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Density and Diversity of Penaeid Shrimp and Fish Species in Near-shore Seagrass Beds of Northern Biscayne Bay, Florida (USA)

Robin Cascioli
Nova Southeastern University, robin.cascioli@gmail.com

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Density and Diversity of Penaeid Shrimp and Fish Species in Near-shore Seagrass Beds of Northern Biscayne Bay, Florida (USA)

By

Robin Cascioli

Submitted to the Faculty of Nova Southeastern University Oceanographic Center in partial fulfillment of the requirements for the degree of Master of Science with a specialty in:

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Marine Environmental Science

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Robin Cascioli
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Oceanographic Center
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Approved:
Thesis Committee
Major Professor:________________________________________
Amy C. Hirons, Ph.D.
Committee Member:______________________________________
Silvia Maciá, Ph.D.
Committee Member:______________________________________
Richard E. Spieler, Ph.D.
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Abstract

Seagrass beds serve critical functions in coastal Florida ecosystems. The beds serve as nursery habitat for many juvenile reef fish species and provide protection for many types of benthic organisms found in Biscayne Bay. They help stabilize sediment that would otherwise increase turbidity around coral reefs, filter the water of contaminants, and help support an entire food web. Three species of seagrass were found at the study sites in northern Biscayne Bay: *Thalassia testudinum, Halodule wrightii,* and *Syringodium filiforme.* This study focused on understanding the organism habitat interaction by determining the species diversity, seasonal densities, and the correlation between population size and individual size for Penaeid shrimp, juvenile fish, and small adult fish at each site over a one year period. Habitat selectivity of various species was determined based on the habitat complexity derived from the various different seagrasses found in each of the beds. Animals predominantly favored *H. wrightii* habitat (Kruskal-Wallis H test: p< 0.0001) and this was likely the result of a decrease in predation risk due to the increased habitat complexity of the seagrass beds. Species diversity did not vary significantly over the course of a year (p= 0.7790), likely due to the lack of large abiotic disturbances (e.g. boating, hurricanes, and extreme salinity changes) to the seagrass beds. Densities of inhabitants changed significantly on a monthly basis, with the overall epifauna densities greatest at the end of the wet season (p< 0.01). The lack of correlation between individual size and overall population size likely indicated the majority of the species caught did not exhibit ontogenetic migration or live in the seagrass beds for the entirety of their life cycle.

Keywords:
Seagrass, diversity, seasonality, habitat selection, Biscayne Bay
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Introduction

Seagrass

Biology

Seagrasses are fully submerged, clonal, marine angiosperms with true roots, stems and leaves that create important ecosystems in estuarine waters (Littler et al., 1989; Fourquarean et al., 2003; Orth et al., 2006). There are approximately 50 species of seagrass found throughout the world’s coasts, excluding the Antarctic and Arctic coasts (Orth et al., 1984; Robertson and Mann, 1984; Hemminga and Duarte, 2000). These species of seagrass are grouped together into 12 genera which are further divided into two families, Potamogetonaceae and Hydrocharitaceae. Angiosperms evolved to live in marine environments during the Cretaceous Period, around 100 million years ago (Den Hartog, 1970; Phillips and Meñez, 1988), and most modern seagrasses evolved 40 million years ago during the late Eocene Period (Hemminga and Duarte, 2000).

Seagrasses are limited in their global distribution mainly by depth and salinity, not temperature; however, the presence of ice in the polar latitudes limits the presence of seagrasses in those regions. Seagrasses are limited in their depth primarily due to light availability; they require a surface irradiance (radiant energy/time reaching the water and seagrass bed) between 4 and 29% to grow and reproduce (Dawes and Tomasko, 1988; Dennison et al., 1993; Purkis and Klemas, 2011). In a study performed in the Indian River Lagoon system, Florida, Steward et al. (2005) determined that light only accounted for 52% of the variability of the depth limit of *Halodule wrightii*. Algal cover, epiphytic growth on the seagrass blades, and bottom reflectance were some of the other factors that caused the variability of depth in which seagrasses grew. Increasing algal cover has had
detrimental effects on seagrass cover and densities by causing die-offs due to decreased light energy (Fourquarean and Robblee, 1999; Hauxwell et al., 2001). If the algal cover does not persist for a long duration of time, the seagrass bed can survive off of its stored energy reserves (Fourquarean and Robblee, 1999). Seagrasses are also limited in their shallowness due to their inability to withstand desiccation; however, *Thalassia testudinum* has the ability lie flat along the sediment and can retain some water. Some species, such as *Syringodium filiforme* and *Ruppia maritima*, showed stunted growth in shallow water due to the decreased room for growth (Kantrud, 1991; Fonseca et al., 2000; Hemminga and Duarte, 2000; Lirman et al., 2008).

Seagrasses are able to tolerate a wide range of salinities and temperatures, but these vary among species. In general, seagrasses can survive in salinities from 10‰ to 45‰; however, once above or below these limits, seagrass growth declines and eventually mortality occurs due to osmotic stress (Quammen and Onuf, 1993). Seagrasses survive in both temperate and tropical regions because they have an extremely wide temperature tolerance range. Seagrasses can survive in water temperatures from 6 to 40°C depending on the species; however, once temperatures extend above the tolerance range for a prolonged time, the photosynthetic capacity decreases, causing mortality (Bulthuis, 1987; Masini et al., 1995; Terrados and Ros, 1995).

Seven species of seagrass are found in South Florida: *Thalassia testudinum*, *Syringodium filiforme*, *Halodule wrightii*, *Halophila johnsonii*, *Halophila decipiens*, *Halophila engelmannii*, and *Ruppia maritima* (Hemminga and Duarte, 2000) (Figure 1). However, *R. maritima* is not a true marine seagrass; it is a freshwater grass that can tolerate levels of salinity influx up to 32‰ (Phillips, 1960); Kantrud, 1991; Les et al.,
Of these seven species of seagrass, only three were the focus of the study: *Thalassia testudinum*, *Syringodium filiforme*, and *Halodule wrightii*. These three species of seagrass are thought to cover more than 60% of the Biscayne Bay substrate, leaving the rest of the substrate in Biscayne Bay bare sand or hard bottom (Lirman and Cropper, 2003; Browder et al., 2005).

**Thalassia testudinum**

*Thalassia testudinum* is commonly known as turtle grass. This species of seagrass has very coarse and fibrous leaves that are flat and wide, reaching widths of 4 to 12 mm and lengths of one meter (Littler and Littler, 2000). The highest productivity rates of all the seagrass species in South Florida can be found with *T. testudinum* (Thomas et al., 1961; Zieman et al., 1989; Lirman et al., 2008). The leaf production rate is equal to or greater than the loss rate, allowing it to maintain high biomass despite frequent leaf loss (Bittaker and Iverson, 1976).

*Thalassia testudinum* is abundant throughout the Caribbean basin; it forms thick mats on substrates composed of sand or mud from Florida south to the Lesser Antilles and the Gulf of Mexico (Littler and Littler, 2000). The depth limit of *T. testudinum* is usually 10 to 12 meters (Den Hartog, 1977) but it can reach as deep as 20 meters when there is limited turbidity (Zieman et al., 1989; Littler and Littler, 2000). Along with a consistent salinity between 24 - 35‰, *T. testudinum* also requires consistent temperatures between 15 - 36°C. Higher temperatures cause mortality and lower temperatures inhibit photosynthesis (Thomas et al., 1961; Mazzotti et al., 2007). Phillips (1960) determined that with extreme temperature, the leaves begin to die and fragment. In order to achieve maximum rates of photosynthesis and productivity, *T. testudinum* requires water temperatures of 28 - 30°C (Phillips and Meñez, 1988) and salinities of 28 - 30‰ (Zieman et al., 1999).

*Thalassia testudinum* reproduces either through sexual reproduction or asexual reproduction, such as through rhizome elongation and clonal growth within the apical meristem (Waycott, 1995; Hemminga and Duarte, 2000). The marine environment is not
a stable environment so it is important to have both modes of reproduction to survive. *Thalassia testudinum* has separate (diecious) male and female plants that exhibit hydrophilous pollination, in which the pollen grains are released in the water column by the male flower to fertilize a female flower (Hemminga and Duarte, 2000). This form of reproduction allows for increased levels of genetic diversity and decreased chances of self-fertilization; however, sexual reproduction in *T. testudinum* can be very sporadic and, in terms of the standing population, insignificant compared to asexual reproduction (Schlueter and Guttman, 1998).

In Biscayne Bay, maximum growth has occurred during April and May (Phillips, 1960), with flower production only occurring during the third week in May. This coincided with water temperatures greater than 25°C (Moffler et al., 1981; Johnson and Williams, 1982). Even though *T. testudinum* produces flowers every year in Biscayne Bay, sexual reproduction can still be rare because the beds can be unisex and less than one percent of the bed may simultaneously flower (Les, 1988).

Gallegos et al. (1992) determined that flowering of *T. testudinum* shoots in a Mexican Caribbean population occurred on average once every 13 years and that only 17% of the shoots produced a flower at least once in their life. These results were supported by Schlueter and Guttman (1998) who studied the genetic diversity of *T. testudinum* beds in the Florida Keys. They found a low level of genetic variation among 16 different sites, with only two sites being genetically different from the others. They believed the ocean acted as a genetic barrier. Therefore, sexual reproduction is secondary to rhizome elongation and clonal growth for the spreading of *T. testudinum* beds (Zieman, 1975; Les, 1988; Gallegos et al., 1992; Schlueter and Guttman, 1998).
**Syringodium filiforme**

*Syringodium filiforme* is commonly known as manatee grass. This species of seagrass has very coarse, cylindrical leaves that can reach heights of 45 cm. *Syringodium filiforme* is widely distributed throughout the Caribbean basin, from Florida south to the Lesser Antilles, and the Gulf of Mexico in sand or fine mud sediment. Manatee grass is found in deeper water than other seagrasses, up to 25 meters deep (Littler and Littler, 2000), because its leaves are extremely susceptible to desiccation (Den Hartog, 1977), and it thrives in lower light energy (Zieman et al., 1989).

*Syringodium filiforme* is found in areas with higher and more stable salinities between 22 - 35‰, than other seagrasses, caused by the direct input of ocean water, but it can also be found in locations that have more brackish water. However, in these areas, *S. filiforme* exhibits stunted growth and is less developed. High productivity and high population growth rates can only be maintained in well-flushed, oceanic areas (Phillips, 1960; Fonseca et al., 2000; Lirman et al., 2008). Once salinity reaches approximately 45‰, *S. filiforme* stops growing and begins to die because of a decreased tolerance to hypersalinity (McMillian and Moseley, 1967). Once water temperatures drop below 20°C, the leaves begin to die because of a decreased tolerance to cold water temperatures (Phillips, 1960; McMillian, 1980).

*Syringodium filiforme* commonly reproduces sexually but it is also capable of asexual reproduction, in which the rhizomes elongate horizontally through apical meristem (Les, 1988; Waycott, 1995). Sexual reproduction is achieved in *S. filiforme* with the use of separate male and female plants that exhibit hydrophilous pollination, in which the pollen grains are released in the water column by the male flower to fertilize a
female flower. The hydrophilous pollination allows for increased levels of genetic diversity and decreased chances of self-fertilization (Schlueter and Guttman, 1998; Hemminga and Duarte, 2000). In South Florida, maximum growth has been observed during April and May (Dawes et al., 1995), with flower production only occurring around the third week in April when water temperatures reach greater than 25°C (Johnson and Williams, 1982). Water temperature is the primary factor controlling when *S. filiforme* flowers; however, floral induction is also affected by changes in the amount nutrients and day length (McMillian, 1980). The seeds of *S. filiforme* have extended dormancy periods of up to three years; this allows for a larger range of seed dispersal (McMillian, 1983).

Asexual reproduction is needed in cases where only female flowers are produced, or male flowers are rare. When there is a female-biased population, there will be a decrease in seed production caused by the lack of pollination (Les, 1988).

**Halodule wrightii**

*Halodule wrightii* is commonly known as shoal grass. This species of seagrass has leaves that are flattened, like *Thalassia testudinum*, but are much narrower, only having a width of 2 to 3 mm. The blades are also much shorter, reaching a height of 10 to 25 cm high. One of the distinguishing features of the *H. wrightii* is the fact that its blades are bidentate; the tip of the blade has two points (Littler et al., 1989; Littler and Littler, 2000).

*Halodule wrightii* has a wide distribution and range of environments in which it can grow (Hall et al., 2006), but it has a low capacity for competition (Den Hartog, 1977). The distribution of *H. wrightii* is throughout the Caribbean basin, from Florida
south to the Lesser Antilles, and the Gulf of Mexico in the soft, sandy or muddy substrates (Littler and Littler, 2000). It is most abundant in shallow waters, 1 to 10 meters deep (Littler et al., 1989), that are subjected to extreme temperature and salinity fluctuations that prevent colonization by other seagrass species (Zieman et al., 1989). Survival of *H. wrightii* can occur in areas with lower salinity; however, densities are greatly depleted at depth due to the lower light energy (Lirman et al., 2008).

*Halodule wrightii* is known as the “pioneering species,” meaning that it is often the first seagrass species to propagate on a bare patch of substrate; after which, other species move in and compete for the same area (Lirman et al., 2008). *H. wrightii* can dominate areas where physical conditions are not conducive to the growth of other seagrasses (Den Hartog, 1977). In Biscayne Bay, however, *Thalassia testudinum* is called the “target species” because it will out-compete *H. wrightii* (Thomas et al., 1961; Den Hartog, 1977; Zieman et al., 1989; Fonseca et al., 2000; Littler and Littler, 2000; Lirman et al., 2008).

*Halodule wrightii* reproduces primarily through asexual reproduction by fragmentation and rhizome elongation, but it has been known to reproduce sexually on rare occasions. Sexual reproduction can be achieved with the use of separate male and female plants that exhibit hydrophilous pollination (Hemminga and Duarte, 2000). In South Florida, maximum growth generally occurs during April and May (Dawes et al., 1995). Flowering has been observed, rarely, in Biscayne Bay from the last week of March to the first week in April (Johnson and Williams, 1982). When *H. wrightii* sexually reproduces, the seeds may be buried in the sediment because the flowers are produced at the same level of the rhizome. The seeds of *H. wrightii* are capable of lying
dormant for years which allows for greater distribution of the seeds once the sediment is disturbed (McMillian, 1981). When *H. wrightii* asexually reproduces, rhizome fragments are more viable in spring than compared to fall. These data coincides with observed growth patterns of *H. wrightii* (Hall et al., 2006). The growth patterns of *H. wrightii* vary depending on the season; fastest growing periods occur in spring and summer and then they are dormant during the fall and winter. In addition to the blade fragmentation, the rhizomes of the *H. wrightii* horizontally grow through the apical meristem allowing for vegetative growth (Waycott, 1995; Hemminga and Duarte, 2000).

**Halophila species**

*Halophila johnsonii, H. decipiens,* and *H. engelmannii* can all be found in South Florida, but in greatly depleted numbers as compared to *Syringodium filiforme, Thalassia testudinum,* and *Halodule wrightii.* *Halophila* spp. can be found on a wide range of substrata, as well as depths. The depth range of *Halophila* spp. is the greatest range for all known seagrass genera (Durako et al., 2003); *Halophila* spp. has been recorded at depths of 90 meters (Den Hartog, 1977). All of the species of *Halophila* found in South Florida are extremely delicate and small in comparison with the previously described species (Littler and Littler, 2000).

*Halophila johnsonii* is commonly known as Johnson’s grass. This species of seagrass can reach a maximum height of five cm and consists of a single leaf attached to the rhizome system via a stem (Littler and Littler, 2000). It can be found in fine sediments and sand with a coastline distribution range of about 200 km, from Sebastian Inlet south to northern Biscayne Bay, making it the most limited range of all the
seagrasses found in the world (Littler and Littler, 2000; Durako et al., 2003; Hall et al., 2006). Depth limitations occur for H. johnsonii because it is outcompeted by H. decipiens at depths greater than three meters; whereas, at depths less than three meters, H. decipiens is outcompeted by H. johnsonii (Durako et al., 2003). These coastal waters where H. johnsonii can be found range in salinities from 15 to 43‰ and temperatures from 21 to 36°C (Dawes et al., 1989; Virnstein et al., 1997).

In 1998 H. johnsonii was listed as Threatened according to the US Endangered Species Act (Federal Register, 1998). One of the factors that may have led to the limited densities of H. johnsonii was the fact that sexual reproduction is unlikely, so reproduction is primarily asexual. Asexual reproduction of H. johnsonii occurs by fragmentation which is imperative for their survival (Durako et al., 2003; Hall et al., 2006). Hall et al. (2006) discovered that the fragmented H. johnsonii remained viable longer in the autumn compared to the spring. The only way for an asexual organism to become suited for the changing environment is by mutation (Durako et al., 2003).

_Halophila decipiens_ is commonly known as paddle grass. This seagrass can grow up to five cm tall and consists of two thin leaves that arise from a single spot on the rhizome (Littler et al., 1989). Distribution occurs throughout soft sand or fine substrate habitats in the Caribbean basin from Florida south to the Lesser Antilles and Gulf of Mexico (Littler and Littler, 2000). _H. decipiens_ is commonly found in waters from three to nine meters deep along undisturbed reefs (Den Hartog, 1977), and it has been recorded at depths as great as 30 meters (Littler et al., 1989). At shallow depths with high levels of irradiance and no shading from other aquatic plants, _H. decipiens_ cannot survive (Dawes et al., 1989). They can be found in limited numbers in shallower waters, in mangrove-
shaded areas, as well as sparsely mixed in with other seagrass species because they are shaded from the sun. A unique property of *H. decipiens* is the fact that it might be highly resistant to organic pollution because they are known to survive in the substrate of boat harbors (Den Hartog, 1977).

*Halophila decipiens* has the ability to reproduce asexually through fragmentation; however, it is believed that through sexual reproduction *H. decipiens* is able to re-establish its annual populations. The flowers of *H. decipiens* form at the base of the leaves causing seed formation to occur right at sediment level, possibly allowing the seeds to be covered by sediment. The seeds have been able to germinate after 1 to 2 years of dormancy. These seeds can be reintroduced into the environment after disturbances and eventually germinate (McMillian and Soong, 1989; McMillian, 1991; Hammerstrom et al., 2006).

*Halophila engelmannii* is commonly known as star grass. This seagrass can reach heights of 20 cm and consists of six to eight leaves attached at a single location on a stem which is attached to the rhizome just below the surface of the sediment. These leaves can grow up to three cm long. Distribution of star grass occurs throughout the Caribbean, from Florida south to the Greater Antilles, and the Gulf of Mexico in the soft sand or fine substrate (Littler and Littler, 2000). The depth of *H. engelmannii* is commonly less than five meters; however, they have been seen at depths as great as 40 meters (Littler et al., 1989). They are usually found alongside *H. decipiens* at depths along undisturbed reefs (Den Hartog, 1977). The coastal waters where *H. engelmannii* can be found have a wide range of salinities and temperatures; however, successful reproduction requires narrower ranges of both. In order to sexually reproduce, *H. engelmannii* requires day lengths of 14
to 24 hours as well as temperatures between 22 and 24°C. Flowering is inhibited if day lengths are shorter than 12 hours or temperatures are below 18.5°C and above 27.5°C (McMillian, 1980).

**Ecological role**

Seagrasses have a multifaceted ecological role; they have the ability to change the chemical, physical, and sedimentary processes of the coastal waters they inhabit (Michot et al., 2002), as well as indicate when the health of the surrounding environment is deteriorating (Johansson and Greening, 2000; Lirman et al., 2008). Seagrass beds are able to provide protection from predators, stabilize the sediment, filter nutrients, and contribute to the grazing and detrital food web (Hemminga and Duarte, 2000).

Seagrasses are able to stabilize sediment that would otherwise increase the turbidity in water surrounding offshore coral reefs, decreasing the reef’s productivity and resultant food web. Seagrasses are also able to filter flowing water by trapping the excess nutrients (Orth et al., 2006); however, if there are too many nutrients in the water, the seagrass will become overgrown with various macroalgae and eventually die from decreased light (Collado-Vides et al., 2007). Seagrasses get their nutrients through their rhizomes within the interstitial water; whereas macroalgae get their nutrients directly from the water. In normal nutrient conditions, the seagrass blades would be in a low-nutrient water column and the roots would be in a nutrient-rich interstitial water environment, allowing for the normal growth balance between seagrass and macroalgae. In nutrient rich waters, the seagrass still get the same amount of nutrients they would normally receive; however, the nutrient-rich water in the water column allows for the
macroalgae to flourish, blocking light from reaching the seagrass (Biber and Irlandi, 2006; Fourquarean et al., 1992; Steward et al., 2005). These algal blooms not only negatively affect the seagrass in the surrounding area but change the species compositions of the beds as well (Fourquarean and Robblee, 1999).

Seagrasses act as primary producers not only for the surrounding area but for the open ocean as well: they are major contributors in the marine food web (McLaughlin et al., 1983; Duarte and Chiscano, 1999; Hemminga and Duarte, 2000). The blades are eaten by macroherbivores (Orth et al., 2006) such as seagrass parrot fish (Leptoscarus vaigiensis), green sea turtles (Chelonia mydas), sea urchins (Toxopneustidae), and manatees (Trichechus spp.) (Thayer et al., 1984; Montague et al., 1995). The organic material that remains when the seagrasses die goes into the detrital food web as particulate or dissolved organic detritus. Most small organisms, such as caridean shrimp (Caridea spp.), are only able to eat the particulate organic detritus because the blades of the seagrass are too fibrous (Zieman et al., 1984). Fleming et al. (1990) determined in a stable isotope study of the primary consumers in Biscayne Bay that primary consumers received 63% of their carbon from the seagrass alone. Similarly, Kieckbrusch et al. (2004) found that invertebrates got 56% of their carbon from seagrasses and vertebrates got 77% of their carbon from seagrasses. These studies showed that seagrass beds were essential for many marine consumers because they provided over half of the carbon needed for survival of the seagrass community (Kieckbrusch et al., 2004).

Benthic monitoring in Florida Bay has shown evidence of sporadic seagrass, sponge, and pink shrimp (Farfantepenaeus duorarum) die-offs for years (Browder et al., 1999; Lirman et al., 2008). In 1987 a Thalassia testudinum die-off of approximately
4000 ha resulted in a wide variety of damage to the Bay ecosystem and demonstrated the ecological importance of seagrass. The die-off caused an increase in the algal biomass due to excess nutrients no longer utilized by the seagrass. The loss of seagrass led to increased turbidity in the surrounding water. The increased turbidity decreased the amount of light reaching the seagrass, one of the most common limiting resources for seagrass, for durations greater than six months; this led to another 1000 km$^2$ loss of $T.\ testudinum$ (Czerny and Dunton, 1995; Holmquist, 1997; Lirman and Cropper, 2003; Irlandi et al., 2004).

The effects of seagrass die-off might also have indirectly caused the die-off of sponges in Florida Bay in the late in 1980s; over 90% of the sponges were either killed or damaged (Fourqurean et al., 2002). It was theorized that seagrass die-offs caused cyanobacteria blooms in Florida Bay which, in turn, caused sponge mortality. In areas affected by seagrass die-off, cyanobacteria blooms occurred shortly after the seagrass began to die, most likely from the nutrients that arise from the death and decomposition of the seagrass; however, the exact causes of cyanobacteria blooms are still debatable. How the sponges were killed is still unknown because there have been no previously reported sponge die-offs associated with cyanobacteria blooms. Due to the duration and density of the bloom, the feeding and filtering processes of the sponge may have been blocked by the mucosa sheath of the cyanobacteria (Butler et al., 1995). It was possible that the cyanobacteria blooms continued to occur in the late summer and early fall because of the initial mass mortality of the sponges. The decreased densities of the sponges filtered water at a decreased rate which was not conducive to controlling the phytoplankton biomass and preventing subsequent blooms (Peterson et al., 2006).
Pink shrimp (*Farfantepenaeus duorarum*) declines in recruitment began in the mid-1980s and continued into the early 1990s. The decline in the stock was likely caused by decreased water quality due to dying or disturbed seagrass habitats. Florida Bay, Biscayne Bay, and various other estuaries located along the coasts of the Gulf of Mexico and Atlantic Ocean up to the Carolinas have seagrass beds that act as nurseries for juvenile *F. duorarum* that had been spawned in the Dry Tortugas, the largest shrimp fishery in South Florida (Farfante, 1970; Ault et al., 1999; Browder et al., 1999). The environmental and anthropogenic conditions that affect the nursery grounds have a pronounced effect on the level of recruitment into the fishery stock. When there is seagrass habitat loss due to die-off, damming, or dredging, there are fewer nursery grounds for the juvenile *F. duorarum* to reside. This situation leads to increased predation on an exposed population of shrimp and a decline in the recruitment (Garcia, 1984). The *F. duorarum* die-off had both an ecological and economic importance because they were, and continue to be, one of Florida’s most valuable commercial species as well as consumed by larger game fish species (Browder et al., 1999; Lirman et al., 2008).

**Restoration**

Restoration of the seagrass beds in Biscayne Bay is a very important factor when studying nearshore marine communities because these actions would affect a large proportion of seagrass species. Race and Fonesca (1996) determined that the main reason seagrass restoration was important was to compensate for environmental damage or loss of habitat through replacement of functions, values, and/or acreage specifically to
seagrass communities. Damages to seagrass habitat change the nature of the communities. Within a damaged area, the species composition could shift from a smaller vertebrate and invertebrate dominated seagrass bed to a larger vertebrate and invertebrate dominated seagrass bed (Bell et al., 2002; Maciá and Robinson, 2005).

In Miami-Dade County, over 11,000 acres of damaged seagrass beds exist (Greening, 2002). Since the seagrass beds are shallow, it is very easy for improper boating to dislodge pieces of the sediment, creating a prop scar or blowouts from the propeller on the engine (Bell et al., 2002). Prop scars are shallow, linear trenches oriented in the direction that the boat was traveling; blowouts are deep and circular because the boat motor remains in one place while prop wash destroys the beds (Whitfield et al., 2004). The hull of the boat can also cause damage to the seagrass beds by creating hull scars and hull impressions (Engeman et al., 2008). Improper boating occurs when the boater is inexperienced or unfamiliar with the waters (Sargent et al., 1995) and is one of the main disturbances that cause physical damage to the seagrass beds and the community living in the seagrass bed (Lirman et al., 2008). If South Florida is riddled with too many prop scars and blowouts, there will be less nursery areas and shelter for the organisms to live, changing the diversity of the entire Biscayne Bay ecosystem (Bell et al., 2002).

Restoration efforts on prop scars have shown success; however, due to the slow growth of the various seagrass, it is a very lengthy process. *Thalassia testudinum* takes, on average, between 5 and 10 years to fully recover from such a disturbance. The slow regrowth is due to the complex nature of the rhizome structure, giving *T. testudinum* the
slowest rhizome-elongation rates of all the various seagrass species (Whitfield et al., 2004).

Ecology and Fauna of Biscayne Bay

Abiotic variation

Biscayne Bay is a shallow lagoon located on the southeast coast of Florida that experiences sudden changes in salinities throughout the year due to both natural and anthropogenic factors (Figure 2) (Serafy et al., 2003; Lirman et al., 2008). Florida undergoes natural fluctuations in the amount of rainfall during the year, distinguished as wet and dry seasons. South Florida can be considered a tropical savannah due to the differences in lengths of the rainy and dry seasons because the dry season tends to last longer than the wet season, causing drought conditions in various years (Hela, 1952). The wet season occurs during the summer, usually between the months of May and October, and the dry season occurs from the middle of fall until spring, usually between the months of October and May. The average start date of the rainy season is May 20th. The start of the rainy season is characterized by a period of three days in which the dew point is over 21°C and the water temperature is at least 27°C (Molleda, 2010).

During the wet season, South Florida may also experience hurricanes as well, adding to the increase in precipitation. During the wet season and hurricane season the surface salinity in Biscayne Bay decreases, while the opposite occurs during the dry season (Duever et al., 1994). Various drainage canals and rivers located along the western margin of the bay are some of the anthropogenic factors that cause large changes in salinity (Serafy et al., 1997; Biber and Irlandi, 2006); whereas, the eastern margins of
the bay have stable salinities year round (Irlandi et al., 2002). Biscayne Bay has a relatively small tidal range of approximately one meter between high and low tides with salinities ranging from 30 to 40‰ (McNulty et al., 1962). The water temperature fluctuates from 18 to 31°C on an annual basis (McNulty et al., 1962; Maciá, 2000).

**Community Composition and Structure**

Seagrass beds provide extensive protection for the different fish and invertebrates living in the vicinity (Thomas et al., 1961; O’Gower and Wacasey, 1967; Maciá, 2000); however, faunal habitat choice depends upon the structural complexity, risk of predation, and amount of inter-specific competition. Seagrass beds sufficiently fulfill all of those parameters, with a high degree of structural complexity and spatial variability. The morphological differences among the seagrass species can result in differences in the fish community composition and diversity due to differences among the size and shapes of the seagrass blades (Malavasi et al., 2007), shoot density, or even the leaf standing crop (Orth et al., 1984). Studies have shown that the species diversity of a seagrass community increases with the increasing biomass (Heck and Wetstone, 1977; Heck and Orth, 1980) and density of the seagrass cover (Zieman et al., 1984).

In a study performed over four years in the Suwannee River estuary, Tsou and Matheson (2002) discovered a seasonal pattern in abundance of the entire community of juvenile and small adult fishes, blue crabs (*Callinectes sapidus*), and pink shrimp (*Farfantepenaeus duorarum*), marked by low abundances in the winter and high abundances in the summer. These patterns coincided with seasonal patterns in salinity and temperature. These results were supported by Tuckey and Dehaven (2004) who
observed a salinity-specific change in March 1998 that coincided with a change in fish species composition they had collected in their study of the Suwannee River estuary. In Biscayne Bay, Lirman et al. (2008) also correlated changes in abundance, diversity, and spatial distribution of benthic organisms, including seagrass, to changing salinities. These results showed that seasonal patterns in these organisms were mainly driven by changing salinities; changing water temperature only had a minimum effect on the species distribution. The increased freshwater runoff decreased the salinity and the distribution of fish. Biomass of *Thalassia testudinum* decreased with increased freshwater runoff as well; *T. testudinum* is extremely sensitive to changes in salinity (Irlandi et al., 2002; Herbert and Fourqurean, 2009).

Specific to this study, seagrass beds in Biscayne Bay are ecologically significant because they greatly affect the fauna living in and around the community. The seagrass provides food for the various organisms (Thayer et al., 1984; Montague et al., 1995; Orth et al., 2006), acts as a nursery for many fish and invertebrate species (Berkley et al., 1985), and provides protection for not only the juvenile fish using the seagrass bed as a nursery but also the organisms that reside in the bed permanently (Thomas et al., 1961; O’Gower and Wacasey, 1967; Maciá, 2000). Seagrass beds have even greater organism densities than mangrove estuaries (Zieman et al., 1984).

Many of the benthic organisms exhibit ontogenetic migrations with movement of juveniles from the seagrass beds to the mangroves and finally to the offshore coral reefs as adults (Thorhaug, 1981; Serafy et al., 2003). Berkley et al. (1985) determined that in Biscayne Bay many game fish were found in the seagrass beds before they migrated out to the reef. Game fish include fish species that have recreational and / or commercial
importance, as well as fish used as bait. The most abundant fish caught were the baitfish pinfish (*Lagodon rhomboides*). Some of the other abundant fish caught included grunts (Haemulidae), snappers (Lutjanidae), and spotted sea trout (*Cynoscion nebulosus*). *C. nebulosus* was most abundant in the shallow water. All of these fish were caught as juveniles or sub-adults (Berkley et al., 1985).

Figure 2. Study area located in Biscayne Bay on the southeast coast of Florida.
This study aimed to assess the ecology and fauna of north Biscayne Bay by asking three different questions relating to population, habitat selectivity, and seasonal variation of epifaunal species composition in these seagrass beds. For the purpose of this study epifaunal species includes all benthic species of fish and Penaeid shrimp. The study also aimed to determine the habitat diversity for each of the beds studied. Different organisms exhibit ontogenetic migration, in which they migrate from near shore to deeper water with age and increased size (Thorhaug, 1981; Serafy et al., 2003) so (1) as populations of Penaeid shrimp, juvenile fish, and small adult fish decrease, will there be an increase in organism size? Seasonal distribution can be marked by changes in salinity and temperature (Tsou and Matheson, 2002) so (2) as the season changes throughout the year from wet to dry, will the population sizes of Penaeid shrimp, juvenile fish, and small adult fish change? Finally, habitat complexity can factor into the species composition of the seagrass bed communities (Orth et al., 1984; Malavasi et al., 2007) so (3) will there be a preference for a particular seagrass species habitat?

Material and Methods

Study Area

Study Sites

This study was conducted in northern Biscayne Bay along the beaches of Virginia Key and Hobie Beach. Four different study sites were used, each varying in their known seagrass composition and location on the islands; a total of eight different seagrass beds were sampled (Maciá et al., 2008). The four sites were named in regards to their location on the islands: North Hobie Beach (NHB), South Hobie Beach (SHB), North Virginia Key (NVK), and South Virginia Key (SVK) (Figure 3).
NHB site was located along the eastern margin of Hobie Beach, facing the port of Miami. The near shore region of this location was very rocky, relegating the growth of seagrass to the shallower, high light energy areas. The bottom deepened quickly, making the site accessible only during low tide (Figure 4). SHB site was located along the western margin of Hobie Beach (Figure 4). NVK and SVK sites were located south of Hobie Beach along the western margins of Virginia Key (Figure 5).

Figure 3. Study sites located along the Rickenbacker Causeway in northern Biscayne Bay: North Hobie Beach (NHB), South Hobie Beach (SHB), North Virginia Key (NVK), and South Virginia Key (SVK).
Figure 4. The area of the *Syringodium filiforme* seagrass bed at NHB (yellow), the *Halodule wrightii* seagrass bed (blue) at SHB, and the *Thalassia testudinum* seagrass bed at SHB (green).
Figure 5. The area of the *Halodule wrightii* seagrass bed (green) at NVK, the *Thalassia testudinum* seagrass bed (red) at NVK, the *H. wrightii* seagrass bed (dark blue), the *Syringodium filiforme* seagrass bed (purple) at SVK, and the *T. testudinum* seagrass bed (light blue) at SVK.

**Study Design**

**Push net**

A shallow water collection apparatus was needed for sampling in water depths of less than one meter. A 1 m² push net was created out of polyvinyl chloride (PVC) pipes with a nylon mesh net size of 5 mm² (Figure 6). The push net was designed to be pushed around in front of the user in a mower-like fashion. Pushing the apparatus at a shallow angle into the seafloor allowed for the capture of not only the organisms living between the blades in the water column but also the organisms residing on the seafloor as well.
A push net was chosen instead of a beach seine mainly because of its easy maneuverability for one-person use. The push net allows for a larger range and rate of collection than a seine net (Strawn, 1954). The push net also allowed targeted sampling in particular locations as opposed to the beach seine which often must pass through different types of seagrass before being pulled to shore.

The push-net is ideal for sampling shallow water that is less than one meter deep; however, it can also work in waters that are as shallow as a few centimeters and as high as one meter, the height of an average adult’s waist. The push net was also capable of
being used in locations where there was no beach present (Strawn, 1954). The push net works most efficiently while sampling in *Thalassia testudinum* and other submerged vegetation; however, if the grass is rigid, it is more difficult to sample (Allen and Inglis, 1958). Push nets are designed with rounded edges to create the least amount of damage to the seagrass. Meyer et al. (1999) found that there was no significant reduction in the *Thalassia testudinum* mean biomass or blade length after trawling from a boat during their study. The push net was better for collecting smaller fish and fish that live on the bottom of the seagrass bed, whereas a seine net can collect larger, faster fish because it covers a larger area. The push net also only catches slower fish because the faster fish are better adapted to get out of the way of the push net as opposed to the beach seine that has a larger surface area (Allen and Inglis, 1958).

**Collection**

Salinity, temperature, and water height were recorded at each site using a hydrometer, digital thermometer, and meter stick, respectively. Samples were collected from the four different sites during daylight hours once a month for an entire year at ebb and slack low tide beginning June 2010 and ending May 2011. The samples of fish and Penaeid shrimp collected were from five repetitions of seven, one meter sweeps through each of the different types of seagrass bed communities present at the site, making certain to sample only in the areas with the target seagrass species. Specimens were kept in separate containers per sweep and identified at the conclusion of the fifth sweep from each of the different monospecific seagrass communities present. Specimens were released at the conclusion of the infield identification, making sure to release the
specimens greater than 200 feet from the monospecific seagrass bed to be sampled next. For the purpose of statistical analysis, the five sweeps for each seagrass bed tested were combined into one data entry.

Initial seagrass cover was measured using a modified Braun-Blanquet method of vegetation identification and abundance measurement (Braun-Blanquet, 1932; Mueller-Dombois and Ellenberg, 1974; Fourquarean et al., 2002) to assure different seagrass-dominant beds were studied. Three, 0.25 meter² PVC quadrats were thrown in random locations in the desired seagrass bed. Within each quadrat, all of the plants were identified and abundances (percent bottom cover) calculated using the following ordinal scale: 0.1= individual, 0.5= sparse, 1= 0-5%, 2= 5-25%, 3= 25-50%, 4= 50-75%, and 5= 75-100%. The sediment type was identified and maximum canopy height of each seagrass species was determined by measuring the tallest individual blade. The seagrass beds studied had a dominant single seagrass species ($p<0.05$) in the abundance ratings in each quadrat. Littler and Littler (2000) and Littler et al. (1989) were used to identify the seagrass and algal genus and/ or species.

**Identification**

Fish and invertebrate identifications were based on taxonomic keys from several different sources. Pipefish and seahorses (Syngnathidae) were identified using dichotomous keys in Dawson's Fishes of the Western North Atlantic (1982). Penaeid shrimp were identified using the NOAA Technical report “Illustrated Key to Penaeoid Shrimp of Commerce in the Americas” (Farfante, 1988). The dichotomous keys in Robins and Ray’s *A Field Guide to Atlantic Coast Fishes North America* (1986),
McEachran and Fechlem’s *Fishes of the Gulf of Mexico*, Vol. 1 (1998) and Vol. 2 (2005), and Böhlke and Chaplin’s *Fishes of the Bahamas and Adjacent Tropical Waters* (1968) were used to identify the remaining juvenile fish species found at the four sites. Identifications and counts were performed and recorded after each sweep. The data collected included density of each species and standard length in mm (SL) (Figure 7) or carapace length in mm (Figure 8) of each individual collected. Organisms were identified to their lowest readily identifiable taxonomic classification.

![Measuring Fish Length](image)

Figure 7. Standard length measurements for fish (Commonwealth of Australia, 2011).
Figure 8. Carapace length measurements for penaeid shrimp (Farfante, 1988).

Statistical Analysis

Statistical analyses were conducted using Stat Disk 8.1 (Triola, 2000) and Microsoft Excel (2010). Maps were created using ArcGIS 10 (ESRI, 2012). Parametric and non-parametric statistical analyses were both used to determine whether the hypotheses were supported or rejected. In order to determine if habitat selectivity was feasible, initial Braun-Blanquet quadrat abundances were analyzed using a single factor Analysis of Variance (ANOVA) to determine if each seagrass bed was significantly (α≤0.05) dominated by a single species of seagrass.

Species diversity of each of the studied seagrass beds was calculated using the Shannon-Weiner Diversity Index (Equation 1). This index demonstrated whether either community was dominated by a low variety of species or a wide variety of species (Shannon and Weaver, 1949).
Equation 1. Shannon Weiner Diversity Index (H’), \( p_i \) is the proportion of number of individuals of each species to the number of individuals of all species.

\[
H' = - \sum p_i \ln p_i
\]

The remaining data collected were tested for normal distribution and, in the cases where the data were not, square root transformations were applied. Any data collected that did not show normality after applying a square root transformation were statistically analyzed using a variety of non-parametric tests dependent upon the number of groups \((k)\) and the number of observations per group \((n_k)\). The Kruskal- Wallis H-test was performed when \(k \geq 3\) and \(n_k \geq 5\) to determine if there was a significant difference among the different populations. In cases where \(n_k < 5\), the Kruskal-Wallis H-test was still used; however, the data were viewed with caution because H doesn’t follow a chi-squared distribution well (Triola, 2000). The Kruskal-Wallis H-test was used to determine if there were significant differences in the habitat choice, species diversity, and seasonality when three or more sites or seagrass species were analyzed. The Wilcoxon Rank-Sum test was performed when \(k = 2\) to determine if there was a significant difference between the two different populations tested. The Wilcoxon Rank-Sum test was used to determine if there were significant differences in the habitat choice, species diversity, and seasonality when there were only two sites or seagrass species being analyzed. The Wilcoxon Signed-Rank test was performed to analyze matched pairs \((k = 2)\) and to determine if there were significant differences in the total epifauna densities between the South Florida 2010-2011 wet and dry seasons. Finally, the Spearman Rank Correlation
Coefficient test was used to determine the correlation between population size and organism size in standard length (SL) (Zwillinger and Kokoska, 1999; Triola, 2000).

Results

**Abiotic Measurements and Vegetation Abundance**

NHB site was located along the eastern margin of Hobie Beach, facing the port of Miami with a mean low tide depth of 107.0 cm. The midwater temperature and salinity varied throughout the year but ranged from 18.9 to 34.0°C and 27 to 38‰, respectively. The area of the sampled seagrass bed was 34.03 m². The site contained only one type of seagrass, *Syringodium filiforme*, with an average canopy height of 35.7 ± 12.7 cm. The near shore region of this location was very rocky, relegating the growth of seagrass to the shallower, high light energy areas. The bottom deepened quickly, making the site accessible only during low tide.

SHB site was located along the western margin of the Hobie Beach. The midwater temperature and salinity varied throughout the year but ranged from 19.4 to 35.6°C and 29 to 38‰, respectively. Two separate seagrass species were studied at the site. *Halodule wrightii* was in abundance closest to the shore line with a mean low tide water depth of 29.9 cm and an average canopy height of 27.7 ± 3.1 cm. The area of the *H. wrightii* bed sampled was 37.85 m². *Thalassia testudinum* was located in deeper water further off shore with a mean low tide water depth of 43.3 cm and an average canopy height of 59.3 ± 14.2 cm. The area of the *T. testudinum* bed sampled was 89.52 m². The two monospecific beds were separated from each other by 29.55 m that contains a mixed zone of both seagrass species.
NVK site was located south of Hobie Beach along the western margins of Virginia Key. The midwater temperate and salinity varied throughout the year but ranged from 20.1 to 34.4°C and 32 to 38‰, respectively. Two separate seagrass species were studied at the site. *Halodule wrightii* was in abundance closest to the shore line with a mean low tide water depth of 24.5 cm and an average canopy height of 18.0 ± 6.6 cm. The area of the *H. wrightii* sampled was 20.29 m². *Thalassia testudinum* was located in deeper water further off shore with a mean low tide water depth of 105.3 cm and an average canopy height of 22.0 ± 2.6 cm. The area of the *T. testudinum* bed sampled was 25.29 m². The two sampled beds were separated by 21.07m that contained bare sand.

SVK site was located south of Hobie Beach along the western margins of Virginia Key. The midwater temperate and salinity varied throughout the year but ranged from 20.1 to 35.7°C and 31 to 42‰, respectively. Three types of seagrass species were studied at this site. *Halodule wrightii* was in abundance closest to the shore line with a mean low tide water depth of 24.5 cm and an average canopy height of 11.7 ± 0.6 cm. The area of the *H. wrightii* bed sampled was 44.21 m². *Thalassia testudinum* was located in deeper water further off shore with a mean low tide water depth of 95.0 cm and an average canopy height of 21.0 ± 2.0 cm. The area of the *T. testudinum* bed was 113.63 m². The *T. testudinum* and the *H. wrightii* beds were separated in areas by 62.28m in which the seafloor became shallower and then deepened. *Syringodium filiforme* was located to the north of the *H. wrightii* and *T. testudinum* beds studied. The *S. filiforme* bed had a mean low tide water depth of 41.0 cm and an average canopy height of 11.0 ± 1.0 cm. The area of the *S. filiforme* bed sampled was 62.62 m² and had a decreased shoot density compared to the NHB *S. filiforme* bed.
The Braun-Blanquet measurements taken from each seagrass bed showed that the dominant seagrass species for each seagrass bed had significantly greater abundance than the other seagrass species found in the quadrate (Table 1), allowing for habitat complexity to be studied in eight different seagrass beds.

Table 1. *P*-values for a Two-Tailed Single Factor ANOVA of the Braun-Blanquet seagrass species measurements. Algae were not factored into this study.

<table>
<thead>
<tr>
<th>Site</th>
<th>Dominant Seagrass Species</th>
<th>Other Seagrass Species found</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHB</td>
<td><em>Halodule wrightii</em></td>
<td><em>Thalassia testudinum</em></td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td><em>Thalassia testudinum</em></td>
<td><em>Syringodium filiforme</em></td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>NHB</td>
<td><em>Syringodium filiforme</em></td>
<td>NONE</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SVK</td>
<td><em>Halodule wrightii</em></td>
<td><em>Thalassia testudinum</em></td>
<td>0.0011</td>
</tr>
<tr>
<td></td>
<td><em>Thalassia testudinum</em></td>
<td><em>Syringodium filiforme</em></td>
<td>0.0113</td>
</tr>
<tr>
<td></td>
<td><em>Syringodium filiforme</em></td>
<td><em>Halodule wrightii</em></td>
<td>0.0013</td>
</tr>
<tr>
<td>NVK</td>
<td><em>Halodule wrightii</em></td>
<td><em>Syringodium filiforme</em></td>
<td>0.0016</td>
</tr>
<tr>
<td></td>
<td><em>Thalassia testudinum</em></td>
<td><em>Syringodium filiforme</em></td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Water temperature at the study sites varied from 19.4 to 35.6º C and the salinity ranged from 29 to 42‰ (Table 2). In 2010, the wet season began May 16, 2010 and lasted until October 3, 2010. During this time Miami International Airport recorded 43.30 inches of rainfall; this was 8.39 inches over the normal average rainfall amount. The 2010-2011 dry season lasted from October 4, 2010 until June 8, 2011, with a recorded rainfall of 11.8 inches in coastal Dade County. This rainfall amount was 7.6
inches below the average rainfall amount for coastal Dade County. For every site except SVK, the water temperature in April 2011 was the highest recorded for the entire 2010-2011 dry season. For every site except SVK, the water temperature in December 2010 was the lowest temperature recorded for the entire 2010-2011 dry season (Molleda, 2010; NOAA et al., 2010; 2011; Rosencrans, 2011).

Table 3. Comparison of the temperature (°C) and salinity (‰) measurements for the 2010-2011 sampling period at each of the four study sites and the air temperatures recorded by NOAA at the Miami International Airport in grey (National Weather Service Forecast Office [NWS], 2011).

<table>
<thead>
<tr>
<th>Site</th>
<th>Month</th>
<th>SHB T (°C)</th>
<th>SHB S (‰)</th>
<th>NHB T (°C)</th>
<th>NHB S (‰)</th>
<th>SVK T (°C)</th>
<th>SVK S (‰)</th>
<th>NVK T (°C)</th>
<th>NVK S (‰)</th>
<th>NWS T (°C)</th>
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</table>
**Ecosystem**

A total of 2,009 animals were caught representing 20 families, 24 genera, and 27 species (Table 3). Syngnathidae was the most speciose family collected with six species; however, Fundulidae and Penaeidae were the most abundant taxa, comprising 46.79% and 27.23% of the total organisms caught, respectively.

Epifaunal species diversity was similar between sites and seagrass bed composition. There were no significant differences in the species diversity among the eight seagrass beds studied (K-W analysis, n=96, p=0.1375; Figure 9), and there were no significant differences in species diversity among the three seagrass species (K-W analysis, n=96, p=0.4889; Figure 10). *H. wrightii* exhibited no significant difference in species diversity among the NVK, SVK, and SHB sites (K-W analysis, n=36, p=0.0930; Figure 11). There was no significant difference in species diversity of *T. testudinum* between the NVK, SVK, and SHB sites (K-W analysis, n=36, p=0.7033; Figure 12). Statistical analyses on the NHB site were not run due to the lack of *H. wrightii* and *T. testudinum* presence at the study site. *S. filiforme* exhibited a significant difference in species diversity when comparing the SVK site to the NHB site (Wilcoxon Rank-Sum, n=24, p=0.0194; Figure 13).

Species diversity was similar across all sampling months among the eight seagrass beds studied (K-W analysis, n=96, p=0.7790; Figure 14) and there were no significant differences between species diversity on a monthly basis when comparing the mean densities of *Halodule wrightii*, *Thalassia testudinum*, and *Syringodium filiforme* (K-W analysis, n=36, p=0.8577). When comparing monthly changes in species diversity, there were no significant differences for *H. wrightii* (K-W analysis, n=36, p=0.8577), *T.*
*testudinum* (K-W analysis n=36, *p*=0.9389), or *S. filiforme* (K-W analysis n=24, *p*=0.5785).

Table 3. Species list of the organisms collected during the duration of the 2010-2011 sampling period from the four study sites.

<table>
<thead>
<tr>
<th>Order</th>
<th>Family</th>
<th>Genus</th>
<th>Species</th>
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</thead>
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<td>Anchoa</td>
<td>sp</td>
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<tr>
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<td>Batrachoididae</td>
<td>Opsanus</td>
<td>beta</td>
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<td>Lucania</td>
<td>parva</td>
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<td>Apogonidae</td>
<td>Astrapogon</td>
<td>puncticulatus</td>
<td>Blackfin Cardinalfish</td>
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<td>Gerreidae</td>
<td>Eucinostomus</td>
<td>sp</td>
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<td>Haemulon</td>
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<td>Penaeidae</td>
<td>Penaeid</td>
<td>shrimp</td>
<td>penaeid shrimp</td>
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Seasonality

The wet season in South Florida lasted for only four months during the 2010-2011 sampling season, whereas the South Florida dry season lasted for eight months according to the National Oceanic and Atmospheric Administration [NOAA] (NOAA et al., 2010; 2011). When assessing all of the sites comprehensively, wet season contained a total of 51% percent of the total epifaunal density, whereas dry season contained a total of 49% of the total epifaunal density.

When assessing each individual site for seasonality, there were varying results between the 2010-2011 wet and dry seasons (Figure 15). The total epifaunal density at the NVK site and the SHB site exhibited no significant differences between the 2010-2011 wet and dry seasons (Wilcoxon Signed Rank: NVK T=69, n=18, \( p > 0.2 \); SHB T=30.5, n=13, \( p > 0.2 \)). However, the total epifaunal density at the SVK site and the NHB site were significantly greater during the 2010-2011 dry season when compared to the 2010-2011 wet season (Wilcoxon Signed Rank: SVK T=34.5, n=20, \( p < 0.01 \); NHB T=5, n=10, \( p = 0.02 \)).

The monthly total epifaunal density changes varied within each site and by seagrass species. The seasonal density distribution patterns (Figure 16) demonstrated that there was an overall increase in total epifaunal densities at the end of the 2011 rainy season. These changes in total epifaunal density were inversely correlated to monthly salinity changes (\( p = 0.016 \); Figure 17), but showed no significant relationship to monthly temperature changes (\( p = 0.952 \); Figure 17).

Correlations between population size and individual organism size throughout the study year were only analyzed for species that were present for more than \( \frac{3}{4} \) of the year.
to allow for the analysis of species that utilize the seagrass habitat as a nursery, instead of daily migratory processes. By analyzing the species that were caught for more than half of the sampling period, changes in population size and individual size could be seen. The following were the only taxa that were present for more than eight months of the year: *Gobiosoma robustum, Floridichthys carpio, Hippocampus zosterae, Lucania parva, Penaeidae, and Syngnathus scovelli*. No significant correlation between individual size and population size was exhibited for any of the analyzed species (all $p>0.05$; Figures 18-23).

**Figure 9.** Overall Shannon-Weiner Diversity Index ($H'$) per seagrass bed during the 2010-2011 sampling period: NHB-*Syringodium filiforme* (1), SHB-*Halodule wrightii* (2), SHB-*Thalassia testudinum* (3), NVK- *H. wrightii* (4), NVK- *T. testudinum* (5), SVK- *H. wrightii* (6), SVK- *T. testudinum* (7), and SVK- *S. filiforme* (8).
Figure 10. Shannon-Weiner Diversity Index (H') measured during the 2010-2011 sampling period in the *Halodule wrightii*, *Thalassia testudinum*, and *Syringodium filiforme* seagrass beds located at NVK, SVK, NHB, and SHB combined.

Figure 11. Shannon-Weiner Diversity Index (H') measured during the 2010-2011 sampling period in the *Halodule wrightii* seagrass beds from NVK, SVK, and SHB.
Figure 12. Shannon-Weiner Diversity Index (H’) measured during the 2010-2011 sampling period in the *Thalassia testudinum* seagrass beds from NVK, SVK, and SHB.

Figure 13. Shannon-Weiner Diversity Index (H’) measured during the 2010-2011 sampling period in the *Syringodium filiforme* seagrass beds from SVK and NHB.
Figure 14. Overall monthly changes of the Shannon-Weiner Diversity Index (H’) when combining all the organisms caught during the 2010-2011 sampling period within *Halodule wrightii*, *Thalassia testudinum*, and *Syringodium filiforme* seagrass beds combined.
Figure 15. 2010-2011 South Florida wet and dry seasons total epifaunal densities by study site location; NVK (A), SVK (B), NHB (C), and SHB (D).
Figure 16. 2010-2011 seasonal pattern of total epifaunal densities in the eight different monospecific seagrass beds located at NVK, SVK, NHB, and SHB with overall density (all sites combined) shown in black.
Figure 17. Correlations of salinity and temperature to total epifauna density over the 2010-2011 sampling period, indicating a slightly inverse relationship between salinity and total epifaunal density.
Figure 18. Regression and correlation of population size to average individual size for *Gobiosoma robustum* grouped by months (sampling date) in which the fish was present during the 2010-2011 sampling period at NVK, SVK, NHB, and SHB (square-root transformed data, $p=0.8911$).

\[ y = 0.0126x + 22.21 \]

Figure 19. Regression and correlation of the population size to average individual size for *Lucania parva* grouped by months (sampling date) in which the fish was present during the 2010-2011 sampling period at NVK, SVK, NHB, and SHB ($p=0.2637$).

\[ y = -0.0117x + 21.75 \]
Figure 20. Regression and correlation of the population size to average individual size for *Hippocampus zosterae* grouped by months (sampling date) in which the fish was present during the 2010-2011 sampling period at NVK, SVK, NHB, and SHB ($p=0.9844$).

Figure 21. Regression and correlation of the population size to average individual size for *Floridichthys carpio* grouped by months (sampling date) in which the fish was present during the 2010-2011 sampling period at NVK, SVK, NHB, and SHB ($p=0.0909$).
Figure 22. Regression and correlation of the population size to average individual size for penaeid shrimp grouped by months (sampling date) in which the shrimp were present during the 2010-2011 sampling period at NVK, SVK, NHB, and SHB ($p=0.0600$).

Figure 23. Regression and correlation of the population to average individual size for *Syngnathus scovelli* grouped by months (sampling date) in which the fish was present during the 2010-2011 sampling period at NVK, SVK, NHB, and SHB ($p=0.2730$).
**Habitat Selectivity**

The total epifaunal densities were significantly greater in *Halodule wrightii* seagrass beds compared to *Thalassia testudinum* or *Syringodium filiforme* seagrass beds (K-W analysis, n=96, p<0.0001; Figure 24). When comparing each seagrass bed within a site, except the NHB site due to a lack of *H. wrightii* present at the site, *H. wrightii* had significantly greater total epifaunal densities than any other seagrass species found within the site (Wilcoxon Rank-Sum: n=24 per site, SHB p=0.0001, NVK p<0.0001; K-W analysis, SVK n=36, p=0.0002). When comparing *Syringodium filiforme* at the two sites where it was present, the NHB site had significantly greater total epifaunal densities than the SVK site (Wilcoxon Rank-Sum: n=24, p=0.0079; Figure 25).

*Halodule wrightii* appeared to be the preferred seagrass habitat of choice for all juvenile and small adult fish species caught during the study. Juvenile and small adult fish densities were significantly greater in *H. wrightii* seagrass beds than *Thalassia testudinum* or *Syringodium filiforme* seagrass beds (K-W analysis, n=96, p<0.0001; Figure 26). When comparing each seagrass bed within a site, except the NHB site due to was a lack of *H. wrightii* present at the site; *H. wrightii* had significantly higher juvenile and small adult fish densities than any other seagrass species found within the site (Wilcoxon Rank-Sum: n=24 per site, SHB p=0.0004, NVK p<0.0001; K-W analysis, SVK n=36, p=0.0004).

The top three most abundant fish species, along with the most abundant invertebrate family, were compared for habitat selectivity. The most abundant invertebrate family, Penaeidae (n=547), was found in significantly greater densities within *Halodule wrightii* (K-W analysis, n=96, p<0.0001; Figure 27). When comparing
the densities of *H. wrightii* to *S. filiforme* beds (Wilcoxon Rank-Sum: *p*= 0.0001) and *H. wrightii* to *T. testudinum* beds (Wilcoxon Rank-Sum: *p*<0.0001), there was a significant difference found between the seagrass species.

*Lucania parva* (rainwater killifish) was the most abundant fish (n=940) caught during the study; however, the specimens caught were primarily found at the SHB site with only a few (n=3) specimens caught at the NHB site. When comparing the SHB seagrass beds, *L. parva* densities were significantly greater in the *H. wrightii* than *T. testudinum* (Wilcoxon Rank-Sum: n=24, *p*= 0.0015; Figure 28). The *H. wrightii* seagrass bed of SHB also had significantly greater densities of *L. parva* than the *S. filiforme* seagrass bed of NHB (Wilcoxon Rank-Sum: n=24, *p*<0.0001).

![Figure 24](image)

Figure 24. Mean total epifauna densities caught during the 2010–2011 sampling period in *Syringodium filiforme, Thalassia testudinum,* and *Halodule wrightii.*
Figure 25. Mean total epifauna densities caught during the 2010-2011 sampling period in *Syringodium filiforme* seagrass beds located at NHB and SVK.

Figure 26. Mean total juvenile and small adult fish densities caught during the 2010-2011 sampling period in *Syringodium filiforme, Thalassia testudinum*, and *Halodule wrightii*. 
Figure 27. Mean total Penaeid shrimp densities caught during the 2010-2011 sampling period in *Syringodium filiforme*, *Thalassia testudinum*, and *Halodule wrightii*.

Figure 28. Mean *Lucania parva* densities caught during the 2010-2011 sampling period in *Syringodium filiforme*, *Halodule wrightii*, and *Thalassia testudinum*. 
Syngnathus scovelli (gulf pipefish) was the second most abundant fish (n=163) caught during the study and was found throughout the year at every site. When comparing the eight seagrass beds sampled, S. scovelli densities were significantly greater in H. wrightii beds (K-W analysis: n=96, p=0.0045; Figure 29). When comparing the different seagrass beds within a site, S. scovelli densities were significantly greater at the NVK site within the H. wrightii seagrass bed (Wilcoxon Rank-Sum: n=24, p=0.0017); however, the SVK and the SHB sites exhibited no significant difference in the S. scovelli densities between the different seagrasses present within each site (Wilcoxon Rank-Sum: SHB n=24, p=0.1659; K-W analysis: SVK n=36, p=0.1436). When comparing densities within the H. wrightii seagrass bed at the NVK site to the densities within the S. filiforme seagrass bed at the NHB site; H. wrightii had significantly greater densities of S. scovelli present (Wilcoxon Rank-Sum: n=24, p=0.0209).

Finally, Gobiosoma robustum (code goby) was the third most abundant fish (n=106) caught during the study and was found throughout the year at every site. When comparing the eight seagrass beds sampled, G. robustum densities were significantly greater in H. wrightii seagrass beds (K-W analysis, n=96, p=0.0289; Figure 30). When comparing the different seagrass beds within a site, G. robustum densities were found to be significantly greater at the NHB site within the H. wrightii seagrass bed (Wilcoxon Rank-Sum: n=24, p=0.0111); however, the SVK and the SHB sites exhibited no significant difference in G. robustum densities between the different seagrasses present at each site (Wilcoxon Rank-Sum: SHB n=24, p=0.2254; K-W analysis, SVK n=36, p=0.2895). There were no significant differences in the G. robustum densities within the
*H. wrightii* seagrass bed at the NVK site compared to the *G. robustum* densities within the *S. filiforme* seagrass bed at the NHB site (Wilcoxon Rank-Sum: n=24, p=0.0567).

Figure 29. Mean *Syngnathus scovelli* densities caught during the 2010-2011 sampling period in *Syringodium filiforme*, *Thalassia testudinum*, and *Halodule wrightii*.

Figure 30. Mean *Gobiosoma robustum* densities caught during the 2010-2011 sampling period in *Syringodium filiforme*, *Thalassia testudinum*, and *Halodule wrightii*. 
Discussion

Abiotic Measurements

The temperature data collected supported the changing seasonal weather patterns for South Florida over the one year study period; however, the salinity data did not follow the same historical trends. Since Biscayne Bay is a shallow water estuary and the study sites were located in shallow water less than 1.1 meters, the water temperature reflected the air temperature during the study as seen in previous studies (e.g. Collier, 1938; Collier and Hedgpeth, 1950; Dawson, 1955). Thus, the increase in water temperature at the sites in April 2011 was likely due to the high air temperatures recorded by NOAA. The decrease in the water temperature at the sites in December 2010 was due to the record cold air temperatures recorded (Molleda, 2010; NOAA et al., 2010).

Variations in salinity and temperature from site to site likely occurred due to differences in the morphology of each site, including the proximity to shore. SVK did not exhibit the same temperature data as the three other sites. The difference was possibly due to a sand bar that was observed during this study to occur at the SVK site alone. The sand bar may have decreased the flow of water from offshore to onshore decreasing the amount of variation in temperature because the cooler bottom water was not able to pass the shallow sand bar. Salinity at all four sites was affected by direct runoff from the islands, changing constantly with daily weather patterns and could not be detected in monthly salinity averages.
Ecosystem

Species diversity was dependent upon the density of total organisms caught and the density of each species caught. Species diversity did not change significantly on a monthly basis; this was likely due to the lack of variation in salinity. However, the results should be viewed with caution due to the small sample size (nk< 5) which increases Type II errors and makes it more difficult to detect significant changes in species diversity. However, the lack of significant monthly changes in species diversity was supported by various studies where changing salinity was the major contributing factor that influenced organism densities (e.g. Heck, 1977; Tsou and Matheson, 2002; Tuckey and Dehaven, 2004; Lirman et al., 2008).

Species diversity did not vary significantly among the study sites; this was likely due to the lack of significant differences in salinities among the four sites. There was less than 2‰ difference between the lowest average salinity and the highest average salinity during the study. If there was greater variation within the salinities at the study sites, then there would likely have been greater variation within the species diversity at the four study sites. Previous studies found that species diversity varied dependent upon changes in the salinity (e.g. Heck, 1977; Tsou and Matheson, 2002; Tuckey and Dehaven, 2004; Lirman et al., 2008).

Lack of significant variation in the salinity measurements likely led to lack of significant variation among the sites, seagrass species, and months. Studies have found that water temperature has a limited effect on the densities of epifauna found on seagrass when compared to salinity. Salinity measurements were not correlated with seasonality; rather, they were dependent on daily precipitation changes because of the sites shallow,
near shore locations and their susceptibility to coastal freshwater runoff. Species diversity did not change significantly on a monthly basis at the four study sites. If species diversity changes were based on differences in water temperature, then there would have been marked monthly variations in species diversity based on previous studies (Heck, 1977; Lirman et al., 2008; Tsou and Matheson, 2002; Tuckey and Dehaven, 2004).

**Seasonality**

Seasonality could not be rigorously determined in this study because the study sites were only assessed for one year. Nonetheless, previous seagrass studies in South Florida found organism densities tended to be greater in the fall, at the end of the rainy season, when compared to spring densities, the end of the dry season. These previous data were in agreement with the results for the overall organism densities found at the sites during this study (e.g. Huh, 1984; Lirman et al., 2008; Tabb et al., 1962; Tsou and Matheson, 2002; Tuckey and Dehaven, 2004). The wet season had greater total epifaunal densities than the dry season, likely due to the slight decreases in salinity from increased rainfall during the South Florida wet season. The lowest salinities found were concurrent with the end of the rainy season and the highest organism densities; meanwhile, the highest salinities recorded were concurrent with the end of the dry season and the lowest organism densities (Huh, 1984; Lirman et al., 2008; Tabb et al., 1962; Tsou and Matheson, 2002; Tuckey and Dehaven, 2004). Gunter (1950) determined that juvenile fish tolerated lower salinities than their adult counterparts, possibly allowing for variations in the adult to juvenile fish and penaeid shrimp ratios at the different sites.
Species densities varied on a monthly basis within every seagrass bed at the study sites. These changes in density were likely related to changes in salinity at each site. The results did show a marked seasonal trend towards higher total densities at the end of the wet season (Figure 17) during the one year study, allowing for the conclusion that there is likely seasonality, perhaps salinity driven, at the study sites (Huh, 1984; Lirman et al., 2008; Tabb et al., 1962; Tsou and Matheson, 2002; Tuckey and Dehaven, 2004).

The NVK and SVK sites had the two highest average salinities for the entire year. However, when assessing the highest and lowest salinities, there were no differences among the four study sites. This suggests that the morphology of the seagrass beds was the reason for the lack of monthly variation in total epifaunal density within the seagrass beds. The similarities between the *Thalassia testudinum* seagrass beds at the NVK and SVK sites were water depth and canopy height. The mean low tide water depth varied by 10.3 cm and the average canopy height varied by one cm; whereas the *T. testudinum* seagrass bed located at SHB differed by more than 50 cm in mean low water depth and more than 30 cm in average canopy height. The increase in water depth increases the foraging capabilities of the predator fish and allows for more large species to actively forge within the seagrass bed. By having high canopy height and low water depths, there are greater places to hide from the predatory fish, increasing the densities of smaller prey fish within SHB study site. The morphological differences among the seagrass beds at the difference sites changed the amount of predation threat, thus, changing the distribution and densities of the different species within each seagrass bed on a monthly basis (Malavasi et al., 2007; Orth et al., 1984; Stoner, 1982, 1984).
When considering predation as a factor that could change species densities on a monthly basis, it makes sense that the SVK *Syringodium filiforme* seagrass bed would not have a significant change. The *S. filiforme* seagrass bed at the SVK study site had the lowest mean low tide water depth to average canopy height ratio of every seagrass bed studied, leading to the least amount of structural complexity for protection. With the limited amount of habitat complexity and protection compared to other seagrass beds within SVK and other sites, there was likely to be a decrease in the species that use the seagrass bed as a more regular habitat. It was plausible that any epifauna that were caught in the *S. filiforme* seagrass bed once was never caught again on a different sampling month because there was likely not sufficient protection from larger predators; however, more data is needed to confirm or deny the theory (Malavasi et al., 2007; Orth et al., 1984; Stoner, 1982, 1984).

No correlation was found between population size and size of each individual organism. All of the juvenile and small adult fish species that were captured during at least two-thirds of the study year are known to utilize seagrass beds and estuaries for the entirety of their life cycles and are not commonly found along the South Florida reef track. The game fish caught during the study that had greater potential for correlations between population size and size of the individual were caught in low numbers and for less than half of the year, reducing any chance for rigorous statistical correlation (McEachran and Fechlem, 1998, 2005; Robins and Ray, 1986; Serafy et al., 2003; Thorhaugh, 1981).

Five juvenile and small adult fish species were caught for at least two-thirds of the study period, all of which are known to spend their life cycles in estuaries. Certain
species of gobies (Gobiidae) can be found living in coral reef ecosystems; however, the
code goby (*Gobiosoma robustum*) which was regularly captured in this study is
commonly found living in protected shallow waters that contain seagrass or algal mats.
This species of goby can be found in coastal waters from northern Florida south in the
Atlantic Ocean and throughout the entire Gulf of Mexico. The commonly found
goldspotted killifish (*Floridichthys carpio*) is often found within saline tidal creeks, flats,
and seagrass beds from the central Atlantic coast of Florida to the Gulf of Mexico. The
captured rainwater killifish (*Lucania parva*) can be found from the Gulf of Mexico north
to Massachusetts, commonly in estuaries and brackish bays. These fish can be found
living among the aquatic vegetation, primarily in *Halodule wrightii*.

Pipefish and seahorses (Syngnathidae) are found worldwide and can be associated
with coral reefs; however, the syngnathids caught during this study are commonly found
in estuaries. The dwarf seahorse (*Hippocampus zosterae*) is closely associated with
seagrass beds but they are sometimes found floating among *Sargassum* algae in the open
ocean. They are found throughout the entire Gulf of Mexico, South Florida, the Bahamas,
and even Bermuda. The Gulf pipefish (*Syngnathus scovelli*) are commonly associated
with *Thalassia testudinum* and algae mats from northern Florida, throughout the Gulf of
Mexico, and south to Brazil (McEachran and Fechlem, 1998, 2005; Robins and Ray,
1986); however, during this study they were found in significantly greater densities
within the *H. wrightii* seagrass beds than *T. testudinum* seagrass beds. *S. scovelli* have
also been recorded in freshwater environments as well (McEachran and Fechlem, 1998,
A slightly negative correlation was detected between population size and individual size of penaeid shrimp. This relationship was expected given the life history of these shrimp. Penaeid shrimp enter the Biscayne Bay ecosystem as juveniles; the individuals that survive the Biscayne Bay juvenile Penaeidae fishery migrate to the Dry Tortugas as adults. Both the Biscayne Bay and the Dry Tortugas fisheries primarily capture pink shrimp (Farfantepenaeus duorarum); however, the fisheries are also comprised of three other species of shrimp: F. aztecus, F. brasiliensis, and F. notialis (Ault et al., 1999; Berkley et al., 1985; Browder et al., 1999; Farfante, 1970; 1988). Even though no correlation between population size and individual size was found in this study similar to that in the Biscayne Bay juvenile Penaeidae fishery, the density pattern was supported by Berkley et al. (1985). The greatest Penaeidae densities were found from August through December 2010. This was the opposite of the results found by Tsou and Matheson (2002) in the Suwannee River estuary off northwestern Florida in which winter had the lowest abundances and summer had the highest abundances of pink shrimp (Farfantepenaeus duorarum).

**Habitat Selectivity**

The greatest organism densities were found throughout the year in Halodule wrightii. The higher total epifaunal densities in H. wrightii compared to Thalassia testudinum and Syringodium filiforme was likely related to a combination of variations in structural complexity and predatory risk (Malavasi et al., 2007; Orth et al., 1984). Thayer and Chester (1989) also determined that sediment content was a contributing factor to the abundance and the species composition of organisms residing within a seagrass bed;
however, since sand was to be the dominant sediment in the Braun-Blanquet analysis at all four study sites, the sediment content variable could be eliminated; thus it likely was not a contributing factor in habitat selection during this study.

The structural complexity of each seagrass bed varied due to differences in blade morphology and shoot density. Blade morphology and shoot density varied greatly among the three different seagrass species found at the study sites. *T. testudinum* had a greater surface area per weight, whereas *H. wrightii* had a low surface area per weight. According to Heck and Orth (1980) and Stoner (1980), *T. testudinum* should have the larger community because the greater surface area leads to a higher degree of protection. The higher shoot density of *H. wrightii* at the study sites increased the amount of biomass per unit area, shifting the habitat preference from *T. testudinum* or *S. filiforme* to *H. wrightii* because the higher biomass increased the amount of protection for the epifauna.

When comparing the shoot density of the *S. filiforme* seagrass beds found at the NHB site and the SVK site, *S. filiforme* at NHB had greater densities supporting the contention that organism densities are positively correlated with shoot density (Heck and Orth, 1980; Stoner, 1980).

The risk of predation also varied due to the different structural complexities of each seagrass species as well as the variable water depths associated with the different seagrass bed locations. In other studies, it was suggested that the risk of predation was the key factor in determining habitat selection (Malavasi et al., 2007; Orth et al., 1984). The possibility of predation was likely one of the main contributing factors that caused *H. wrightii* to be the seagrass habitat with the greatest densities of juvenile fish, small adult fish, and invertebrate taxa. Stoner (1982) noted that fish exhibited decreased invertebrate
foraging capabilities in *S. filiforme* when compared to *H. wrightii*. Another possible contributing factor to predation was water depth because the *H. wrightii* seagrass beds in this study were located in shallower waters than the *T. testudinum* beds and *S. filiforme* beds, possibly leading to a decreased amount of predation within the beds. Since there were decreased water depths, larger predators, such as *Lagodon rhomboides* (pinfish), had a significant decrease in foraging efficiency due to the decreased foraging area of the water column. Stoner (1984) determined that *L. rhomboides* tend to be more abundant in *H. wrightii* seagrass beds when compared to *T. testudinum* and *S. filiforme*. So it is likely that shallow water depth and not the seagrass species was the primary factor decreasing the prevalence of *L. rhomboides* collected in the *H. wrightii* seagrass bed during this study.

All of the most abundant species of juvenile and small adult fish (*Lucania parva*, *Gobiosoma robustum*, *Syngnathus scovelli*, *Floridichthys carpio*, and *Hippocampus zosterae*), and Penaeidae invertebrates were found in significantly higher numbers within *H. wrightii* seagrass beds than in either *T. testudinum* and *S. filiforme* beds. The results for juvenile and small adult fish were comparable to numerous studies done on species compositions within seagrass beds (e.g. Huh, 1984; Stoner, 1982, 1984; Thayer and Chester, 1989; Thayer et al., 1999). When assessing Penaeidae, Virnstein and Howard (1987) determined they were most dense in *S. filiforme* seagrass beds. However, when comparing the Penaeidae densities within *S. filiforme* to the densities within *H. wrightii* seagrass beds, Penaeidae densities were significantly greater in *H. wrightii* than *S. filiforme* indicating that there were multiple variables influencing the distribution of Penaeidae during this study. It is likely that the structural complexities of the different
seagrass beds in this study and Virnstein and Howard (1987) differed. If this is the case, it is likely that the Penaeidae distributions would differ in the two different studies.

**Conclusion**

The objectives of this study were to answer three different hypotheses and determine the species diversity and evenness at the study sites throughout the sampling year. The first hypothesis tested was: juvenile fish, small adult fish, and penaeid shrimp populations are inversely related to individual organism size. The second hypothesis tested was: juvenile fish, small adult fish, and Penaeidae densities will exhibit a seasonal distribution with higher organism densities in the fall and lower organism densities in the spring. The final hypothesis was: overall organism habitat selection will predominantly favor one specific seagrass species.

Species diversity was determined to vary dependent upon changes in salinity from site to site and month to month. Due to the fact that there were no substantial meteorological disturbances and that the average salinity only varied by 2‰ between the four study sites, there were no overall significant changes to the species diversity for the duration of the study (Heck, 1977; Lirman et al., 2008; Tsou and Matheson, 2002; Tuckey and Dehaven, 2004).

This study rejected the first hypothesis that the juvenile fish, small adult fish, and Penaeidae populations are inversely related to individual organism size, indicating that the juvenile fish, small adult fish, and invertebrates were not leaving the seagrass community once they reached maturity. The majority of the juvenile and small adult fish caught during the study remained in the seagrass beds for the entirety of their life cycle.
Penaeidae migrate with age, indicating that there should be decreased body size with increased population caused by the arrival of new larval recruits entering the Biscayne Bay estuary from the Dry Tortugas. These results were not seen in the data, possibly due to the fact that many of the juvenile Penaeidae may have already been caught in the Biscayne Bay juvenile penaeid shrimp fishery (Ault et al., 1999; Berkley et al., 1985; Browder et al., 1999; Farfante, 1970; Malavasi et al., 2007; McEachran and Fechlem, 1998, 2005; Orth et al., 1984; Robins and Ray, 1986; Serafy et al., 2003; Stoner, 1982, 1984; Thorhaugh, 1981; Tsou and Matheson, 2002).

This study accepted the second hypothesis that juvenile fish, small adult fish, and Penaeidae densities will exhibit a seasonal distribution with higher organism densities in the fall at the end of the wet season and lower organism densities in the spring at the end of the dry season. Overall, wet season had a greater total epifaunal density than dry season; however, this study failed to reject the hypothesis when looking at each individual site. These site variations were likely caused by variations in the seafloor morphology (Huh, 1984; Lirman et al., 2008; Tabb et al., 1962; Tsou and Matheson 2002; Tuckey and Dehaven, 2004).

This study accepted the third hypothesis that overall organism habitat usage will predominantly favor one specific seagrass species. The overall habitat choice of all juvenile fish, small adult fish, and invertebrate Penaeidae was *Halodule wrightii* for various different reasons that likely included decreased risk of predation and an increase in habitat complexity. A decreased risk of predation was likely caused by the increased shoot density which increased the habitat complexity of the *H. wrightii*. The decreased water depth in which the *H. wrightii* seagrass beds were located likely added to the
decreased risk of predation (Malavasi et al., 2007; Orth et al., 1984; Thayer and Chester, 1989; Virnstein and Howard, 1987).

Potential sources of error can occur with any field ecological study. One major source of was the collection method. By using a push net instead of a beach seine, habitat usage could be studied, but that also reduced the chances of catching faster swimming predatory fish. By having shorter sampling areas than a beach seine there was less chance for slower fish to escape the net, possibly increasing their abundance. These fish would most likely exhibit an ontogenetic, migratory shift so a prey-induced bias was created in the data. Due to the length of the study, seasonality in seagrass beds was extremely difficult to prove. In order to remove error from the seasonality data, subsequent years would have to have been studied to provide replicates.

Future possible studies include: beach use on the seagrass beds and the seagrass communities along the dog beaches of Key Biscayne, Port of Miami Construction on the water quality and seagrass to algae composition in the surround area off of Hobie Beach, and diel changes in the species composition in Bear Cut to monitor the daily movements of adult reef fish.
Literature Cited


Zieman, J.C. 1975. Seasonal variation of turtle grass, Thalassia testudinum König, with reference to temperature and salinity effects. Aquatic Botany 1: 107-123.

