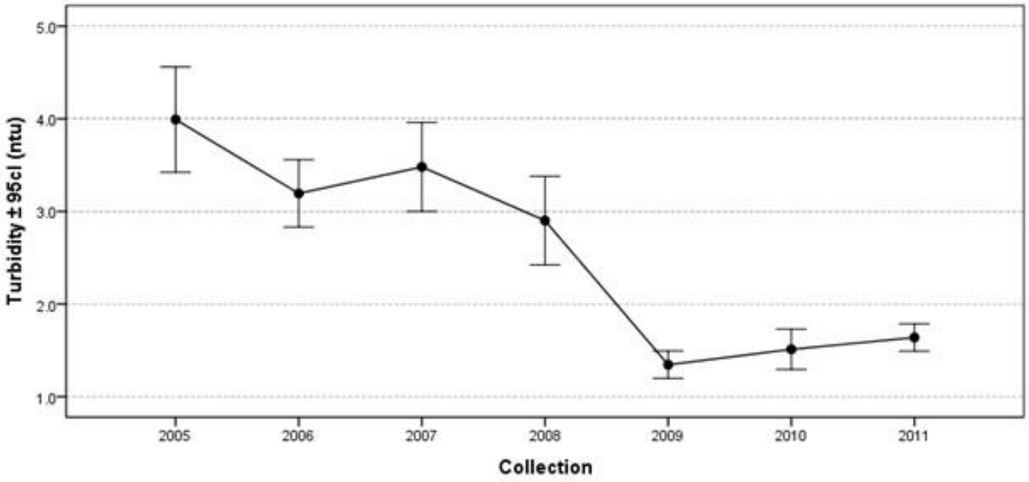

Figure 12E.

Figures 12A-E. Annual mean environmental and physical parameters measured in the Port of Miami basin across the 2005-2011 sampling period with 95% CI error bars: A) surface and bottom temperature (°C), B) surface and bottom salinity (‰), C) water depth (cm), D) sediment depth (cm), E) turbidity (NTU).

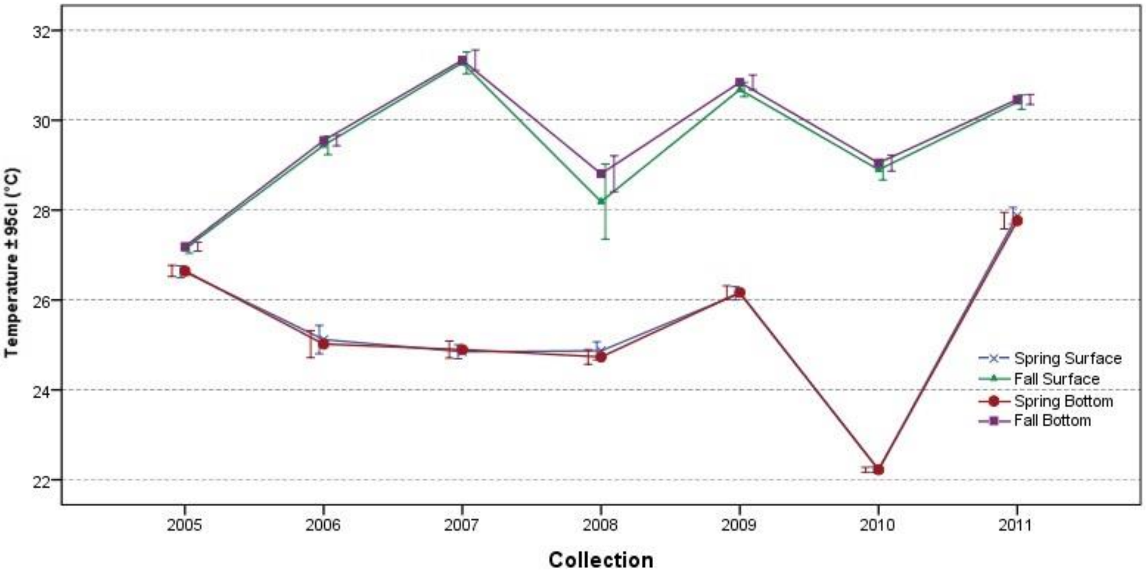

Figure 13A.

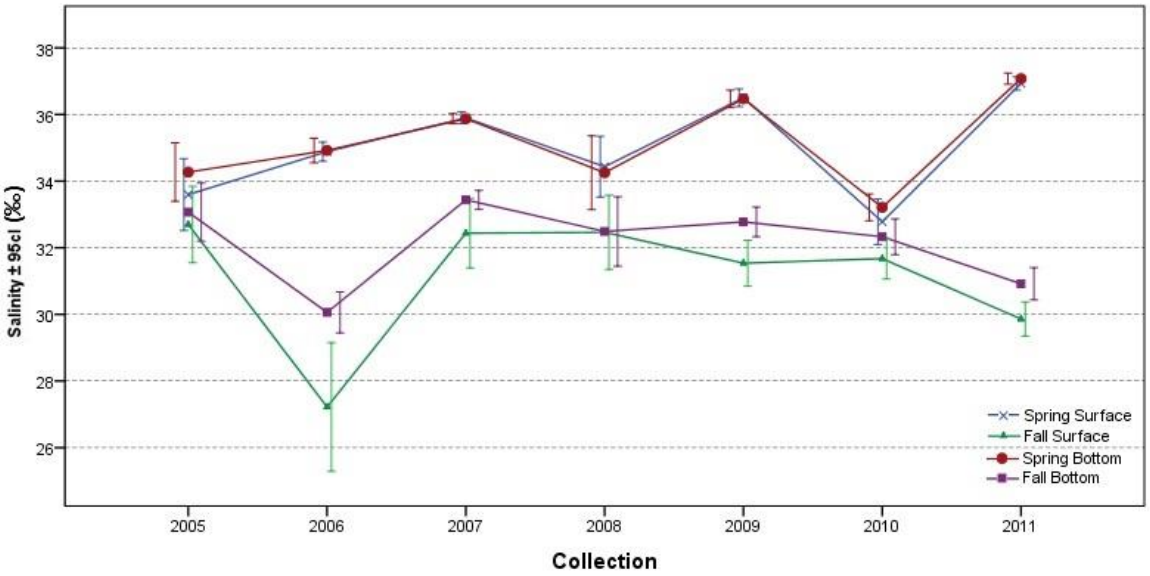

Figure 13B.

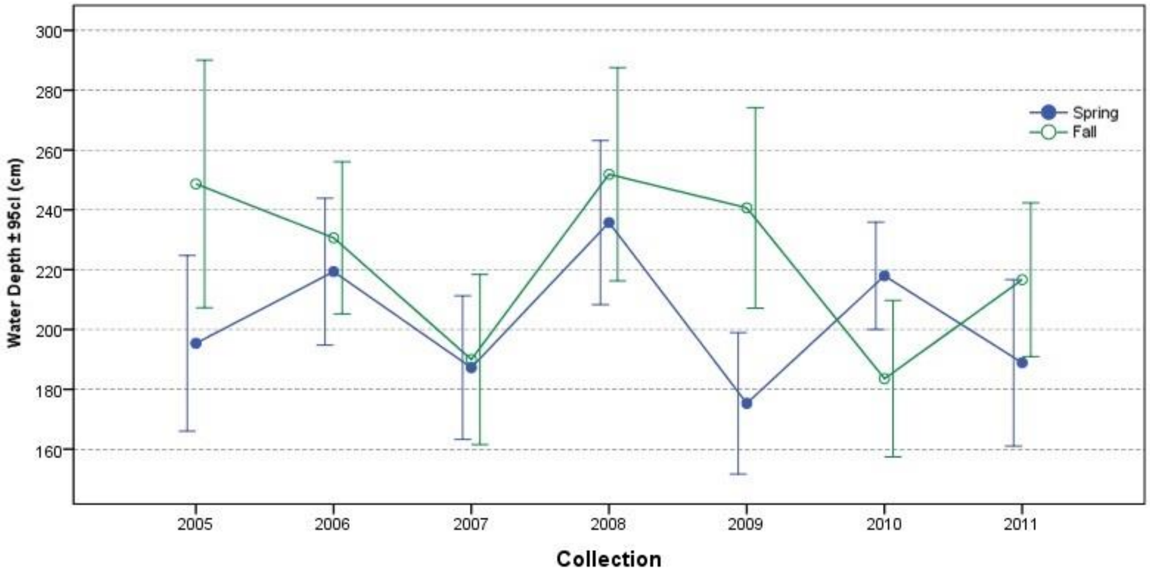

Figure 13C.

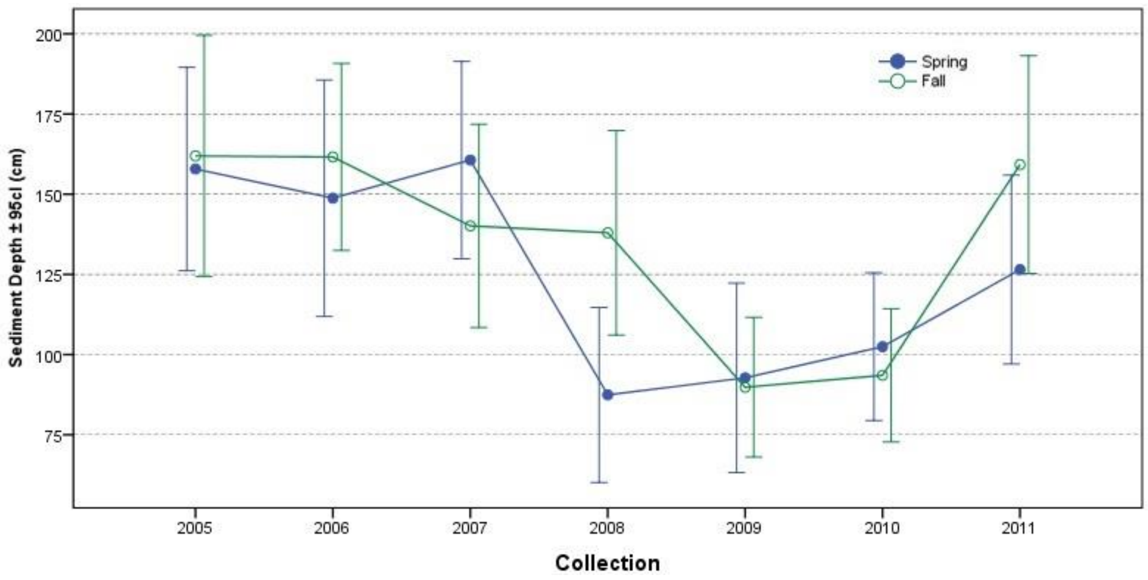

Figure 13D.

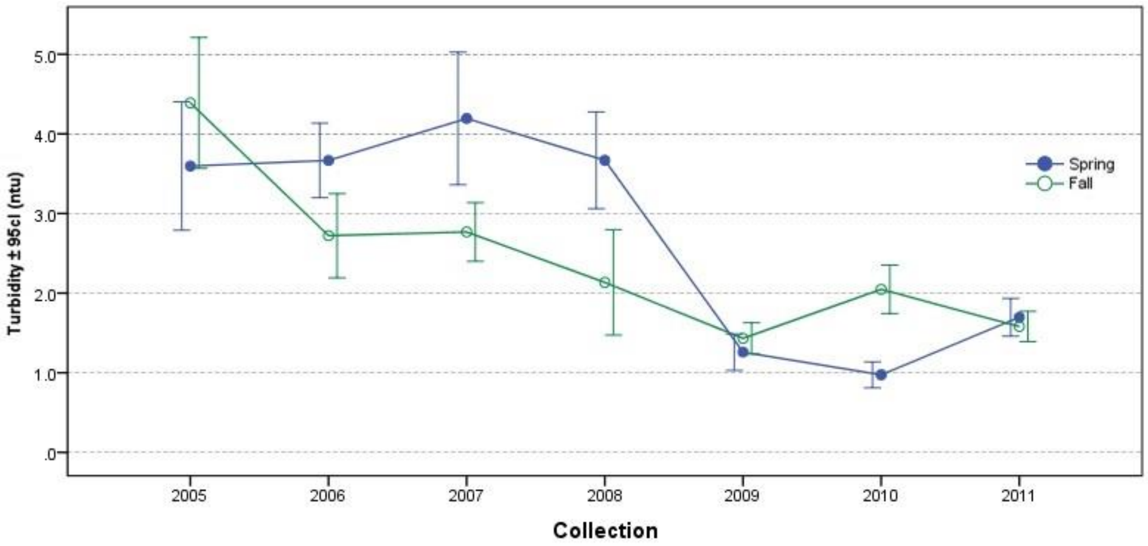

Figure 13E.

Figures 13A-E Seasonal mean environmental and physical parameters measured in the Port of Miami basin across the 2005-2011 sampling period with 95% CI error bars: A) surface and bottom temperature (°C), B) surface and bottom salinity (‰), C) water depth (cm),D) sediment depth (cm), E) turbidity (NTU).

Environmental and physical parameters differed between some sample sites within the basin in relationship to their proximity to coastal regions, channels, or other significant landmarks (see Figure 3). Spatial variation by site (1-30) among environmental and physical parameters was determined by a one way ANOVA. There was a significant spatial effect on water depth, sediment depth, and salinity ($p < 0.01$), but not with temperature or turbidity measurements ($p > 0.05$) (Table 10). Generally, measurements were consistent across the POM basin, but variation in water depth, sediment depth, and salinity between sample sites was seen especially in areas of the basin which were influenced by fresh and saltwater inputs (Figure 3).

There was a significant difference in average overall water depth ($F_{29, 389} = 10.698$, $p \leq 0.001$) between the sampling sites. The lowest average water depths were recorded in the shallow Virginia Key Protected Area Grass patch and the East Coast Grass patch, with Site 7 (no entry zone) measuring the shallowest overall (97.07 ± 24.55cm). The highest average water depth measurements were recorded in channel sites, like Site 4 (310.21 ± 106.19cm) over the sample period. Within the basin, 48.2% of sites measured water depths ranging from 200 to 300 cm deep. Sediment depth variation ($F_{29, 388} = 7.4$, $p \leq 0.001$) seen between the sampling sites showed that the shallower no entry zones exhibited the highest sediment depths, e.g., Site 7 (222.5 ± 91.42cm) and the deeper channel sites exhibited the lowest sediment depths, e.g., Site 4 (47.21 ± 35.33cm) (refer to Figure 3). Sediment depths at 40.7% of sites measured ranged from 100 to 200cm.

Significant differences were seen in salinity distributions in the POM basin. Surface salinity ($F_{1, 29} = 2.209$, $p \leq 0.001$) and bottom salinity ($F_{1, 29} = 2.001$, $p = 0.002$) revealed the highest concentrations at site 22 located at the mouth of Norris Cut leading to the ocean, 35.28 ± 1.63 ‰ and 35.29 ± 1.6 ‰, respectively. The lowest surface and bottom salinity measurements were recorded at site 28 (at the mouth of the Miami River and the bridge leading north of the port) (30.0 ± 5.15 ‰) and site 1 (bottom southwest corner of basin-city east coast) (31.69 ± 3.26 ‰). Sites closest to the Miami coastal freshwater outputs displayed the lowest salinity measurements, while sites located closer to Fisher Island and Norris cut, which leads out to the Atlantic Ocean, displayed the highest salt concentrations (refer to Figure 3). Surface salinity ranged between 30-40 ‰ at 85% of the sites; bottom salinity ranged between 30-40 ‰ at 91% of the sites.

There was no significant variation in water temperature or turbidity among study sites ($p > 0.05$), but recorded high and low measurements reflected location within the POM sample basin. The highest surface and bottom temperature measurements were recorded at sites closest to the Miami City coast; i.e. site 8 (city east coast) (27.76 ± 2.65 ^{o}C) and site 28 (at the mouth of the Miami River and the bridge leading north of the port) (27.71 ± 2.91 ^{o}C) (refer to Figure 3). The lowest surface and bottom temperature measurements were recorded at sites near channels and cuts, for example site 19 (27.02 ± 3.25 ^{o}C) and site 27 (27.11 ± 2.75 ^{o}C). Water temperatures measured at the surface and bottom of the basin ranged 25 to 30 ^{o}C at 60.5% and 58.5% of the sites, respectively. Lowest turbidity measurements were recorded in the no entry zone at Site 7 (1.65 ± 0.7 NTU) while the highest measurements were recorded at Site 5, a channel site with significant boat activity (3.78 ± 2.3 NTU) (see Figure 3). 45.2% of sites measured turbidity levels below 2 NTU (See Appendix 6).

Table 10. Summary of One-way ANOVA results for spatial effects of Environmental and Physical Measurements among the 30 sample sites within the POM basin. Differences significant at $p \leq 0.05$ (2-sided test). Temperature (°C), salinity (‰), turbidity (NTU), sediment depth (cm), and water depth (cm).

Measure	N	Mean ± SD	*F*	*p*
Surface Temperature	420	29.14 ± 1.35	10.698	0.000
Bottom Temperature	420	29.12 ± 1.42	7.400	0.000
Surface Salinity	420	33.40 ± 3.71	0.961	0.526
Bottom Salinity	420	34.00 ± 3.25	0.064	1.000
Turbidity	420	1.64 ± 0.58	0.031	1.000
Sediment Depth	418	145.29 ± 84.60	2.209	0.000
Water Depth	419	202.75 ± 72.48	2.001	0.002

3.2.1 Comparison of Environmental and Physical Measurements between FIAN and Other Monitoring Networks

Nutrient and other environmental data collected from other monitoring agencies within the POM basin were analyzed in order to assess other potential impacts on water quality. Timing and methods differ among monitoring programs resulting in gaps and uncertainties when merging data sets (RECOVER 2014); however, reasonable correlations can be obtained for some variables. Of all the measurements available from DBHYDRO (SFWMD), sufficient data for the study period was found for nine parameters from monitoring stations BB22 and BISC130: salinity, water temperature, turbidity, organic-carbon (OC), dissolved oxygen (DO), pH, chlorophyll-a (CHL-A), nitrate+nitrite (NO_x), and total phosphate (TP). Unlike FIAN sampling methods, salinity and DO were reported from depths of 1m or greater (Table 11). Although there were gaps in these data with missing full and partial years, a few months of those partial years had available data. Any flagged data in the DBHYDRO database indicating problems were excluded. Averages for SFWMD were calculated between the SERC-FIU and DERM stations for a historical timeline of annual measurements for comparison with this study (see Table 11). One way ANOVAs determined that there were significant temporal effects seen in SFWMD environmental variables such as DO, pH, turbidity, and NO_X. Temperature, salinity, CO, CHL-A, and TP did not show significant variation between available sample years.

Excluding the first year of the study period, 2005, significant changes in dissolved oxygen (DO) (F(5,127) = 3.677, $p = 0.004$) and pH (F(5,131) = 3.658, $p = 0.004$) were observed across some years. Between 2006 and 2011 the average DO (6.26 ± 0.98 mg/L) within the basin fluctuated slightly, but the largest change was seen in 2008 with the highest concentration recorded (8.44 ± 7.38). The average pH across the study period, 8.03 ± 0.14, remained basic in nature. The lowest pH was recorded in 2006 (7.91 ± 0.03), gradually increasing by 2007, and then reaching the highest, most basic level across the study period by 2008 (8.12 ± 0.09). Even with variation documented in pH among years, most measurements were near 8.00.

SFWMD average temperature (26.05 ± 3.63 ^{o}C) and salinity (33.26 ± 3.66 ‰) measurements were recorded for 2006 through 2011. Temperature ($F(5,131) = 0.519$, p

= 0.762, ns) and salinity (*F*(5,130) = 2.002, *p* = 0.083, ns) displayed similar measurements across the collection. Salinity and temperature data from POM followed a steady pattern similar to SFWMD data, with a few exceptions (Figures 14B and 14C). FIAN collected data bi-annually from 30 sites around the harbor, while SFWMD data was collected from a single point monthly. Therefore, the FIAN collection shows generally greater annual averages of turbidity and salinity than SFWMD. Between 2006 and 2011 the SFWMD turbidity measurements averaged 1.37 ±1.15 NTU; however, the turbidity measurements were significantly lower over the last three years of the collection when compared to the previous three years (*F*(5,67) = 7.218, *p* < 0.000). The SFWMD turbidity record followed the same general pattern as the FIAN POM data, showing a decreasing trend in suspended solids across years within the basin (Figure 14A).

A five year record from the SFWMD for CHL-A (2007-2011) (Mean = 0.73 ± 0.56 mg/M^3) revealed no significant variation among years (*F*(4,37) = 2.118, *p* = 0.098, ns), but the last three years of the collection had the highest average readings. Over the last four years of the study period (2008-2011), the average OC (Mean = 2.06 ± 2.60 mg/L, *F*(3,34) = 0.089, *p* = 0.966, ns) and TP (Mean = 0.004 ± 0.002 mg/L, *F*(3,34) = 0.210, *p* = 0.889, ns) concentrations remained fairly stable; however, NO_x (Mean = 0.004 ± 0.017 mg/L) did exhibit significant variation between sample years (*F*(3,32) = 4.233, *p* = 0.013), with the lowest values reported in 2011 (Table 11).

Weather data provided by NOAA and the FSU Climate Center showed 2005 with the highest volume of precipitation over the study period, +6.3 in departure from normal (68.2 in), while 2009 exhibited the least amount, -9.8 in departure from normal (52.1 in) (refer to Figure 15A). All other sample years varied slightly above or below the average rainfall for the Miami area, 61.9 in. Visual inspection of graphs from POM salinity and the Miami rainfall history show the natural pattern of salinity decreasing with increasing rainfall (inches). Average annual air temperatures in Miami showed colder than normal years in 2005 and 2010, and the warmest year on record during the study period was 2011 (Figure 15B).

Table 11. SFWMD monthly water quality parameters. Average water quality data measurements of 2 monitoring sites (BB22 and BISC130) in the POM basin. Mean water quality measurements listed ± standard deviation for temperature (° C), salinity (‰), turbidity (NTU), dissolved oxygen (DO) (mg/L), pH (field units), chlorophyl-a (CHL-A) (mg/M^3), total organic Carbon (OC) (mg/L), Nitrate+Nitrite (NO$_x$) (mg/L), and total Phosphate as P (TP) (mg/L). Salinity and DO were reported from depths of 1 m or greater. DBHYDRO database flagged files omitted.

Year	Temperature	Salinity	Turbidity	Dissolved Oxygen (DO)	pH, field	Chlorophyl-a (CHL-A)	Carbon, Total Organic (OC)	Nitrate+Nitrite (NO$_x$)	Phosphate, Total as P (TP)
2005	.	.	.	.	.	.	.	.	.
2006	25.70 ± 1.51	35.00 ± 1.27	1.51 ± 0.68	7.41 ± 0.88	7.91 ± 0.03	.	.	.	.
2007	26.18 ± 3.19	34.78 ± 2.21	1.84 ± 1.97	6.45 ± 0.65	8.02 ± 0.19	0.29 ± 0.17	.	.	.
2008	25.44 ± 2.98	33.52 ± 7.41	2.29 ± 0.66	8.44 ± 7.38	8.12 ± 0.09	0.40 ± 1.34	2.12 ± 0.52	0.009	0.004
2009	27.12 ± 3.32	33.53 ± 2.99	1.09 ± 0.78	5.85 ± 1.45	8.07 ± 0.07	0.85 ± 0.30	2.22 ± 1.49	0.017 ± 0.021	0.004 ± 0.004
2010	25.63 ± 4.69	32.10 ± 2.89	0.57 ± 0.18	6.09 ± 0.68	8.04 ± 0.12	0.93 ± 0.41	1.71 ± 4.75	0.004 ± 0.014	0.004 ± 0.001
2011	26.20 ± 3.45	32.88 ± 2.66	0.59 ± 0.20	6.11 ± 0.77	7.98 ± 0.14	0.79 ± 0.26	2.23 ± 0.32	0.006 ± 0.010	0.003
AVG	26.05 ± 3.63	33.26 ± 3.66	1.37 ± 1.15	6.26 ± 0.98	8.03 ± 0.14	0.73 ± 0.56	2.06 ± 2.60	0.004 ± 0.017	0.004 ± 0.002

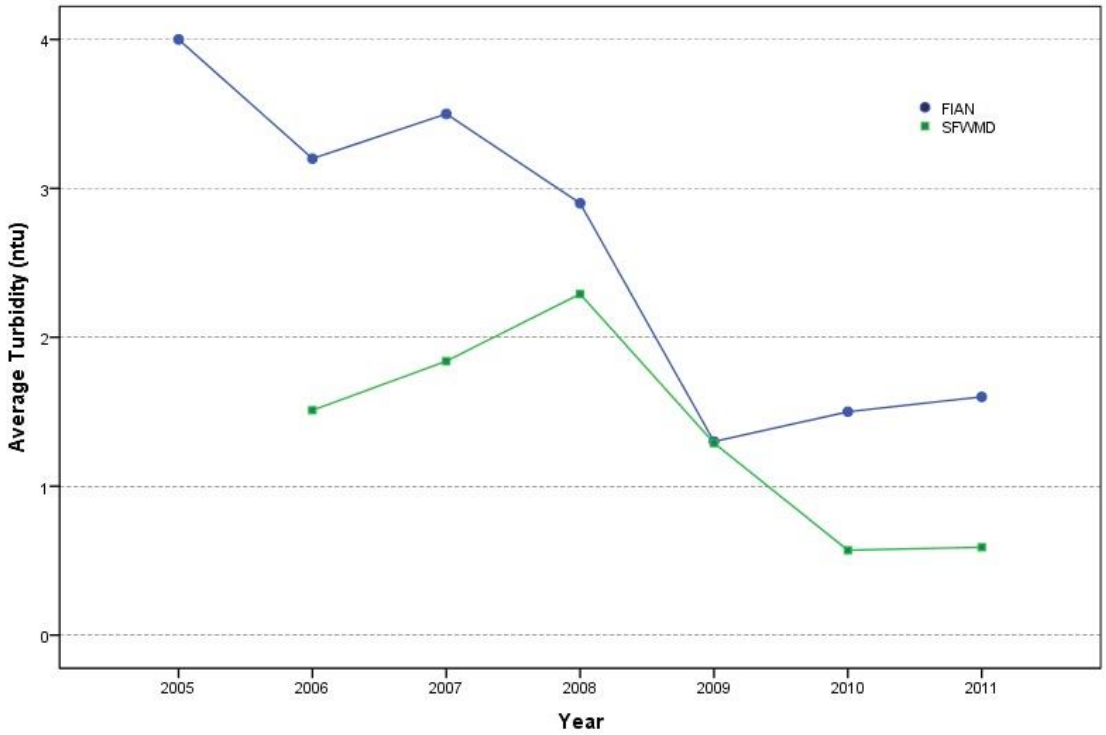

Figure 14A.

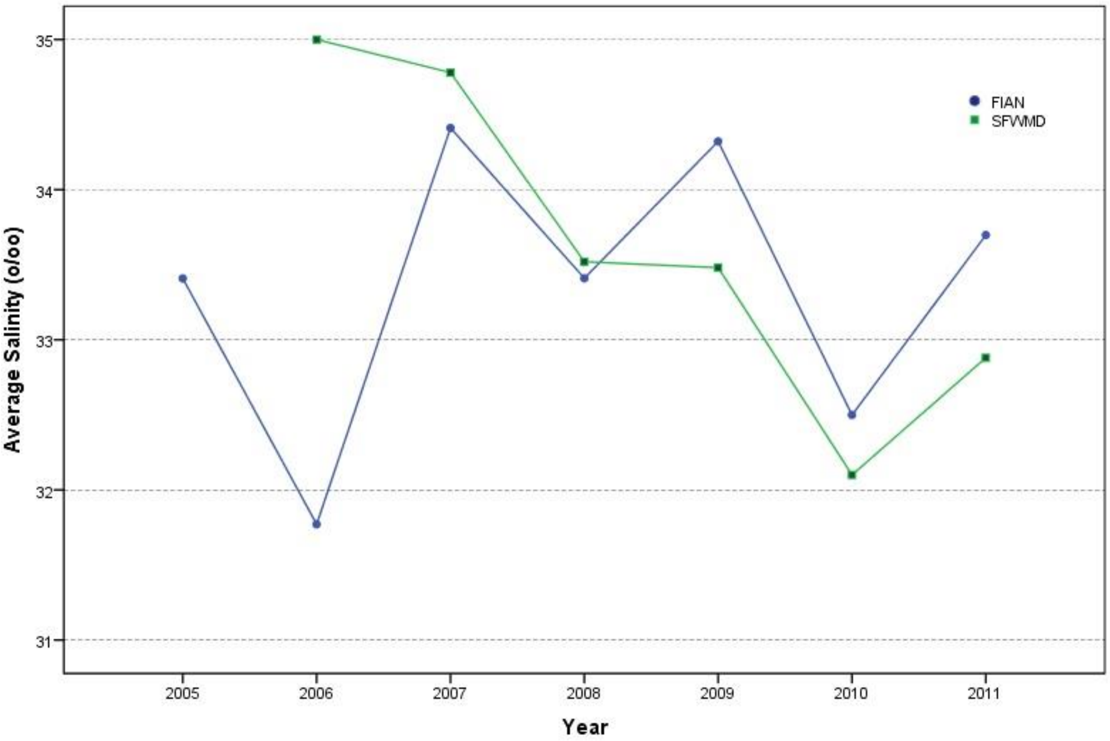

Figure 14B.

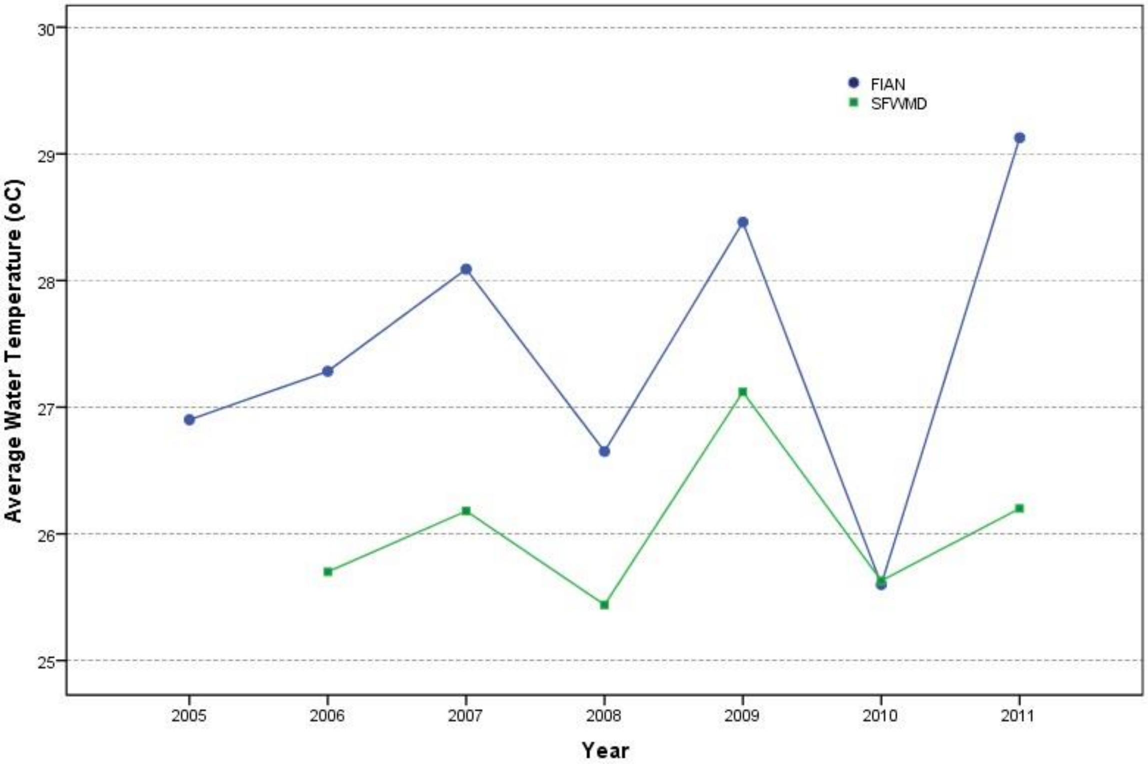

Figure 14C.

Figures 14A-C. Graphs: Mean annual environmental conditions in POM basin based on available data. Data are from this study (FIAN) and the SFWMD in the Port of Miami basin across the 2005-2011 sampling period: A) turbidity (NTU), B) salinity(‰) and, C) average water temperature (°C).

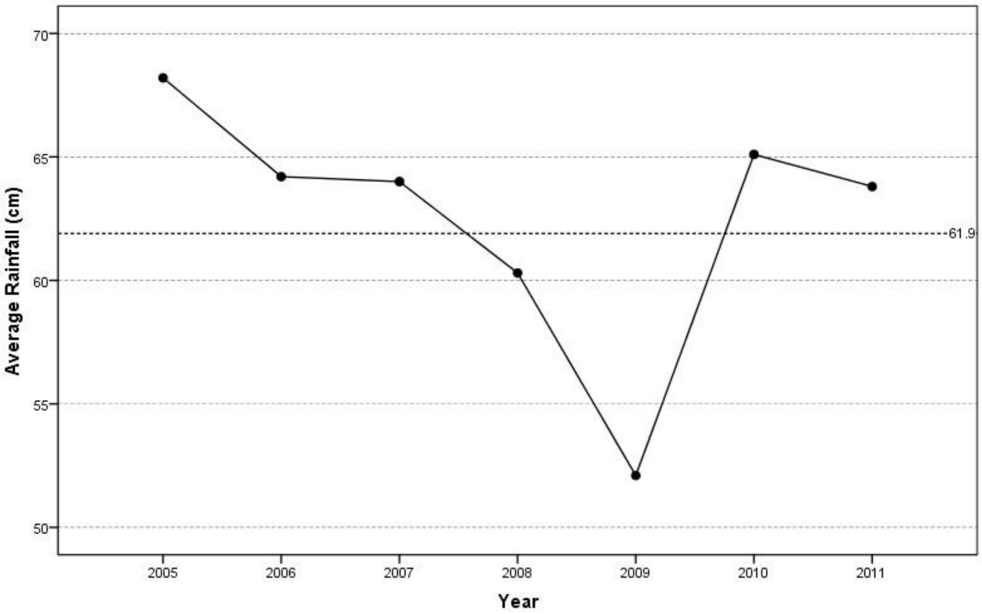

Figure 15A.

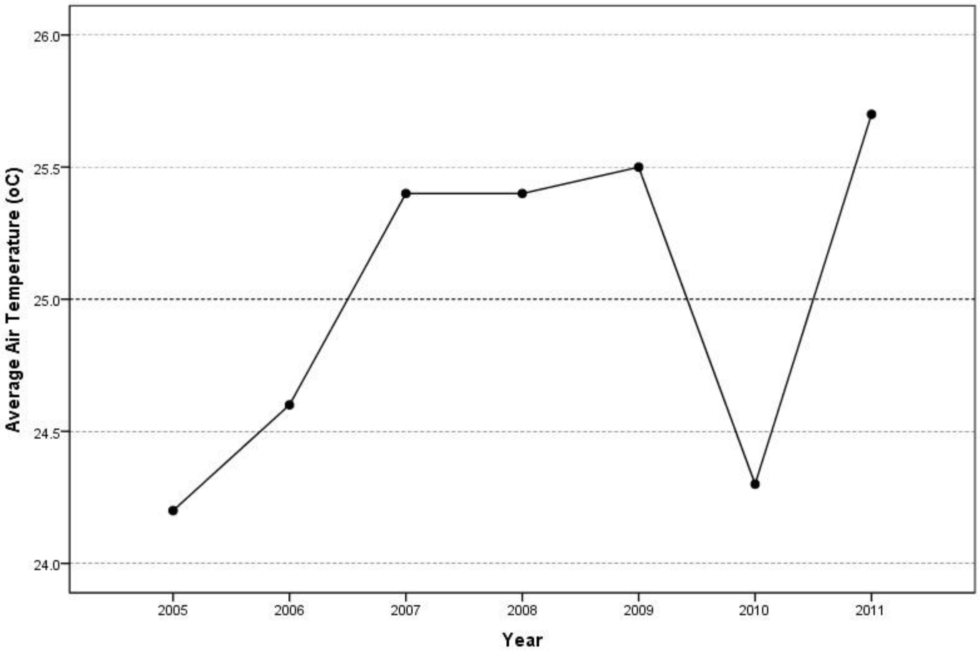

Figure 15B.

Figures 15A-B. NOAA Weather Graphs: A) Miami annual rainfall (inches) (average 61.9 in) and B) air temperatures (^{o}C) 2005-2011 (average 25 ^{o}C). Dashed line represents annual average for the Miami area. All data provided by NOAA and the FSU Climate Center: http://climatecenter.fsu.edu/products-services/data/precipitation/miami

3.3 FIAN Seagrass Community Relations with the Environmental and Physical Measurements

3.3.1 Relationships between Seagrass Presence and the Environmental and Physical Conditions

The baseline regression model (Table 12, Model 1A) investigating temporal effect (seasonal and annual) on seagrass presence was not statistically significant ($p > 0.05$). Year and season of collection were not significant predictors of the presence of seagrass. However, the baseline regression model (Table 12, Model 1B) investigating the effect of environmental and physical variables on the presence of seagrass was statistically significant ($F = 8.025$, $p < 0.001$) and explained 12.1% ($R^2 = 0.121$) of the variability. Temperature, salinity and sediment depth were not significant predictors of the presence of seagrass ($p > 0.05$). Only water depth ($\beta = -0.001$, $p < 0.001$) and turbidity ($\beta = -0.020$, $p = 0.009$) were significant predictors of seagrass presence.

When the baseline models were combined to include effects of both temporal (year and season) and the environmental and physical variables on seagrass presence, the model did not change, and still explained 12.1% of variability ($R^2 = 0.121$, $F = 6.213$, $p < 0.001$) (Table 12, Model 1C). Adding temporal variables did not influence the model, because they were not significant contributors ($p > 0.05$), as seen in the baseline temporal model (model 1A). Water depth ($\beta = -0.001$, $p < 0.001$) and turbidity ($\beta = -0.020$, $p = 0.020$) remained the only effective predictors of seagrass presence.

The final regression model (Table 12, Model 1D), which investigated the combined effects of temporal, the environmental and physical variables, and the presence of algae on seagrass presence, was the best model ($F = 5.798$, $p < 0.001$) but still only explained 12.5% ($R^2 = 0.125$) of variability. However, the temporal variables and algae presence did not significantly affect the model ($p > 0.05$). Water depth ($\beta = -0.001$, $p < 0.001$) and turbidity ($\beta = -0.019$, $p = 0.025$) were the only significant predictors of seagrass presence in the final model. As such, seagrasses are more likely to occur in shallower waters with greater water clarity. Overall, depth and water clarity in the POM basin were the only effective predictors of seagrass presence in all models involving environmental effects, see Table 12, Models 1B-D.

Table 12. Models 1A-D. Multiple Regression models for Seagrass occurrence and environmental variables. Seagrass and algae measured as present (1) or absent (0). Water depth, and sediment depth are measured in cm, temperature is measured in ^{o}C, salinity is measured in ‰, and turbidity is measured in NTU. β is an unstandardized coefficient of regression, reported with standard error and significance, *p*-value. Conventional variables include year of sample (2005-2011), season (1 = spring, 2 = fall). A. Models evaluating grass occurrence for conventional variables (year*season). B. Models evaluating grass occurrence for environmental variables (depth, temp, salinity, etc.). C. Models evaluating grass occurrence adjusted for conventional and environmental variables. D. Models evaluating grass occurrence adjusted for conventional, environmental and algae variables. *Significance = $p < 0.05$.

Model Set 1A-D	**Model 1-A**						**Model 1-B**				
2005-2011	N	β	SE	*p*			N	β	SE	*p*	
Seagrass Present											
Year	420	0.010	0.007	0.135							
Season		0.005	0.027	0.860							
						Water Depth	418	-0.001	0.000	<0.001	*
						Sediment Depth		0.000	0.000	0.225	
						Turbidity		-0.020	0.007	0.009	*
						Surface Temperature		-0.014	0.023	0.542	
						Bottom Temperature		0.014	0.023	0.548	
						Surface Salinity		-0.007	0.006	0.274	
						Bottom Salinity		0.005	0.009	0.565	
	Model 1-C						**Model 1-D**				
Year	418	-0.001	0.008	0.944		Year	418	-0.001	0.008	0.887	
Season		-0.005	0.052	0.921		Season		-0.002	0.052	0.977	
Water Depth		-0.001	0.000	<0.001	*	Water Depth		-0.001	0.000	<0.001	*
Sediment Depth		0.000	0.000	0.235		Sediment Depth		0.000	0.000	0.224	
Turbidity		-0.020	0.009	0.020	*	Turbidity		-0.019	0.009	0.025	*
Surface Temperature		-0.015	0.024	0.538		Surface Temperature		-0.015	0.024	0.513	
Bottom Temperature		0.015	0.026	0.560		Bottom Temperature		0.016	0.026	0.538	
Surface Salinity		-0.007	0.006	0.277		Surface Salinity		-0.007	0.006	0.281	
Bottom Salinity		0.005	0.009	0.607		Bottom Salinity		0.004	0.009	0.636	
						Algae Present		0.061	0.044	0.166	

3.3.2 Relationships between Seagrass Species Densities and Environmental and Physical Conditions

The baseline regression models (Table 13, Models 2-4A) investigating temporal effects (seasonal and annual) on individual seagrass cover-densities were not statistically significant ($p > 0.05$). There were no temporal effects seen in the seagrass species cover-densities within the POM basin. Cover of individual seagrass species did not change dramatically between seasons or years during the collection period, but some environmental measurements within the basin were found to have an effect on the seagrasses. The baseline regression models (Table 13, Models 2-4B) investigating the effects of environmental variables on seagrass species cover were all statistically significant ($p < 0.001$). Temperature, salinity and turbidity were not significant predictors of individual seagrass coverage within the basin ($p > 0.05$). Water depth was a significant predictor for each species ($p < 0.01$), and was the only significant predictor in the models for *Thalassia* ($\beta = -0.005$, $p < 0.001$) and *Halodule* cover-densities ($\beta = -0.003$, $p < 0.001$). The environmental effect baseline models explained 20.2% ($R^2 = 0.202$, $F = 3.320$, $p = 0.002$) of variability in *Thalassia* cover-density (Table 13, Model 3B), and 5.4% ($R^2 = 0.054$, $F = 14.789$, $p < 0.001$) of variability in *Halodule* cover-density (Model 4B). The baseline model for *Syringodium* explained 12.9% ($R^2 = 0.129$, $F = 8.663$, $p < 0.001$) of variability in cover-density (Table 13, Model 2B), and in addition to water depth, sediment depth was also a significant predictor. Increased water depth predicted decreased cover-density for all seagrass species, and increased sediment depth predicted increased *Syringodium* cover-density (Table 13, Models 2-4B).

However, when the baseline models were combined to include effects of both temporal and environmental variables on seagrass cover-density, all models improved (Table 13, Models 2-4C). Other variables were not effective predictors of seagrass cover-density, but the combined models showed a significant annual effect on *Syringodium* F = (7.398, $p < 0.001$) (Model 2C) and *Thalassia* ($F = 12.323$, $p < 0.001$) (Table 13, Model 3C) density. 14% ($R^2 = 0.140$) of the variability in *Syringodium* and 21.4% of variability in *Thalassia* cover-density ($R^2 = 0.214$) were explained by the models. When all variables were combined, the models fit the data better than the baseline regressions and show that for every increase in year (see Figure 8), there was a decrease in *Syringodium* (β = -0.083, p = 0.036; Table 13, Model 2C) and *Thalassia* cover-density (β = -0.062, p = 0.025; Table 13, Model 3C). Water depth (β = -0.003, $p <$ 0.001) remained the only significant predictor of *Halodule* cover-density, with the model only explaining 5.8% (R^2 = 0.058, F = 2.777, p = 0.004) of variability.

The comprehensive regression model investigating the combined effects of temporal, environmental and physical, and algae cover-density variables on seagrass cover-density, was the best model for each individual seagrass species (Table 13, Models 2-4D). The model significantly explained (F = 9.432, $p <$ 0.001) 23.3% (R^2 = 0. 233) of variability in *Syringodium* density. Season, temperature, salinity, turbidity, and green and brown algae density were not significant predictors of *Syringodium* density ($p >$ 0.05). The model predicted that *Syringodium* cover-density would increase with shallower water depth, lower calcareous algae cover-density, and higher red algae cover-density ($p <$ 0.01; Table 13, Model 2D). The model also showed that *Syringodium* cover-density decreased through the study period. In the model for *Thalassia* (F = 9.014, $p <$ 0.001), 22.5 % (R^2 = 0. 225) of variability in cover-density was explained, with water depth as the only significant predictor. *Thalassia* cover-density tended to be higher in shallower water depth (β = -0.006, $p <$ 0.001) (Table 13, Model 3D). Water depth and red algae cover-density were the only significant predictors in the *Halodule* cover-density model (F = 3.096, $p <$ 0.001), which was only able to explain 9.1% (R^2 = 0. 091) variability (Table 13, Model 4D). Shallower water depth (β = -0.003, $p <$ 0.001) and decreased red algae cover-density (β = -0.229, p = 0.002) predicted increased *Halodule* cover-density.

Table 13. Models 2-4 A -D. Multiple Enter-wise Regression models for individual seagrass cover-densities and environmental and physical measurements. *Syringodium*, *Thalassia*, and *Halodule* seagrass cover-density measurements are in #/m^2. Water depth and sediment depth are measured in cm, temperature is measured in ^{o}C, salinity is measured in ‰, turbidity measured in NTU. β is an unstandardized coefficient of regression, reported with standard error and significance, *p*-value. Conventional variables include year of sample (2005-2011), season (1 = spring, 2 = fall). A. Models evaluating seagrass cover-density for conventional variables (year*season). B. Models evaluating seagrass cover-density for environmental variables (depth, temp, salinity, etc.). C. Models evaluating seagrass cover-density adjusted for conventional and environmental variables. D. Models evaluating seagrass cover-density adjusted for conventional, environmental and habitat (algae) variables. *Significance = $p < 0.05$.

Model Set 2A-D	**Model 2-A**						**Model 2-B**				
2005-2011	N	β	SE	*p*			N	β	SE	*p*	
***Syringodium* Cover-Density**											
Year	420	-0.052	0.035	0.140							
Season		0.009	0.142	0.949							
						Water Depth	418	-0.005	0.001	<0.001	*
						Sediment Depth		0.002	0.001	0.006	*
						Turbidity		-0.010	0.039	0.798	
						Surface Temperature		-0.050	0.121	0.679	
						Bottom Temperature		0.043	0.121	0.720	
						Surface Salinity		-0.006	0.034	0.854	
						Bottom Salinity		-0.053	0.046	0.253	
	Model 2-C						**Model 2-D**				
Year	418	-0.083	0.040	0.036	*	Year	418	-0.113	0.038	0.003	*
Season		-0.306	0.271	0.260		Season		-0.154	0.260	0.554	
Water Depth		-0.005	0.001	<0.001	*	Water Depth		-0.005	0.001	<0.001	*
Sediment Depth		0.002	0.001	0.015	*	Sediment Depth		0.001	0.001	0.112	
Turbidity		-0.054	0.045	0.233		Turbidity		-0.026	0.043	0.543	
Surface Temperature		-0.079	0.123	0.521		Surface Temperature		-0.105	0.118	0.371	
Bottom Temperature		0.116	0.134	0.388		Bottom Temperature		0.227	0.130	0.080	
Surface Salinity		-0.003	0.034	0.928		Surface Salinity		0.002	0.032	0.955	
Bottom Salinity		-0.070	0.048	0.149		Bottom Salinity		-0.072	0.046	0.120	
						Red Algae		0.629	0.101	<0.001	*
						Green Algae		-0.257	0.180	0.153	
						Brown Algae		0.355	0.377	0.348	
						Calcareous Algae		-0.433	0.146	0.003	*

Model Set 3A-D	**Model 3-A**						**Model 3-B**				
2005-2011	N	β	SE	*p*			N	β	SE	*p*	
***Thalassia* Cover-Density**											
Year	420	-0.021	0.026	0.420							
Season		-0.088	0.102	0.390							
						Water Depth	418	-0.005	0.001	<0.001	*
						Sediment Depth		0.000	0.001	0.609	*
						Turbidity		-0.008	0.027	0.773	
						Surface Temperature		0.119	0.084	0.157	
						Bottom Temperature		-0.093	0.084	0.269	
						Surface Salinity		0.033	0.023	0.165	
						Bottom Salinity		0.001	0.032	0.986	

	Model 3-C						**Model 3-D**				
Year	418	-0.062	0.027	0.025	*	Year	418	-0.054	0.028	0.052	
Season		0.184	0.188	0.329		Season		0.155	0.189	0.413	
Water Depth		-0.005	0.001	<0.001	*	Water Depth		-0.006	0.001	<0.001	*
Sediment Depth		0.000	0.001	0.938		Sediment Depth		0.000	0.001	0.601	
Turbidity		-0.043	0.031	0.163		Turbidity		-0.052	0.031	0.098	
Surface Temperature		0.136	0.085	0.111		Surface Temperature		0.136	0.086	0.114	
Bottom Temperature		-0.129	0.093	0.167		Bottom Temperature		-0.145	0.094	0.125	
Surface Salinity		0.039	0.023	0.100		Surface Salinity		0.038	0.023	0.107	
Bottom Salinity		0.011	0.034	0.749		Bottom Salinity		0.013	0.034	0.705	
						Red Algae		-0.134	0.074	0.069	
						Green Algae		0.061	0.131	0.640	
						Brown Algae		0.292	0.275	0.289	
						Calcareous Algae		0.095	0.106	0.369	

Model Set 4A-D	**Model 4-A**						**Model 4-B**				
2005-2011	N	β	SE	*p*			N	β	SE	*p*	
***Halodule* Cover-Density**											
Year	420	-0.031	0.023	0.183							
Season		0.107	0.092	0.246							
						Water Depth	418	-0.003	0.001	<0.001	*
						Sediment Depth		0.000	0.001	0.949	
						Turbidity		0.038	0.027	0.160	
						Surface Temperature		0.017	0.082	0.835	
						Bottom Temperature		0.016	0.082	0.843	
						Surface Salinity		-0.008	0.023	0.733	
						Bottom Salinity		0.002	0.031	0.961	

	Model 4-C						**Model 4-D**				
Year	418	-0.036	0.027	0.185		Year	418	-0.031	0.027	0.257	
Season		-0.006	0.185	0.973		Season		-0.025	0.185	0.892	
Water Depth		-0.003	0.001	<0.001	*	Water Depth		-0.003	0.001	<0.001	*
Sediment Depth		0.000	0.001	0.777		Sediment Depth		0.000	0.001	0.869	
Turbidity		0.018	0.031	0.559		Turbidity		0.013	0.031	0.681	
Surface Temperature		0.016	0.084	0.845		Surface Temperature		0.046	0.084	0.586	
Bottom Temperature		0.020	0.092	0.827		Bottom Temperature		-0.039	0.092	0.672	
Surface Salinity		-0.005	0.023	0.818		Surface Salinity		-0.007	0.023	0.750	
Bottom Salinity		0.001	0.033	0.972		Bottom Salinity		0.001	0.033	0.983	
						Red Algae		-0.229	0.072	0.002	*
						Green Algae		-0.148	0.128	0.248	
						Brown Algae		-0.465	0.268	0.084	
						Calcareous Algae		0.036	0.104	0.727	

3.3.3 Relationships between Average Seagrass Canopy Height and Environmental and Physical Conditions

To investigate temporal effects (either by season or by year) on average seagrass canopy height, a baseline regression model (Table 14, Model 5A) was used ($F = 7.689$, $p = 0.001$) explaining 3.9% ($R^2 = 0.039$) of variability in seagrass canopy height. Season was not a significant predictor of canopy height ($p > 0.05$) in this model; however, average seagrass canopy height increased with increasing years, $\beta = 1.527$, $p < 0.001$ (Table 14, Model 5A).

The effects of environmental variables on average seagrass canopy height were examined by the baseline regression model (Table 14, Model 5B), which was found to be statistically significant ($F = 10.195$, $p < 0.001$) and able to explain 16% ($R^2 = 0.160$) of the variability in seagrass canopy height. Temperature (surface and bottom) and surface salinity were not significant predictors of canopy height ($p > 0.05$), but the model showed that shallower water depth, decreased turbidity, lower bottom salinity, and deeper sediment depth predicted increased canopy height ($p < 0.01$; Table 14, Model 5B).

The combined regression model (Model 5C) investigating the effects of temporal and environmental variables on average seagrass canopy height ($F = 9.195$, $p < 0.001$) was better than the individual baseline models in that it explained 18.2% ($R^2 = 0.182$) of variability in the seagrass canopy height. Season, temperature (surface and bottom), surface salinity, and turbidity were not significant predictors of seagrass canopy height ($p > 0.05$) in this model; however, increasing year, shallower water depth, lower bottom salinity, and deeper sediment depth predicted increased seagrass canopy height ($p < 0.01$; Table 14, Model 5C).

A final regression model (Table 14, Model 5D) investigating the combined effects of temporal, environmental, and algae cover variables on seagrass canopy height was the best model ($F = 10.666$, $p < 0.001$) and explained 27.4% ($R^2 = 0.274$) of variability in seagrass canopy height. Season, temperature (surface and bottom), surface salinity, turbidity, as well as green and brown algae cover were not significant predictors of seagrass canopy height ($p > 0.05$) in this model. Seagrass canopy height was affected by multiple factors that included sediment and water depths, salinity, and the presence of red and calcareous algae. Shallower water depth, lower bottom salinity, and decreasing calcareous algae cover predicted increased average seagrass canopy height ($p < 0.01$; Table 14, Model 5D).

Table 14. Models 5A-D. Multiple Enter-wise Regression Models for Average Seagrass Canopy height and environmental and physical measurements. Algae cover-density measurements are in #/m^2. Canopy height measurement, water depth, and sediment depth are measured in cm, temperature is measured in °C, salinity is measured in ‰, turbidity measured in NTU. β is an unstandardized coefficient of regression, reported with standard error and significance, *p*-value. Conventional variables include year of sample (2005-2011), season (1 = spring, 2 = fall). A. Models evaluating seagrass cover-density for conventional variables (year*season). B. Models evaluating seagrass canopy height for environmental variables (depth, temp, salinity, etc.). C. Models evaluating seagrass canopy height adjusted for conventional and environmental variables. D. Models evaluating seagrass canopy height adjusted for conventional, environmental and habitat (algae) variables. *Significance = $p < 0.05$.

Model Set 5A-D	**Model 5-A**						**Model 5-B**				
2005-2011	N	β	SE	*p*			N	β	SE	*p*	
Average Canopy Height											
Year	420	1.527	0.425	<0.001	*						
Season		2.641	1.704	0.122							
						Water Depth	418	-0.054	0.012	<0.001	*
						Sediment Depth		0.033	0.010	0.002	*
						Turbidity		-1.619	0.508	0.002	*
						Surface Temperature		2.365	1.396	0.091	
						Bottom Temperature		-2.380	1.395	0.089	
						Surface Salinity		0.489	0.412	0.236	
						Bottom Salinity		-1.847	0.581	0.002	*
	Model 5-C						**Model 5-D**				
Year	418	1.497	0.477	0.002	*	Year	418	1.184	0.460	0.010	*
Season		-0.153	3.270	0.963		Season		1.275	3.125	0.683	
Water Depth		-0.051	0.012	<0.001	*	Water Depth		-0.044	0.012	<0.001	*
Sediment Depth		0.039	0.010	<0.001	*	Sediment Depth		0.031	0.010	0.002	*
Turbidity		-0.723	0.578	0.212		Turbidity		-0.442	0.554	0.426	
Surface Temperature		2.336	1.415	0.100		Surface Temperature		1.849	1.349	0.171	
Bottom Temperature		-2.442	1.554	0.117		Bottom Temperature		-0.873	1.500	0.561	
Surface Salinity		0.383	0.409	0.350		Surface Salinity		0.460	0.389	0.238	
Bottom Salinity		-1.862	0.609	0.002	*	Bottom Salinity		-1.840	0.578	0.002	*
						Red Algae		7.153	1.185	<0.001	*
						Green Algae		-0.806	2.363	0.733	
						Brown Algae		6.842	4.641	0.141	
						Calcareous Algae		-5.354	1.811	0.003	*

4.0 Discussion

This study set out to determine whether there were any effects of natural and anthropological change evident in the Port of Miami basin seagrass habitat. Some trends and patterns were detected in the basin. South Florida experiences seasonal and annual weather variation (Sutula et al. 2003) and the POM basin is impacted by shipping and a large coastal human population (Caccia and Boyer 2005; CDMP 2011; FDH 2012). The seagrass habitats in the POM basin are susceptible to many anthropogenic disturbances due to the continued development in the area. The distribution and growth of submerged aquatic vegetation (i.e. seagrass and algae) within an estuarine environment are controlled by a combination of factors. Decreases in seagrass populations have been attributed to environmental change (e.g. changes in water clarity, light attenuation and salinity) and anthropogenic-induced damage to the habitat particularly the introduction of pollutants, coastal development, dredge and fill activities, and motor vessel damage (Littler et al. 1989; Sargent et al. 1995; Hall et al. 1999).

4.1 Habitat Patterns of Benthic Vegetation

The Port of Miami basin, within the North Biscayne Bay region, is designated as a tall-canopy mixed seagrass habitat within South Florida (Robblee and Browder 2012) and is dominated by three principal species of seagrass found in South Florida (*S. filiforme, T. testudinum,* and *H. wrightii*) and several of the algae characteristic of South Florida seagrass beds. Over half the sample sites within the basin contained a mixture of all three of these seagrass species along with associated algae (Table 3). Algae are important secondary habitat builders within the POM basin. From the four algae types, red and calcareous-green algae were most abundant and green and brown algae were the least abundant groups observed (Figure 11).

Spatial patterns of the three principle seagrasses and associated algae observed in the basin are most likely dictated by habitat conditions (Figure 3). The average canopy height and the seagrass and algae coverage-densities were generally greater in the shallower and protected sites versus the deeper, busy channel sites. Among the FIAN seven collection years (2005-2011), the three main seagrasses species showed no significant variation in their cover-density (Figure 8, Appendix 1). In contrast, the average seagrass canopy height did experience larger changes across the sample years

(Figure 10, Appendix 2). This could be due to slightly greater cover-densities of the taller grass species like *Syringodium* and *Thalassia* (Figure 1) during certain years. Calcareous and brown algae cover-density did exhibit variation among the study years (Figure 11). Brown algae variation can most likely be attributed to the low occurrence of these species within the basin. Red and green algae, both abundant, did not exhibit significant change in cover-density across the collections (Figure 11).

Seasonal differences in seagrass and algae distribution were expected in South Florida coastal waters (Phillips 1960; Moffler and Durako 1982; Dineen 2001; Robblee and Browder 2012). The three principle seagrasses in this study displayed no significant change in cover-density or occurrence between seasons (spring and fall) (see Table 5). However, *Syringodium* and *Halodule* canopy heights as well as the overall average seagrass canopy height did exhibit seasonality within the POM basin (Table 5). Although not significant, seagrass occurrence was just marginally higher in the fall collections. Significant seasonality was observed in some of the algae groups. Generally, densities of red and brown algae are higher in the spring (dry season) than in the fall (wet season) and the cover-densities of green and calcareous algae are higher in the fall than in the spring in the POM basin (Table 5). Red algae showed the greatest variation between sampling seasons. The seasonal differences seen between the algae groups may be explained by the greater occurrence of algae found in the spring collections (Appendix 4).

Most seagrass species exhibit seasonality in both growth and biomass. The three major seagrasses monitored are all dioecious plants (Moffler and Durako 1987) and can grow by sexual and asexual reproduction. Because of the seasonal nature of flowering in seagrasses, water temperature is suggested to play an influential role in controlling floral development as well as subsequent flower density and seed production (Phillips 1960; Moffler and Durako 1982). In Florida, flowering in *S. filiforme* and *H. wrightii* is rare, so Phillips (1960) speculated that most production occurs through vegetative growth, rhizome elongation and new branch growth. New shoot production is reported to be abundant throughout the year for *S. filiforme* and *H. wrightii*, except in the coldest winter months (Phillips 1960). In Florida, *T. testudinum* undergoes seasonal fluctuations in productivity and cover-density, with maximums usually occurring during warmer summer months (Dineen 2001). The warmer fall sampling season is expected to have taller canopy heights as well as greater cover-densities of the 3 major seagrasses. In the POM basin, generally, the fall (wet season) collections measured greater cover-density of *Halodule* and *Syringodium.* Unexpectedly, *Thalassia* measurements were generally higher in the spring (dry season) collections (Table 5). Seagrass canopy heights are generally higher in the fall, after the growth that follows spring seagrass reproduction (Appendix 2). The seasonal changes in water quality (natural or anthropogenic) and algae presence are important to this study because of their likely impact on seagrass growth and distribution; however, the fluctuations in water quality and algae between the spring and fall seasons may not have been extreme enough to cause a substantial seasonal impact on the seagrass cover-densities or canopy heights within the POM basin.

4.2 Environmental and Physical Measurements

Environmental conditions within the POM basin were typical of South Florida inshore waters; water temperatures ranged between 25-30 °C and salinity between 30-40 ‰. Water clarity was generally clear with turbidity around 2 NTU, which is a safe level for seagrass habitat growth. Water depth measurements were generally between 200-300 cm and the substrate was comprised of a mixed mud and sand sediment that mostly measured 100-200 cm deep (see Appendix 3).

Within the POM basin, the sites located within or near the channels and cuts generally recorded the deepest water depths and shallowest sediment depths (Figure 3). The protected Bill Sadowski Critical Wildlife Area near Virginia Key (USACE 2004) displayed much shallower water depths and measured the deepest sediment depths. Due to previous dredge-and-fill activities to permit boat traffic through the basin, sediment is more easily disturbed in the channels where less vegetation is present to stabilize loose sediment. The shallow protected areas have more stable sediment that is more suitable for supporting grass and algae. Surface and bottom salinity measurements within the basin are highest near the channels and cuts that lead out to the Atlantic Ocean, while the lowest salinities are located in the coastal sites near the Miami River, where freshwater and nutrients enter the system from inland (Figure 3, Appendix 6).

Studies by Caccia and Boyer (2005) showed higher salinity in the dry season in all areas of Biscayne Bay, except in the Central bay area, which did not show seasonal variability because it is a well-mixed zone, exchanging waters with the Atlantic. The water flow in the North Bay region is restricted due to the construction of dredged islands and causeways (Bialczak et al. 2001), and also has greater freshwater influence from the canals and the Miami River, and in turn is influenced more heavily during the wet season from increased river flow (Caccia and Boyer 2005). Compared to other regions of Biscayne Bay, salinities are generally lower and water clarity is diminished in the North Bay region due to relatively high freshwater discharge combined with a low flushing rate (Browder et al. 2005). Larsen (1995) also found that during the dry season less freshwater reached the bay because of increased upstream storage and lower groundwater levels. This large range in annual salinity can impact the benthic seagrass community (Montague and Ley 1993) by affecting growth, survival, reproduction, and other critical physiological processes of the plants (Browder et al. 2005).

The water temperature, salinity and water depth data collected from the POM basin exhibited the typical seasonal pattern observed in South Florida. Within the basin, the wet season displays significantly lower salinities, higher water temperatures, and deeper water depths than the dry season (2005-2011). Surface salinity decreases during the wet season due to the influx of freshwater from precipitation and subsequent Miami River flow, while the opposite occurs during the dry season (Duever et al. 1994). Warmer air temperatures and larger quantities of summer rain raise water temperatures and decrease the salinity levels by the end of the wet season. During the dry season months (spring/winter), air temperatures are cooler and in turn the salinity levels are usually higher.

As expected, sediment depth and turbidity did not show substantial seasonal patterns over the sample period; turbidity measurements were slightly lower and sediment depths were slightly higher during the fall (see Figures 13E and 13D). Research by Caccia and Boyer (2005) found turbidity in Biscayne Bay is generally lower in the wet season (fall), most likely due to less wind influence and less mixing of bay waters. The POM basin is surrounded by land and manmade structures which can influence the impacts from wind and potentially reduce mixing. Sedimentation is usually greater in the fall as well, which could be due to more detritus entering the system after spring seagrass reproduction (Phillips 1960; Moffler and Durako 1982; Dineen 2001).

4.3 Relationships between Seagrass and the Environmental and Physical Measurements

The current study investigated the extent to which seagrass cover-density would change seasonally and annually over the collection years (2005-2011) and whether the measured environmental and physical variables explained significant variation among seagrass presence and cover-density. It was found that sedimentation and water depth are the only major physical variables influencing the cover-density of seagrass within the POM basin. The single best predictor of seagrass cover-density (Table 13, Models 2-4 A-D) was water depth. The models also showed that seagrasses are more likely to be present in areas with shallower water depths characterized by low turbidity where light levels are sufficient for photosynthesis (Table 12, Models 1A-D). The conditions in the POM basin, excluding deep channels, offer a suitable environment for growth of benthic vegetation. Most of the basin contains shallow enough waters with thick sediment for seagrass rhizomes to grow well. It was expected that temperature and salinity would have a greater effect on seagrass distribution, but due to the low variability in measurements across the entire collection, no significant relationships were expressed between these variables.

Tropical seagrasses can tolerate a wide range of temperatures, but temperatures above 43 °C can cause mortality (Biebl and McRoy 1971; Campbell et al. 2006; Diaz-Almela et al. 2007; Ehlers et al. 2008) and temperatures lower than 20 °C can inhibit photosynthesis and eventually lead to death (Thomas et al. 1961; Mazzotti et al. 2007). Temperature primarily controls flowering in S. *filiforme*, with the optimal range to induce flowering between 22-24 °C (McMillian 1980). Leaf kill can occur in S. *filiforme* when temperatures fall below 20 °C (Phillips 1960). Optimum water temperature for *T. testudinum* and *H. wrightii* growth ranges between 20-30 °C (Phillips 1960; Fourqurean et al. 2002; Whitfield et al. 2004; Short et al. 2010c). Within the POM basin, water surface and bottom temperatures did not exceed 32.5 °C and did not drop below 20.8 °C.

Salinity for optimal growth of various seagrass species has been found to occur between 10 to 30 ‰ (Phillips and Meñez 1988). In general, seagrass growth declines at salinities in excess of 45 ‰ (Quammen and Onuf 1993) and if exposed to extreme salinity levels, seagrass tissues suffer from osmotic stress which can lead to a loss of functionality, and eventually the tissue becomes necrotic and dies (Biebl and McRoy

1971). Observations made by Phillips (1960) found that the optimum salinity range in Florida for growth of S. *filiforme* is around 20 - 25 ‰. The optimum range for *T. testudinum* is approximately 25- 38.5 ‰ and *H. wrightii,* with the greatest range, has been reported growing in abundance in salinities from 12.0 - 38.5 ‰ (Phillips 1960). Generally, *H. wrightii* tends to be more abundant in shallow inshore areas because it can tolerate frequent tidal exposure and low salinities (Dawes et al. 2004). Salinities of 45–60 ‰ can cause *S. filiforme* and *T. testudinum* to stop growing, but *H. wrightii* can continue to grow even at 72‰ (McMillan and Moseley 1967). Laboratory studies done by Lirman and Cropper (2003) found that out of the three main species found in Florida, S. *filiforme* was most susceptible to changes in salinity with the highest mean blade extension rates recorded at 25 ‰ and dropping dramatically at both higher and lower salinity. *Thalassia testudinum* exhibited peak leaf elongation rates at 40 ‰. Seagrasses can tolerate fluctuations in salinity, but prolonged exposure to extreme conditions can become detrimental to their survival. Within the POM basin, 87.9% of the sample sites had salinity ranging between 30-40 ‰. The surface salinity within the POM basin had a much greater range than bottom salinity most likely due to the influence of freshwater canal discharge and precipitation. Salinity conditions are ideal for seagrass growth in the POM basin as long as there are no sudden or prolonged changes to the delivery of freshwater to the basin.

Water depth influences the distribution of seagrass species. The optimum depth for growth in *S. filiforme* ranges from around 1-3 m (Duarte et al. 2007) and for *T. testudinum* the ideal depth is between 1-20 m (Littler et al. 1989). *Halodule wrightii* is a hardy species that can tolerate exposure at low tides (Phillips and Menez 1988; Fonseca 1994; Haynes 2000; Short et al. 2010a) and prefers depths ranging between 0-2 m (Haynes 2000). All three of these seagrass species can be observed at much greater depths in clearer waters (Phillips and Menez 1988; Fonseca 1994; GMP 2004; Short et al. 2010a; Short et al. 2010b), most likely as a function of light penetration (Phillips 1960). *Halodule wrightii* has also been observed to exhibit a second abundance peak in some areas along the deep-water edge of *T. testudinum* and *S. filiforme* meadows (Iverson and Bittaker 1986; Zieman and Zeiman 1989). The water depth in the POM basin averaged around 2 m (ranging between 1-3 m across the basin, see Appendix 3), which is within the ideal range for all three major seagrass species.

The thick sandy-mud sediments in the POM basin average over 1 m in depth (see Appendix 3) and are ideal for seagrass root and rhizome growth. *Halodule wrightii* are often found in sediment less than 5 cm, but may be found in sediments as deep as 25 cm (Phillips and Menez 1988; Fonseca 1994). *Syringodium filiforme* rhizomes are usually found in sediment 1-10 cm deep and *T. testudinum* rhizomes often grow down to 20 cm below the surface (Phillips and Menez 1988; Fonseca 1994). The sediment depth within POM averaged over twice as deep as most benthic vegetation requires for stable growth. This is due to the bottom and shorelines being altered drastically by dredging in the 1900's, to provide for the development of the surrounding lands and for navigation channels (Hefty et al. 2001). The bay was dredged and filled with spoil from construction in order to create land, causing unstable shorelines (Caccia and Boyer 2007). Sediment that is too deep or loose can be resuspended easily and reduce water clarity. The seawalls created to stabilize the developed land reflect wave energy, which contributes to the resuspension of bottom sediments (Hefty et al. 2001). Since the seagrass and benthic algae communities rely on light reaching the bottom, water clarity is of crucial significance (Hefty et al. 2001).

Previous studies done by Caccia and Boyer (2005) found that the North Bay had the highest turbidity, almost twice that observed in other areas, because it is influenced by the runoff of five canals, stormwater runoff, the Port of Miami, Munisport landfill and the urban landscape (Caccia and Boyer 2005). The overall turbidity in Biscayne Bay averages around 2 NTU (Caccia and Boyer 2005). Levels observed in the POM basin in the data used in this study averaged just slightly over 2 NTU. When the waters are less clear, seagrasses may produce elongated leaves so that they can reach the light closer to the surface and may form less dense canopies in order to avoid self-shading (Short et al. 1995; Collier et al. 2008). However, the seagrass canopy height does not seem to correlate with seagrass density within the POM basin, in fact, *Syringodium* canopy height is taller when seagrass density is greater (Figure 8 and Figure 9).

Available Results from SFWMD during the collection period (2006-2011) show that there has been minimal variation in the measured environmental variables (Table

11). Also, all variables were within a suitable range for seagrass production. The Biscayne Bay region is an oligotrophic estuary that requires minimal phosphorus and nitrogen inputs (Carey et al 2011). The nutrient environment of seagrass meadows world-wide has an average phosphate concentration of 0.35 uM (0.033 mg/L) (Hemminga 1998). The SFWMD reported average TP concentrations (2008-2011) at 0.004 ± 0.017 mg/L and NO_x concentrations (2008-2011) at 0.004 ± 0.017 mg/L (Table 11). Hemminga (1998) documented that seagrasses worldwide require DO measurements averaging above 2 mg/L and within the POM basin, DO measured an average of 6.26 ± 0.98 mg/L (Table 11). The average pH (2006-2011) within the POM basin, 8.03 ± 0.14 units (Table 11), is basic in nature and at an ideal level for the coastal region. The average CHL-A across all of Biscayne Bay is reported as 1.0 ± 1.5 mg/m^3 (Johns and Kelble 2013). SFWMD average CHL-A concentrations (2007-2011) remained on the low level in the POM basin, 0.73 ± 0.56 mg/m^3 (Table 11). High levels of chlorophyll-a in a system often indicate poor water quality and low levels often suggest good conditions (McPherson and Miller 1994; Tomasko et al. 2001). SFWMD OC concentrations (2008-2011) were generally low, averaging 2.06 ± 2.60 mg/L (Table 11). Within the POM basin available nutrient concentrations remained fairly low and as such did not have any significant adverse impact on the seagrass community.

4.4 Environmental, Physical, Weather and Anthropogenic Changes Related to Seagrass Variations

Annual rainfall and storm activity in the Miami area, coupled with air temperatures, can influence the environmental and physical measurements (especially salinity, water temperature, and turbidity) within the POM basin and in turn impact the seagrass. Some slight changes in seagrass cover-density were documented between certain years in possible relation to weather or construction events. Salinity fluctuations between sample years in the POM are most likely due to storm activity, or lack thereof, and influences from ocean exchange and river outputs. Salinity measurements in 2006 were the lowest on record in the POM basin (Figure 12B), possibly due to the increased rain in the region resulting from the high storm activity in 2005, which included two hurricanes that directly impacted South Florida (NOAA 2006). The 2006 collection year marked the beginning of a drought period in South Florida (NOAA 2006) and 2007 saw drought conditions persisting across most of South Florida; however, the Miami area measured rainfall just a few inches above normal for the year (NOAA 2007) (Figure 15A). The data shows the largest increase in salinity between 2006 and 2007 (Figure 12B). This could be due in part to the overall shallower water depths recorded during 2007, tide conditions, and the drought conditions across South Florida. Less freshwater flow from canals and rivers inland could have influenced the salinity within the basin as well. Salinity was seen to increase between the 2010 and 2011 sample years, possibly due to the persisting dry conditions from La Niña. Salinity generally remained in the optimum range for seagrass growth with minimal variation among seagrass cover-density, even during years with larger salinity variations.

A significant increase in water depth was seen between the 2007 and 2008 samples. This could be due to the fact that 2008 marked the end of the drought conditions in South Florida that had persisted since 2006. The early part of 2008 was wetter than expected and the summer was also wetter than normal, with heavy rainfall in mid-August from tropical storm Fay passing through the area (NOAA 2008). 2009 experienced a very dry winter, very dry spring, then a very wet early summer, followed by average rainfall until heavy rainfall in the last half of December (NOAA 2009). Rainfall varied across the year; however, Miami records show the least amount of rainfall during the study period occurred in 2009 (only 52.1 inches; -9.8 in departure from average, Figure 15A). Due to La Niña conditions that developed in the summer of 2010, dry conditions persisted from October 2010-June 2011, and this period is documented with driest conditions for the region in 80 years (Molleda 2010).

The year 2011 had dryer than normal conditions, due to the wet season falling 20 days short of normal (NOAA 2011), and brought drought condition back to most of South Florida by the end of the year (NOAA 2010). 2011 also marked the 6th consecutive year with no hurricanes directly impacting South Florida (NOAA 2011). The most significant changes seen in seagrass cover-density and water temperature were between the 2009, 2010 and 2011 sampling years in POM. In this study, 2009 and 2011 had the warmest water temperatures on record, while in contrast, 2010 had the coldest. These differences can be explained by the annual air temperatures recorded in Miami during that time. December 2009 ended with a period of record setting cold temperatures that stretched into the early months of 2010 (NOAA 2010). 2010 experienced extremes, with some of the coldest and hottest temperatures across South Florida (NOAA 2011), and concluded with the coldest December on record (NOAA 2010). The cold temperatures documented in the winter of 2009-2010 and in December of 2010 were mainly caused by a strongly negative North Atlantic Oscillation (NAO) and Arctic Oscillation (AO) (NOAA 2010). These strongly negative atmospheric oscillations essentially "flip" the weather patterns across North America, forcing the jet stream to plunge Arctic air masses from northern Canada into the southeastern U.S., including Florida (NOAA 2010). There is an average of 51 days of 90+ °F and 2 days of sub-40 °F temperatures annually in South Florida (NOAA 2010). In 2009 Miami-Dade experienced 121 days with temperatures at or above 90 °F, the highest number of days since the record began in 1937 (NOAA 2009), 2010 recorded 103 days at 90+ °F and 6 mornings with temperatures sub-40 °F, (NOAA 2010), and 2011 documented the 2nd most number of days, 118, with a record 44 consecutive days at 90+ °F (NOAA 2011). The extreme cold winter air temperatures from the AO in 2010 are likely responsible for the cooler surface and bottom water temperatures measured throughout the year within the POM basin. In 2011, on the opposite end of the spectrum, an unusually warm spring, warmer than normal summer (with record high temps), and one of the warmest Decembers on record (NOAA 2011) raised the water temperatures within the POM to their highest measurements across the entire study period (Figure 12A).

The two major meadow building seagrasses, *Syringodium* and *Thalassia*, experienced a decline in cover-density over the 2010 collection, but then rebounded by 2011 (Figure 8). This may be due to natural variability, but the influence of the colder temperatures (Figure 12A and Figure 15B) in 2010 may have negatively impacted both *Syringodium* and *Thalassia* in the short run, both measuring their lowest cover-density during that collection year. The greatest cover-density measurements for *Thalassia* were just a year prior, 2009. *Thalassia* was showing an increasing trend over the sample period until 2010. *Halodule* showed minimal change over the collection years (Figure 8), most likely due to its high tolerance range of environmental conditions such as habitat deterioration, eutrophication, and increased turbidity (Short et al. 2010a). Red algae and calcareous algae cover-density experienced some of their greatest variation between 2009 and 2011, with 2010 displaying the highest measurements over the entire collection (Figure 11). The colder temperatures in 2010 may have allowed some algae species to experience greater productivity over the seagrass, but overall there was no significant negative impact on seagrass. The lowest occurrence of seagrass among sample sites (30) was recorded at the beginning of the study in 2005 and the highest occurrence in 2011 when the study was completed (Figure 5).

This study found that turbidity is generally lower across the sample area (Figure 12E) than previous reports had indicted (Ecosummary Biscayne Bay 2002; Caccia and Boyer 2005). However, Caccia and Boyer (2005) predicted that the turbidity in the North Bay will continue to degrade over time. Before this study began in the spring of 2005, three hurricanes affected the South Florida region in 2004, one in August and two in September (NOAA 2004). 2005 then experienced two large hurricanes that directly impacted South Florida at the end of August (Katrina) and October (Wilma) (NOAA 2005). There was also construction activity present in 2005. During the months of June through August, 2005, the project that began in 1990 to deepen the POM shipping channel from 35 to 42 feet was completed using new confined blasting techniques that minimized impacts to the ecosystem (USACE 2007). The project was able to successfully blast through limestone bedrock and deepen the port. Turbidity and sediment depth measurements for 2005 were significantly higher than other years. The amount of storm activity prior to, and during the first year of sampling, in addition to blasting in the channels most likely attributed to the disturbance and resuspension of sediment within the basin. After the 2005 collection year, there were no other hurricanes impacting the South Florida region during the study period. The lack of storms in proceeding years has most likely aided in the recovery of turbidity. By the end of the study period turbidity levels measured below 2 NTU, which is much lower than the levels measured in 2005 (Figure 12E).

After major modifications in the region, loss of the stabilizing vegetation and the continuing resuspension and erosion of unconsolidated sediment are the principal causes of chronic turbidity in areas of the bay (Wanless et al. 1984). The Florida Fish and Wildlife Conservation Commission reported areas of significant seagrass decline between 1950 and 2000; including a 43 percent loss of seagrass in the northern section of

Biscayne Bay near Miami (FFWCC 2002). Studies done by Blair et al. (2011) found that seagrass cover was extensive (159,363 acres) in the Biscayne Bay region and was found to be increasing in area in all subregions of the bay from 1992 to 2005 except in North Biscayne Bay, where it lost 660 acres, or 11%. Results from this study show that from 2005 to 2011 the seagrass habitat within the POM in North Biscayne Bay has remained fairly stable and even shows an overall increased in occurrence by the end of the last collection year (Figure 5). The lack of major storm activity, improved water management practices, and regulated construction activity in the Miami area may have supported fairly stable salinity measurements and contributed to the general decline in turbidity and overall improved water clarity in the POM basin. This may have aided in the quick recovery of the seagrass from the 2010 cold event. There are many contributing factors as to the distribution and cover of benthic vegetation in the POM basin. It is difficult to identify one dominant cause of disturbance in habitat over the course of the sampling period due to the limitations of the study and the number of possible variables involved in vegetation growth and distribution.

4.4.1 Algae and Nutrient Changes Related to Seagrass Variations

During the past century, human activities have had a tremendous impact on the global cycling of nutrients in coastal systems (Caccia and Boyer 2007). The export of phosphorus to the oceans has increased threefold compared to pre-industrial and pre-agricultural levels while the export of nitrogen has increased even more dramatically (Caraco 1995). Most seagrass beds contain benthic and epiphytic algae (FMNH 2015) that may contribute significantly to the system (Heijs 1987; Verheij and Erftemeijer 1993; Jupp et al. 1996; Sidik et al. 2001). However, when a water quality disturbance involving nutrients occurs in an area, there is the potential to shift the dynamics between the seagrass and algae cover (Fourqurean et al. 1995; FMNH 2015). Multer (1988) found that high biomass of macroalgae appears under the conditions on low and moderate seagrass shoot density, indirectly demonstrating the competitive relationship between seagrasses and macroalgae. It was expected that there would be stronger competition between grass and algae in POM because of the low seagrass cover-density recorded; however, no significant shifts were detected during the study period. The lowest occurrence of algae in record in POM was in 2006 and the highest in 2007 (Figure 5). Without an accurate record of nutrient concentrations for these sample years, it is difficult to determine the cause behind this shift. It is possible the change in occurrence may be due to overall shallower sites sampled in 2007, which may support more algae species.

Monitoring over the past century has been inconsistent in the POM region, so it is difficult to establish a solid data record. The useable data from the SFWMD agencies showed little to no significant variation in measured nutrients between sampling years for most of the variables. There were no consistent data records from the SFWMD prior to 2008 for TP (total phosphate) or NO_x (nitrate+nitrite) concentrations within the POM basin. Data show that available nutrient concentrations have remained fairly low over the last four years of the study period. Between 2008 and 2011 the TP averaged 0.004 ± 0.017 mg/L and NO_x concentrations averaged 0.004 ± 0.017 mg/L (Table 11). There are many forms of Nitrogen in an aquatic environment, and since the SFWMD records for Nitrogen measurements covered several different types between agencies, it is difficult to determine any significant relationships between variables within the basin. The lack of consistent nutrient data for some variables makes it difficult to make solid connections between agencies. Even with a large uncertainty in pairing the sample collection dates and times, is it suggested a reasonable correlation can be made for some variables between other agencies and monitoring programs (RECOVER 2014).

There have been indications that the Biscayne Bay ecosystem is slowly recovering, although conditions are not expected to return to those of the early 1900s, before settlement (Cantillo et al. 2000). The water quality in North Biscayne Bay has improved substantially in the last 30 years and now generally meets or exceeds local, state and federal standards for recreational uses and propagation of fish and wildlife through regulatory action and shoreline revetment and restoration projects (SFWMD 2000). DERM has even documented significant return of benthic communities in some portions of North Biscayne Bay as a result of improved water quality (SFWMD 2000). The bay still receives a considerable amount of nutrients, trace metals, organic chemicals and particulates from storm water runoff, canal discharge, and other sources (BBAP 2011) which is still a concern for environmental agencies.

Initially detected in 2002, a macroalgae bloom composed of mainly *Anadyomene* spp. has continually persisted along parts of the western shoreline of Biscayne Bay, just south of the Rickenbacker Causeway and the Port of Miami basin (RECOVER 2014). The impact of the prolonged algae bloom has resulted in a shift from a seagrass dominated community to a macroalgal dominated community in that region (RECOVER 2012). Macroalgae can potentially have one of the greatest effects on the seagrass cover-densities in an area, but even with some significant increases in cover detected in of some algae groups in the POM between years, there was no obvious detrimental impact observed to the seagrass. The fragile balance between the seagrass and algae must be maintained through proper water management practices.

The Integrated Biscayne Bay Ecological Assessment and Monitoring Project (IBBEAM) report for CERP combined the sampling efforts of four individual projects funded by the RECOVER Monitoring and Assessment Plan (MAP): Salinity Monitoring Network, Nearshore SAV (submerged aquatic vegetation), Alongshore Epifauna, and Mangrove Fish. The project concluded that the nearshore habitats in Biscayne Bay are occupied by floral and faunal species assemblages operating below their productive potential, due, in part, to inadequate and unnatural freshwater flows limiting the duration and spatial extent of mesohaline conditions (RECOVER 2014). Despite this, IBBEAM determined that the occurrence of *H. wrightii* and *T. testudinum* in the study area remained largely stable over the period of record, similar to the findings from this study (FIAN). Seagrass cover-density and spatial distribution fluctuated somewhat seasonally and varied across years within the POM basin, but no clear temporal trend in seagrass cover was apparent. The seagrass species remain fairly stable within the port.

4.5 Future Threats to Seagrass Habitats

Over the next century, the predicted changes in global climate will alter many of the factors that shape the coastal ecosystem of South Florida (RECOVER 2014). Climate change has the potential to cause sea level rise, increased temperatures, changes in precipitation patterns, and changes in the intensity and/or frequency of extreme weather events (ICLEI 2010). This can lead to a rapid loss and substantial changes to the benthic communities along the coasts (Wanless et al. 1994). Studies done by the Organization for Economic Cooperation and Development (OECD) identified Miami–Dade as the county with the highest amount of vulnerable assets exposed to potential coastal flooding, with costs projected at around $3.5 trillion (Nicholls et al. 2007). A major consequence of climate change is an increase in water temperature in the North Atlantic. Models predict that increases in tropical sea surface temperature can lead to an increase in number and intensity of tropical storms, with larger peak wind speeds and more heavy precipitation (Mann et al. 2009; IPCC 2007). Global sea surface temperature increasing by one degree Celsius could result in a 30% increase in category 4 and 5 storms worldwide (Elsner et al. 2008). Over the past decade the Copenhagen Diagnosis (a report written by twenty-six climate scientist from eight countries) has found evidence of a global increase in the number of category 4 and 5 hurricanes (Allison et al. 2009). These climate deviations can alter habitat productivity and eutrophication by changing the delivery of fresh water, nutrients, and sediments (Scavia et al. 2002). With climate changes, the composition and distribution of biotics that occur in the coastal ecosystem will shift (Scavia et al. 2002).

5.0 Conclusions

The primary objectives of this study were to: 1) characterize the seagrass community (e.g., species composition, cover, and distribution); and 2) characterize the environmental and physical conditions (e.g., salinity, temperature, turbidity, and water and sediment depths); and 3) determine if there are relationships between the seagrass community and the environmental and physical conditions; and 4) evaluate if the natural or anthropogenic changes in South Florida have influenced the seagrass habitat and the environmental and physical conditions within the Port of Miami. Results showed that there was minimal change in seagrass distribution, cover-density, and occurrence over the collection period. The habitat in POM is stable, which is an improvement from the 2005 report of aerial photography, which reported a large decline in the North Biscayne Bay basins from previous years (Blair et al. 2011). Monitoring has shown that restrictions and regulations in the area have mostly been effective in reducing the loss of seagrass habitat. The construction environmental safety regulations and mitigation have minimized any major impact on the health of the port’s seagrass community.

Some seasonal and annual patterns were evident in the environmental and physical measurements within the basin. The research shows that turbidity has improved since the start of the project with recordings currently half of what was seen in previous years (Ecosummary Biscayne Bay 2002; Caccia and Boyer 2005). There is seasonal variation in water temperature and salinity; the fall season has warmer water temperatures and lower salinities after the summer rain. Air and water temperatures displayed an overall increasing trend across the study period, which may negatively impact the environment in the future.

In a few cases certain environmental and physical data were considered significant enough to be used as predictors of seagrass cover-density or occurrence. However, in most cases the environmental measurements supported the null hypothesis when attempting to predict variation in vegetation cover-density or occurrence and were removed from the regression models due to their lack of correlation or contribution. In the POM the model showed that water depth is the major factor that determines the cover-density and occurrence of the dominant habitat building seagrasses. The models also revealed that sediment depth and turbidity also played an important role in the seagrass cover-density and occurrence within the basin. Areas with lower turbidity and deeper sediment depths are ideal for seagrass establishment and growth.

The seagrass habitats within the POM have been influenced by natural and anthropogenic changes over time. Most of the significant changes seen in the measured variables can be related to weather/storm events; however, some construction activity during the study period could have contributed to slight increases in turbidity during certain collections. The first collection year (2005) experienced major construction (dredging) and heavy storm (hurricane) activity in the region which created higher turbidity measurements within the POM for that year. The weather at the end of 2009 and throughout 2010 produced a prolonged cold period which negatively impacted seagrass cover-densities.

The seagrass habitats in North Biscayne Bay have been subject to a number of disturbances including storm scour, uprooting and overgrazing by animals, introduction of invasive species, infection by pathogens and parasites, algal blooms, commercial fishing practices, stress due to water quality degradation and reduced water clarity, physical impacts from dredge and fill operations, prop scaring, vessel wakes and groundings, and physical and toxicological impacts due to spills of oil and other toxic materials (Short and Wyllie-Echeverria 1996; Kemp 2000; Fourqurean et al. 2002; FMRI 2003; Orth et al. 2006; BBAP 2011). Even with the major direct and indirect impacts to the region, the benthic habitat continues to persist in the area.

It is easy to relate large visible events to change in seagrass distribution, but there are many other underlying causes involved in the process. A longer, more complete study of the water quality within the region is recommended for future conservation and management. The completion of the Deep Dredge Project leaves opportunity for future research regarding the status of the Port habitat and environmental conditions. The existing habitat has been documented and studied over the years through several agencies. Although environmental and physical measurements from SFWMD agencies were not completely consistent, they still provided a general record of measurements for comparison. Future studies from DERM and USGS (2014-2016) (Daniels and Grimes 2016) and other agencies can examine possible habitat damage from the construction activities that may help educate on successful and unsuccessful construction techniques in marine habitats. If blasting and dredging techniques are implemented correctly, there should be minimal impact to the surrounding seagrass habitats, as seen in 2005 and 2010.

Some environmental and physical conditions within the POM have improved and the seagrasses have remained fairly stable over the course of the study, but several potential threats may be an issue in the future. The global distribution of seagrass beds has changed gradually over time in response to several factors for instance sea-level and temperature, as well as extreme high and low storm activity; however, anthropogenic pressures have been identified as currently having the largest impact on seagrass loss change (Orth et al. 2006). South Florida, including Miami, continues to grow in population and tourism, and in turn more direct modifications will be required to the surrounding areas to support this trend. The potential for increased runoff and pollution from inland sources, and the direct impacts from new construction and irresponsible boating activity are a major threat to the seagrass habitats within the Port of Miami. The global climate shift also has major potential to harm the coastal habitats with increased intensity in air and water temperatures and storm activity, as well as the threat from sea level rise. The complex ecology and multiple roles that seagrass communities provide are the reason to maintain and improve their habitat (Dawes 1998). Seagrasses are a vital part of the South Florida coastal ecosystem and economy. With increased monitoring efforts from environmental agencies and with more outreach and education to the public, these valuable seagrass habitats will continue to sustain themselves in the future.

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7.0 Appendix

Appendix 1. Biotic Temporal Descriptives. Average vegetation cover-density measurements of 30 sites in the POM basin. Mean biotic measurements listed ± standard deviation for cover-density (#/m2)

Year	Season	*Syringodium*	*Thalassia*	*Halodule*	*Halophila*	Red Algae	Calcareous Algae	Green Algae	Brown Algae
2005	Dry	1.51 ± 1.58	0.73 ± 1.22	0.80 ± 0.95	0.05 ± 0.14	0.40 ± 0.46	0.28 ± 0.39	0.04 ± 0.14	0.02 ± 0.07
	Wet	1.36 ± 1.54	0.57 ± 1.20	0.49 ± 0.89	0.13 ± 0.56	0.34 ± 0.62	0.31 ± 0.45	0.33 ± 0.66	0.04 ± 0.14
	AVG	1.43 ± 1.55	0.65 ± 1.20	0.64 ± 0.93	0.09 ± 0.41	0.37 ± 0.54	0.30 ± 0.42	0.19 ± 0.49	0.03 ± 0.11
2006	Dry	1.24 ± 1.47	0.68 ± 1.27	0.78 ± 1.28	0.01 ± 0.03	0.49 ± 0.54	0.21 ± 0.30	0.27 ± 0.43	0.03 ± 0.10
	Wet	1.67 ± 1.73	0.64 ± 1.37	0.55 ± 1.07	0.06 ± 0.22	0.29 ± 0.48	0.30 ± 0.50	0.28 ± 0.44	0.07 ± 0.16
	AVG	1.45 ± 1.61	0.66 ± 1.31	0.67 ± 1.17	0.03 ± 0.16	0.39 ± 0.52	0.25 ± 0.41	0.27 ± 0.43	0.05 ± 0.14
2007	Dry	1.57 ± 1.49	0.80 ± 1.20	0.57 ± 0.76	0.01 ± 0.03	0.69 ± 0.61	0.32 ± 0.54	0.13 ± 0.30	0.003 ± 0.02
	Wet	1.70 ± 1.52	0.56 ± 0.79	0.68 ± 1.14	0.09 ± 0.34	0.25 ± 0.57	0.55 ± 0.50	0.22 ± 0.28	0.05 ± 0.15
	AVG	1.63 ± 1.50	0.68 ± 1.01	0.63 ± 0.96	0.05 ± 0.24	0.47 ± 0.63	0.44 ± 0.53	0.17 ± 0.29	0.02 ± 0.10
2008	Dry	1.35 ± 1.37	0.83 ± 1.26	0.49 ± 0.69	0.11 ± 0.47	1.13 ± 0.94	0.21 ± 0.35	0.07 ± 0.17	0.31 ± 0.47
	Wet	1.43 ± 1.55	0.59 ± 0.89	0.56 ± 1.11	0.20 ± 0.66	0.22 ± 0.42	0.40 ± 0.54	0.14 ± 0.44	0.03 ± 0.13
	AVG	1.39 ± 1.45	0.71 ± 1.09	0.52 ± 0.92	0.15 ± 0.57	0.68 ± 0.85	0.31 ± 0.46	0.10 ± 0.33	0.17 ± 0.37
2009	Dry	1.33 ± 1.48	0.74 ± 1.02	0.19 ± 0.36	0	0.90 ± 0.78	0.10 ± 0.20	0.03 ± 0.12	0.01 ± 0.03
	Wet	1.23 ± 1.74	0.79 ± 1.13	1.00 ± 1.22	0.35 ± 1.02	0.12 ± 0.24	0.36 ± 0.45	0.11 ± 0.23	0
	AVG	1.28 ± 1.60	0.77 ± 1.07	0.59 ± 0.98	0.17 ± 0.74	0.51 ± 0.69	0.23 ± 0.37	0.07 ± 0.18	0.003 ± 0.02
2010	Dry	1.24 ± 1.24	0.22 ± 0.47	0.35 ± 0.73	0	1.55 ± 1.03	0.11 ± 0.25	0.10 ± 0.31	0.01 ± 0.03
	Wet	0.82 ± 0.93	0.40 ± 0.49	0.69 ± 0.81	0.05 ± 0.22	0.03 ± 0.06	0.20 ± 0.28	0.24 ± 0.50	0
	AVG	1.03 ± 1.10	0.31 ± 0.48	0.52 ± 0.79	0.03 ± 0.15	0.79 ± 1.05	0.15 ± 0.27	0.17 ± 0.42	0.003 ± 0.02
2011	Dry	1.30 ± 1.34	0.75 ± 0.97	0.48 ± 0.87	0.003 ± 0.02	0.69 ± 0.55	0.34 ± 0.59	0.07 ± 0.16	0.02 ± 0.12
	Wet	1.38 ± 1.22	0.58 ± 0.92	0.45 ± 0.81	0	0.19 ± 0.41	0.54 ± 0.69	0.18 ± 0.30	0.02 ± 0.07
	AVG	1.34 ± 1.27	0.66 ± 0.94	0.47 ± 0.83	0.001 ± 0.01	0.44 ± 0.54	0.44 ± 0.64	0.13 ± 0.25	0.02 ± 0.10
Average	Dry	1.36 ± 1.41	0.68 ± 1.09	0.52 ± 0.86	0.02 ± 0.19	0.83 ± 0.81	0.22 ± 0.40	0.10 ± 0.26	0.06 ± 0.22
	Wet	1.37 ± 1.49	0.59 ± 1.00	0.63 ± 1.02	0.12 ± 0.54	0.21 ± 0.44	0.38 ± 0.51	0.21 ± 0.43	0.03 ± 0.11
	AVG	1.37 ± 1.45	0.63 ± 1.05	0.58 ± 0.94	0.07 ± 0.41	0.52 ± 0.72	0.30 ± 0.46	0.16 ± 0.36	0.04 ± 0.17

Appendix 2. Canopy Height Temporal Descriptives. Average seagrass canopy height measurements of 30 sites in the POM basin. Mean height measurements listed ± standard deviation for canopy height (cm).

Year	Season	Average Canopy	*Syringodium* Canopy	*Thalassia* Canopy	*Halodule* Canopy	*Halophila* Canopy
2005	Dry	25.99 ± 12.02	36.17 ± 13.00	25.10 ± 6.84	15.04 ± 5.55	2.50 ± 3.00
	Wet	26.65 ± 20.25	36.52 ± 19.21	25.71 ± 14.24	14.62 ± 9.53	3.22 ± 3.03
	AVG	26.31 ± 16.33	36.32 ± 15.78	25.38 ± 10.62	14.86 ± 7.34	2.81 ± 2.78
2006	Dry	25.20 ± 16.70	36.23 ± 15.53	23.20 ± 5.74	13.38 ± 5.44	3.00
	Wet	30.58 ± 16.80	37.80 ± 15.51	28.42 ± 12.46	13.08 ± 5.65	3.00
	AVG	27.84 ± 16.81	37.08 ± 15.32	25.81 ± 9.82	13.27 ± 5.41	3.00
2007	Dry	21.89 ± 11.47	28.56 ± 11.08	25.53 ± 9.99	12.39 ± 3.88	2.00
	Wet	32.14 ± 14.61	39.42 ± 10.19	33.02 ± 11.61	21.96 ± 9.10	5.11 ± 2.71
	AVG	27.39 ± 14.10	34.87 ± 11.77	29.49 ± 11.37	17.03 ± 8.36	3.87 ± 2.57
2008	Dry	29.64 ± 17.45	36.78 ± 16.27	22.08 ± 8.44	13.98 ± 6.23	5.83
	Wet	27.35 ± 22.15	36.19 ± 23.62	23.04 ± 17.66	16.02 ± 8.14	3.47 ± 2.61
	AVG	28.51 ± 19.74	36.50 ± 19.81	22.58 ± 13.74	14.91 ± 7.05	4.06 ± 2.44
2009	Dry	28.03 ± 13.60	35.99 ± 11.99	25.25 ± 10.06	9.84 ± 3.53	0
	Wet	29.13 ± 12.14	33.51 ± 14.04	31.61 ± 10.48	21.25 ± 8.85	4.93 ± 1.55
	AVG	28.55 ± 12.82	34.82 ± 12.87	28.33 ± 10.60	17.02 ± 9.17	4.93 ± 1.55
2010	Dry	36.79 ± 21.45	46.13 ± 18.82	20.31 ± 7.50	12.67 ± 4.92	0
	Wet	34.25 ± 18.41	46.83 ± 18.17	33.38 ± 9.74	22.68 ± 8.86	3.06 ± 0.42
	AVG	35.47 ± 19.79	46.45 ± 18.28	29.02 ± 10.90	19.04 ± 9.02	3.06 ± 0.42
2011	Dry	32.19 ± 14.99	40.53 ± 13.46	27.66 ± 10.01	15.06 ± 4.61	4.00
	Wet	37.78 ± 16.91	45.90 ± 18.47	32.22 ± 11.69	24.24 ± 9.76	0
	AVG	34.98 ± 16.09	43.27 ± 16.25	29.87 ± 10.94	20.07 ± 8.99	4.00
Average	Dry	28.62 ± 16.14	37.43 ± 15.08	24.62 ± 8.86	13.31 ± 5.10	2.98 ± 2.21
	Wet	31.31 ± 17.70	39.68 ± 17.42	30.33 ± 12.57	19.81 ± 9.34	3.90 ± 2.07
	AVG	29.96 ± 16.97	38.55 ± 16.29	27.60 ± 11.30	16.59 ± 8.20	3.57 ± 2.12

Appendix 3. Temporal Environmental and Physical Descriptives. Average environmental and physical data measurements of 30 sites in the POM basin. Mean environmental and physical measurements listed ± standard deviation for temperature (°C), salinity (‰), turbidity (NTU), sediment depth (cm), and water depth (cm). N = 210 for dry and wet season. N = 420 for AVG measurements.

Year	Season	Surface Temp	Bottom Temp	Surface Salinity	Bottom Salinity	Turbidity	Sediment Depth	Water Depth
2005	Dry	26.63 ± 0.36	26.65 ± 0.34	33.60 ± 2.88	34.27 ± 2.35	3.60 ± 2.16	157.87 ± 84.97	195.37 ± 78.61
	Wet	27.14 ± 0.27	27.19 ± 0.27	32.70 ± 3.07	33.07 ± 2.34	4.39 ± 2.20	161.93 ± 100.82	248.67 ± 110.87
	AVG	26.88 ± 0.41	26.92 ± 0.41	33.15 ± 2.99	33.67 ± 2.40	3.99 ± 2.20	159.90 ± 92.46	222.02 ± 99.00
2006	Dry	25.12 ± 0.85	25.02 ± 0.81	34.88 ± 0.77	34.92 ± 0.99	3.67 ± 1.25	148.77 ± 98.69	219.33 ± 65.82
	Wet	29.44 ± 0.55	29.55 ± 0.32	27.22 ± 5.17	30.06 ± 1.64	2.72 ± 1.42	161.60 ± 78.12	230.63 ± 68.09
	AVG	27.28 ± 2.29	27.29 ± 2.36	31.05 ± 5.32	32.49 ± 2.79	3.19 ± 1.41	155.18 ± 88.48	224.98 ± 66.64
2007	Dry	24.84 ± 0.43	24.90 ± 0.50	35.90 ± 0.47	35.87 ± 0.41	4.19 ± 2.23	160.66 ± 80.86	187.24 ± 63.06
	Wet	31.28 ± 0.64	31.34 ± 0.62	32.44 ± 2.80	33.44 ± 0.77	2.77 ± 0.99	140.10 ± 81.87	191.23 ± 73.82
	AVG	28.06 ± 3.28	28.12 ± 3.30	34.17 ± 2.65	34.66 ± 1.37	3.48 ± 1.86	150.20 ± 81.33	189.27 ± 68.18
2008	Dry	24.87 ± 0.54	24.73 ± 0.44	34.43 ± 2.44	34.25 ± 0.38	3.67 ± 1.63	87.43 ± 73.10	235.73 ± 73.40
	Wet	28.19 ± 2.24	28.81 ± 1.07	32.46 ± 2.99	32.49 ± 2.79	2.13 ± 1.77	137.97 ± 85.43	251.87 ± 95.44
	AVG	26.53 ± 2.32	26.77 ± 2.21	33.45 ± 2.88	33.37 ± 2.99	2.90 ± 1.86	112.70 ± 82.84	243.80 ± 84.80
2009	Dry	26.15 ± 0.39	26.17 ± 0.40	36.50 ± 0.71	36.47 ± 0.70	1.26 ± 0.61	92.77 ± 79.12	175.30 ± 63.30
	Wet	30.68 ± 0.43	30.84 ± 0.44	31.54 ± 1.85	32.78 ± 1.20	1.43 ± 0.53	89.80 ± 58.32	240.67 ± 89.80
	AVG	28.42 ± 2.32	28.51 ± 2.40	34.02 ± 2.86	34.62 ± 2.10	1.35 ± 0.57	91.28 ± 68.93	207.98 ± 83.78
2010	Dry	22.23 ± 0.16	22.22 ± 0.15	32.78 ± 1.82	33.21 ± 1.08	0.97 ± 0.44	102.47 ± 61.72	217.93 ± 48.07
	Wet	28.90 ± 0.61	29.05 ± 0.48	31.67 ± 1.63	32.33 ± 1.44	2.05 ± 0.82	93.53 ± 55.57	183.57 ± 70.02
	AVG	25.56 ± 3.39	25.64 ± 3.46	32.23 ± 1.81	32.77 ± 1.34	1.51 ± 0.84	98.00 ± 58.40	200.75 ± 62.01
2011	Dry	27.88 ± 0.50	27.77 ± 0.50	36.93 ± 0.55	37.08 ± 0.46	1.70 ± 0.64	130.86 ± 76.47	188.90 ± 75.85
	Wet	30.40 ± 0.42	30.46 ± 0.29	29.86 ± 1.37	30.92 ± 1.29	1.58 ± 0.51	159.23 ± 90.88	216.63 ± 68.81
	AVG	29.14 ± 1.35	29.12 ± 1.42	33.40 ± 3.71	34.00 ± 3.25	1.64 ± 0.58	145.29 ± 84.60	202.75 ± 72.48
Average	Dry	25.39 ± 1.72	25.35 ± 1.70	35.00 ± 2.16	35.15 ± 2.01	2.72 ± 1.91	125.64 ± 84.03	202.90 ± 69.39
	Wet	29.43 ± 1.66	29.61 ± 1.43	31.13 ± 3.43	32.15 ± 2.07	2.44 ± 1.60	134.88 ± 84.15	223.32 ± 86.41
	AVG	27.41 ± 2.64	27.48 ± 2.65	33.07 ± 3.46	33.65 ± 2.53	2.58 ± 1.76	130.28 ± 84.11	213.14 ± 78.95

Appendix 4. Average vegetation cover-density measurements of 30 sites in the POM basin. Mean biotic measurements listed ± standard deviation for cover-density (#/m2). N = 14 total number of sample collections. Refer to Figure 3. Red = Miami City East Coast; Light Green = East Coast Grass patch; Dark Green = No Entry Zone Virginia Key Grass patch; Blue = Channel through center of basin; Yellow = Channel and Cuts South of Port Islands.

Site #	*Syringodium*	*Thalassia*	*Halodule*	*Halophila*	Red Algae	Calcareous Algae	Green Algae	Brown Algae
1	1.12 ± 0.89	0.23 ± 0.27	0.47 ± 0.65	0.10 ± 0.24	0.49 ± 0.79	0.85 ± 0.68	0.15 ± 0.26	0.01 ± 0.02
2	2.71 ± 1.60	0.12 ± 0.26	0.29 ± 0.54	0	0.31 ± 0.52	0.26 ± 0.33	0	0
8	0.93 ± 1.21	0.13 ± 0.36	0.67 ± 0.72	0.64 ± 1.36	0.36 ± 0.56	0.40 ± 0.35	0.44 ± 0.78	0.05 ± 0.14
9	1.99 ± 1.22	0.36 ± 0.52	0.35 ± 0.65	0	0.78 ± 0.82	0.43 ± 0.84	0.10 ± 0.25	0.14 ± 0.25
16	1.22 ± 1.49	0.32 ± 0.46	0.82 ± 1.06	0.11 ± 0.27	0.58 ± 0.74	0.37 ± 0.38	0.26 ± 0.29	0
23	0.92 ± 1.08	0.75 ± 0.99	0.80 ± 0.86	0	0.40 ± 0.66	0.10 ± 0.22	0.15 ± 0.32	0.01 ± 0.04
10	2.50 ± 1.20	1.01 ± 1.40	0.74 ± 0.64	0	1.00 ± 1.23	0.10 ± 0.19	0.04 ± 0.10	0.06 ± 0.14
17	3.32 ± 0.85	1.08 ± 1.01	0.28 ± 0.54	0	0.94 ± 0.82	0.03 ± 0.10	0.12 ± 0.28	0.01 ± 0.04
24	2.19 ± 1.64	0.21 ± 0.33	0.55 ± 0.84	0	0.62 ± 0.76	0.09 ± 0.20	0.04 ± 0.13	0.01 ± 0.02
6	2.02 ± 1.75	1.27 ± 1.64	0.54 ± 0.88	0.43 ± 1.09	0.75 ± 1.20	0.09 ± 0.23	0.44 ± 0.46	0.01 ± 0.02
7	1.05 ± 1.09	3.13 ± 1.85	0.84 ± 1.44	0	0.48 ± 0.78	0	0.36 ± 0.30	0.04 ± 0.13
13	2.42 ± 1.81	0.14 ± 0.41	0.02 ± 0.05	0	0.64 ± 0.74	0.33 ± 0.54	0.33 ± 0.42	0.13 ± 0.35
14	2.39 ± 1.71	1.11 ± 1.05	1.33 ± 1.72	0	0.50 ± 0.69	0.06 ± 0.14	0.26 ± 0.44	0
15	0.27 ± 0.35	0.49 ± 0.52	1.83 ± 1.79	0	0.33 ± 0.55	0.05 ± 0.10	0.04 ± 0.06	0.05 ± 0.14
20	1.62 ± 1.27	0.77 ± 1.02	0.14 ± 0.37	0	0.67 ± 0.81	0.37 ± 0.34	0.04 ± 0.10	0.14 ± 0.30
21	1.72 ± 1.46	0.60 ± 0.58	0.57 ± 0.83	0	0.47 ± 0.65	0.24 ± 0.33	0.10 ± 0.27	0.10 ± 0.36
3	1.95 ± 1.38	0.84 ± 1.09	0.78 ± 1.07	0.02 ± 0.06	0.47 ± 0.68	0.13 ± 0.18	0.10 ± 0.27	0.02 ± 0.09
4	0.38 ± 0.83	0.48 ± 0.82	0.52 ± 0.72	0.04 ± 0.10	0.56 ± 0.62	0.38 ± 0.41	0.08 ± 0.10	0.02 ± 0.05
5	0.10 ± 0.36	0.23 ± 0.48	0.56 ± 0.79	0.51 ± 1.01	0.28 ± 0.50	0.22 ± 0.36	0.10 ± 0.23	0.00 ± 0.01
11	1.83 ± 1.52	0.66 ± 0.79	0.58 ± 0.71	0	0.39 ± 0.45	0.26 ± 0.41	0.10 ± 0.19	0
12	0.48 ± 0.78	0.33 ± 0.44	1.27 ± 1.38	0	0.41 ± 0.41	0.53 ± 0.58	0.13 ± 0.44	0.01 ± 0.04
18	1.48 ± 1.13	0.20 ± 0.31	0.47 ± 0.69	0	0.67 ± 0.93	0.62 ± 0.73	0.21 ± 0.71	0
19	0.79 ± 1.53	0.09 ± 0.27	0	0.00 ± 0.01	0.42 ± 0.45	0.31 ± 0.45	0.38 ± 0.83	0.07 ± 0.27
22	1.30 ± 1.48	1.19 ± 1.30	0.26 ± 0.54	0.01 ± 0.04	0.43 ± 0.55	0.62 ± 0.56	0.05 ± 0.12	0.02 ± 0.05
25	0.10 ± 0.23	0.41 ± 0.78	0.54 ± 0.77	0.15 ± 0.39	0.32 ± 0.33	0.39 ± 0.44	0.05 ± 0.10	0.01 ± 0.05
26	0.67 ± 0.83	0.72 ± 1.05	0.27 ± 0.72	0.01 ± 0.04	0.25 ± 0.34	0.47 ± 0.55	0.06 ± 0.14	0.07 ± 0.14
27	1.40 ± 0.96	1.74 ± 1.32	0.13 ± 0.28	0	0.76 ± 0.84	0.69 ± 0.48	0.17 ± 0.28	0.14 ± 0.45
28	0.78 ± 1.42	0.07 ± 0.22	0.87 ± 1.05	0.05 ± 0.11	0.48 ± 0.89	0.12 ± 0.19	0.16 ± 0.20	0.05 ± 0.12
29	0.94 ± 1.15	0.02 ± 0.09	0.56 ± 0.95	0.14 ± 0.30	0.55 ± 0.96	0.32 ± 0.68	0.20 ± 0.38	0.14 ± 0.27
30	0.39 ± 0.78	0.32 ± 0.69	0.26 ± 0.58	0.02 ± 0.09	0.27 ± 0.40	0.25 ± 0.37	0.05 ± 0.14	0.01 ± 0.02
Total	1.37 ± 1.45	0.63 ± 1.05	0.58 ± 0.94	0.07 ± 0.41	0.52 ± 0.72	0.30 ± 0.46	0.16 ± 0.36	0.04 ± 0.17

Appendix 5. Canopy Height Spatial Descriptives. Average canopy height measurements of 30 sites in the POM basin. Mean measurements listed ± standard deviation for canopy height cm). Refer to Figure 3. Red = Miami City East Coast; Light Green = East Coast Grass patch; Dark Green = No Entry Zone Virginia Key Grass patch; Blue = Channel through center of basin; Yellow = Channel and Cuts South of Port Islands.

Site #	N	Average Canopy
1	12	33.15 ± 17.18
2	14	42.84 ± 16.75
8	13	25.94 ± 16.92
9	13	39.34 ± 12.47
16	13	26.07 ± 12.42
23	14	27.50 ± 14.10
10	14	38.93 ± 15.30
17	14	45.97 ± 13.73
24	14	38.29 ± 15.76
6	14	38.28 ± 15.04
7	14	36.66 ± 6.05
13	13	57.67 ± 30.19
14	14	36.03 ± 13.23
15	14	22.20 ± 11.45
20	14	33.60 ± 12.59
21	14	27.23 ± 14.01
3	13	33.58 ± 17.35
4	11	17.72 ± 8.06
5	11	12.25 ± 8.94
11	13	29.34 ± 11.99
12	13	19.89 ± 8.78
18	14	32.45 ± 17.84
19	7	28.98 ± 15.19
22	13	20.70 ± 7.87
25	11	14.38 ± 7.89
26	11	21.03 ± 12.08
27	14	20.32 ± 8.40
28	14	19.15 ± 9.32
29	12	27.85 ± 18.20
30	8	13.22 ± 7.18
Total	383	29.96 ± 16.97

Miami City East Coast
East Coast Grass patch
No Entry Zone Virginia Key Grass patch
Channel through center of basin
Channel and Cuts South of Port Islands

Appendix 6. Spatial Environmental and Physical Descriptives. Average environmental and physical data measurements of 30 sites in the POM basin. Mean environmental and physical measurements listed ± standard deviation for temperature (°C), salinity (‰), turbidity (ntu), sediment depth (cm), and water depth (cm). N = 14 total number of sample collections. Refer to Figure 3. Red = Miami City East Coast; Light Green = East Coast Grass patch; Dark Green = No Entry Zone Virginia Key Grass patch; Blue = Channel through center of basin; Yellow = Channel and Cuts South of Port Islands.

Site #	Surface Temp	Bottom Temp	Surface Salinity	Bottom Salinity	Sediment Depth	Water Depth	Turbidity
1	27.67 ± 2.76	27.71 ± 2.68	31.68 ± 3.51	31.69 ± 3.26	119.71 ± 55.71	240.43 ± 82.80	1.93 ± 1.14
2	27.57 ± 2.83	27.53 ± 2.87	31.94 ± 3.17	32.25 ± 3.07	135.86 ± 51.40	239.21 ± 53.08	2.00 ± 1.24
8	27.76 ± 2.65	27.68 ± 2.73	31.58 ± 3.38	31.92 ± 3.06	80.29 ± 35.43	254.79 ± 58.74	2.37 ± 1.58
9	27.66 ± 2.76	27.66 ± 2.80	32.05 ± 2.92	32.34 ± 2.82	66.29 ± 62.40	228.21 ± 45.40	2.54 ± 1.75
16	27.45 ± 2.74	27.51 ± 2.78	31.29 ± 4.55	32.58 ± 2.50	54.64 ± 58.34	266.00 ± 106.71	2.04 ± 1.23
23	27.45 ± 2.66	27.45 ± 2.76	31.42 ± 6.02	33.19 ± 1.98	129.14 ± 66.77	232.00 ± 68.94	2.60 ± 1.76
10	27.55 ± 2.73	27.55 ± 2.77	32.63 ± 2.87	32.96 ± 2.58	144.21 ± 72.96	197.21 ± 52.10	2.62 ± 1.88
17	27.68 ± 2.66	27.66 ± 2.68	32.61 ± 3.42	33.19 ± 2.28	164.21 ± 71.49	153.57 ± 30.97	2.80 ± 1.67
24	27.44 ± 2.61	27.49 ± 2.70	31.94 ± 4.79	33.34 ± 2.05	163.71 ± 56.32	179.21 ± 36.07	2.69 ± 2.00
6	27.24 ± 2.91	27.35 ± 2.99	33.88 ± 2.57	34.04 ± 2.32	178.93 ± 88.38	143.71 ± 66.40	2.52 ± 1.72
7	27.41 ± 2.78	27.44 ± 2.81	34.21 ± 2.48	34.39 ± 2.40	222.50 ± 91.42	97.07 ± 24.55	1.65 ± 0.69
13	27.51 ± 2.83	27.56 ± 2.85	34.31 ± 2.34	34.47 ± 2.13	172.14 ± 90.79	206.14 ± 60.84	2.53 ± 1.41
14	27.16 ± 2.74	27.41 ± 2.67	33.91 ± 3.14	33.79 ± 3.13	209.93 ± 57.98	110.07 ± 45.83	1.97 ± 1.15
15	27.51 ± 2.55	27.53 ± 2.52	35.09 ± 1.60	35.06 ± 1.61	210.36 ± 98.85	99.50 ± 50.19	3.29 ± 2.26
20	27.07 ± 2.74	27.36 ± 2.70	34.04 ± 2.57	34.40 ± 2.21	194.64 ± 76.58	189.14 ± 31.91	2.83 ± 1.91
21	27.36 ± 2.78	27.49 ± 2.86	34.78 ± 1.85	34.88 ± 1.82	154.71 ± 100.28	164.71 ± 63.17	2.51 ± 1.22
3	27.68 ± 2.71	27.73 ± 2.83	32.30 ± 2.83	32.72 ± 2.52	132.08 ± 76.41	245.00 ± 36.36	1.89 ± 1.22
4	27.32 ± 2.80	27.35 ± 2.79	33.81 ± 2.31	34.04 ± 2.38	47.21 ± 35.33	310.21 ± 106.19	3.55 ± 3.89
5	27.24 ± 2.88	27.36 ± 2.73	33.88 ± 2.44	34.42 ± 2.64	48.64 ± 35.06	274.79 ± 69.47	3.78 ± 2.30
11	27.41 ± 2.70	27.41 ± 2.70	33.65 ± 2.37	33.97 ± 1.96	53.79 ± 49.88	243.50 ± 47.80	2.70 ± 2.15
12	27.52 ± 2.73	27.52 ± 2.74	33.69 ± 2.58	34.03 ± 2.32	96.71 ± 41.26	271.50 ± 40.01	2.70 ± 1.34
18	27.35 ± 2.62	27.47 ± 2.74	32.60 ± 4.18	33.97 ± 1.51	94.46 ± 61.82	255.38 ± 50.24	2.71 ± 1.66
19	27.02 ± 3.25	27.49 ± 2.74	34.10 ± 2.99	33.16 ± 3.26	103.36 ± 87.96	251.14 ± 36.20	3.08 ± 2.37
22	27.40 ± 2.60	27.43 ± 2.61	35.28 ± 1.63	35.29 ± 1.60	73.50 ± 80.98	206.50 ± 105.34	2.43 ± 1.15
25	27.37 ± 2.54	27.45 ± 2.68	32.99 ± 3.30	34.18 ± 1.89	128.29 ± 50.14	267.79 ± 47.93	2.57 ± 1.34
26	27.16 ± 2.68	27.31 ± 2.66	32.99 ± 3.31	33.75 ± 3.26	126.71 ± 60.73	229.79 ± 48.59	2.59 ± 1.49
27	27.32 ± 2.67	27.11 ± 2.75	34.31 ± 2.27	34.59 ± 2.24	172.21 ± 102.29	177.43 ± 55.91	2.84 ± 2.01
28	27.60 ± 2.78	27.71 ± 2.91	30.00 ± 5.15	32.79 ± 2.66	158.00 ± 72.99	229.57 ± 61.59	2.51 ± 1.26
29	27.46 ± 2.47	27.45 ± 2.65	30.81 ± 4.80	33.62 ± 1.99	164.36 ± 46.42	223.00 ± 46.97	2.57 ± 1.53
30	27.14 ± 2.66	27.38 ± 2.59	33.56 ± 3.26	34.10 ± 2.22	105.43 ± 79.19	214.57 ± 82.52	2.69 ± 1.81
Total	27.42 ± 2.64	27.48 ± 2.65	33.05 ± 3.46	33.64 ± 2.53	130.28 ± 84.11	213.20 ± 79.04	2.58 ± 1.76