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Reef Fish Spatial Distribution and Benthic Habitat Associations on the Southeast Florida Reef Tract

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By

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List of Acronyms

APRD	Aggregated Patch Reef-Deep
APT	All Purpose Tool
ANOSIM	ANalysis Of SIMilarity
ANOVA	ANalysis Of VAriance
BFZ	Bahamas Fracture Zone
CRCP	(NOAA) Coral Reef Conservation Program
CPDP	Colonized Pavement-DeeP
CPSH	Colonized Pavement-SHallow
DPRC	DeeP Ridge Complex
FDEP	Florida Department of Environmental Protection
FRT	Florida Reef Tract
GIS	Geographic Information Systems
GPS	Global Positioning System
LIDAR	LIght Detection And Ranging
LIRI	LInear Reef-Inner
LIRM	LInear Reef-Middle
LIRO	LInear Reef-Outer
m	Meter
MDS	Multiple Dimensional Scaling
nm	Nautical Mile
NOAA	National Oceanographic and Atmospheric Administration
NTMR	No Take Marine Reserve
PDF	Portable Document Format
PSU	Primary Sampling Unit
PTCH	PaTCH Reef
PRIMER	Plymouth Routines In Multivariate Ecological Research
PVC	PolyVinyl Chloride
QA/QC	Quality Assurance and Quality Control
RGDP	RidGe-DeeP
RGSH	RidGe-SHallow
RVC	Reef fish Visual Census
SCUBA	Self-Contained Underwater Breathing Apparatus
SCRS	SCattered Rock in unconsolidated Sediment
SEFCRI	SouthEast Florida Coral Reef Initiative
SE FRT	SouthEast Florida Reef Tract
SEM	Standard Error Measurement
SIMPER	SIMilarity PERcentages analysis
SPGR	SPur and GRoove
SSU	Second-stage Sample Unit

Abstract

The Florida Reef Tract (FRT) extends from the tropical Caribbean up the southeast coast of Florida into a temperate environment where tropical reef assemblages diminish with increasing latitude. This study used data from a three-year comprehensive fishery-independent survey to quantify reef fish spatial distribution along the Southeast FRT and define where the assemblage shifts from tropical to temperate. A total of 1,676 reef fish visual census samples were conducted to assess the populations on a stratified-random selection of sites of marine hardbottom habitats between the Miami River and St. Lucie inlet. Multivariate analyses were used to investigate differences in assemblages among sites. Depth (<10 m and 10-33 m), general habitat (reef or hardbottom), and slope (high or low) strata were examined to explain the dissimilarities between assemblages. A general trend of cold-tolerant temperate fish dominated the northern assemblages and more tropical species dominated further south. Seven reef fish assemblage biogeographic regions were determined. In shallow habitats the data clustered in three spatial regions: One south of Hillsboro inlet, one in Northern Palm Beach south of Lake Worth inlet, and one north of Lake Worth inlet. The assemblage in deep habitats mainly split in close proximity to the Bahamas Fracture Zone south of Lake Worth Inlet. The presence of reef habitat aided in splitting the southern assemblage regions from the northern all-hardbottom assemblage regions in both the shallow and deep habitats. Substrate relief was significantly correlated with the differences in the northernmost deep assemblages but did not appear to affect the remainder of the shallow and deep assemblages. This bioregional study creates a baseline assessment of reef fish assemblages of the Southeast FRT for future analyses.

Keywords: Ecology, multivariate analyses, biogeography, range shift, community latitudinal transition, assemblage structure

1.0 Introduction

1.1 Importance of Study

Coral reef fishes comprise the most species-rich assemblages of vertebrates on earth. Over the past several decades, there have been substantial changes in the composition of the biomass and density of reef fish assemblages (Ault, Bohnsack, and Meester 1998; Mora 2008; Kopp, Bouchon-Navaro, Louis, et al. 2010; Kopp, Bouchon-Navaro, Cordonnier, et al. 2010). Therefore, assessing current assemblages to understand species' distributions in the Caribbean is needed. Such studies should quantify the reef fish assemblages by both habitat and habitat regions to understand the current distribution of fishes and their habitat associations. This is essential information to provide a robust baseline for detecting future assemblage and individual species changes due to natural impacts such as climate change, cold-water influences, etc. (e.g. hurricane, excessive freshwater flooding). The establishment of a baseline will also be invaluable in the detection of the annual effects of anthropogenic inputs to a system (e.g., oil spills, pollution) including effects of management actions.

The patterns of species' density and distribution vary both spatially and temporally. Distinguishing the intensity of such variations is a first step along the way to comprehending the factors that help structure an assemblage (Tuya, Wernberg, and Thomsen 2011). The distribution of mobile animals such as reef fishes is heavily influenced by both abiotic and biotic factors (Walker, Jordan, and Spieler 2009). Temperature, for example, has a large effect on the distribution of some fishes like the *Centropristis striata* (black seabass), which is typically a temperate water fish and primarily found in the north of Florida (Robins and Ray 1986). Ecological processes like food availability, recruitment, predation, and competition, are examples of some biotic factors that can lead to patterns of density and distribution (Shapiro 1991). Determining the relative importance of such abiotic and biotic factors can help in defining the structure of reef fish assemblages. The distribution of many marine species is also related to certain habitats and depth regimes. Species like *Opistognathus aurifrons* (yellowhead jawfish),

Ptereleotris helenae (hovering goby), *Ptereleotris calliurus* (blue goby), and *Malacanthus plumieri* (sand tilefish) are found only in sandy areas where they make their burrows. Members of the *Gerreidae* (mojarra) family infrequently are seen on reefs and instead inhabit shallow sand-swept shorelines and grass, rubble, or mud flats (Humman and Deloach 2002). Life histories can also play a role in distribution; some juveniles may initially settle on one type of nursery habitat then move onto different habitats as they grow and mature (Shapiro 1991). For instance, juvenile *Haemulidae* (grunt) species are found typically in mangroves, estuaries, or nearshore reefs while the more mature grunts occur mainly on offshore reefs close to the sediment and seagrass beds they use for nighttime feeding. Recognizing these relationships between species and their preferred habitat can enable better inventory estimations and extrapolations (Walker, Jordan, and Spieler 2009; Walker 2008).

Benthic habitat maps can be valuable tools in the process of detecting a correlation between reef fish and certain preferred habitats, currents, and depth regimes (Mellin et al. 2009; Walker 2012). Mapping data are collected through remote sensing methods like high-resolution bathymetry, satellite imagery, and aerial photography and then displayed as geographic information system (GIS) vector data. The GIS vector data aid in enabling the quantification of a feature's spatial relationship in the landscape and its areal extent (Walker 2012; Walker, Riegl, and Dodge 2008). These remote sensing techniques allow for the acquisition of large amounts of data on the characterization of broad areas of the seafloor quickly and economically, providing the foundation for large-scale resource mapping and modeling (Walker 2012; Walker, Riegl, and Dodge 2008). Remote sensing can be applied to help bridge the gap between *in situ* data and broader patterns in the seascape (Costa, Dijkstra, and Walker, in review). Thus, biological surveys, if appropriately distributed throughout an area, can be analyzed with benthic mapping data to elicit otherwise obscure spatial associations (Walker, Jordan, and Spieler 2009; Walker and Gilliam 2013). In the absence of a comprehensive *in situ* biological data, spatial analyses of benthic habitat maps could fill a significant role in identifying statistically

distinct physical biogeographic regions based on the morphology of habitats (Walker 2012).

The Florida Reef Tract (FRT) is the only barrier reef in the continental United States and is recognized as the third largest barrier reef chain ecosystem in the world, stretching across roughly 595 km of coastline. (Walker and Gilliam 2013; Finkl and Andrews 2008). This high-latitude reef tract has been divided into five geographic subsystems—Dry Tortugas, lower Keys, middle Keys, upper Keys, and mainland southeast—based on differing location, geomorphology, habitats, sediment types, temperature regimes and/or current systems (Lindeman et al. 2000; Brandt et al. 2009). The FRT starts in the Dry Tortugas subsystem and runs for about 135 km in an east-west orientation mostly at latitude 24.5°N (Walker and Gilliam 2013). At about 25.5°N, it arcs northeast for about 245 km of coastline which includes the lower, middle and upper keys (Walker and Gilliam 2013). The final mainland southeast subsystem extends north to about 27.25°N to the end of the FRT (Walker and Gilliam 2013). The mainland Southeast (SE) FRT subsystem consists of several linear, shore-parallel, coral reef assemblages separated from one another longitudinally by sand flats extending north from the Florida Keys for approximately 215 km (Walker 2012; Walker and Gilliam 2013; Finkl and Andrews 2008). The section of the SE FRT that is the focus for my project has been extensively mapped using multiple remote sensing techniques making it an ideal location to perform bioregional spatial analyses (Figure 1) (Walker and Gilliam 2013; Walker 2012; Walker, Riegl, and Dodge 2008; Riegl et al. 2005).

Bioregional groupings of assemblages are valuable at the broadest scales to better comprehend the processes of evolution, extinction and biodiversity (Harvey et al. 2013). Since the 1800s, latitudinal gradients have been identified as biogeographic indicators for landscape-wide distribution and diversity of marine organisms (Engle and Summers 1999; Willig, Kaufman, and Stevens 2003; Ebeling and Hixon 1991; Walker 2012; Macpherson 2002). In order to better anticipate and understand the outcome of local anthropogenic impacts and natural disturbances, it is vital to identify the abiotic and biotic makeup of the

bioregion as whole (Harvey et al. 2013; Lourie and Vincent 2004). Southeast Florida is located at the convergence of the subtropical and temperate climate zones (Chen and Gerber 1990; Lugo et al. 1999) and benthic species latitudinal and cross-shelf assemblage differences have been reported along the SE FRT (Walker 2012; Walker and Gilliam 2013; Klug 2015). Through spatial analyses, Walker (2012) and Walker and Gilliam (2013) determined five boundaries that defined six coral reef ecoregions from Miami-Dade County to Martin County (Figure 1). Walker (2012) described a latitudinal benthic habitat zonation where the overall live stony coral cover and the size and number of distinct benthic features attenuates in a northward progression. Walker and Gilliam (2013) reported that temperature is a major controlling factor in the benthic assemblages between the coral reef ecoregions. Klug (2015) reported that there are benthic differences between habitats and regions that align with the coral reef ecoregions. Fish species diversity is often related to coral diversity (Smith, Chave, and Kam 1973) and certain benthic features are strongly associated with specific reef fish populations and demographics (Brandt et al. 2009; Smith et al. 2011). It follows that the fish assemblages would vary along this latitudinal gradient similar to the benthos. However, many species and even life-stages of the same species (e.g. juveniles, adults) have spatial distribution patterns that differ from one another. It remains to be shown whether the fish assemblages of the SE FRT agree with the benthic habitat based coral reef ecoregions of Walker (2012) and Walker and Gilliam (2013).

1.2 Coral Reef Ecoregions

The Coral Reef Ecoregions discussed in my study were originally defined by Walker (2012) and Walker and Gilliam (2013) and a summary of each follows. The southernmost coral reef ecoregion defined by Walker (2012) is the Biscayne region spanning 22 km to the south from Government Cut (25°45’44.35”N) in Miami-Dade County. The Biscayne region was not surveyed for this project.

The Broward-Miami Coral Reef Ecoregion extends roughly 48 km (134.67 km^2 total mapped area) along the coast of mainland SE Florida (Walker 2012). This ecoregion is the second largest and is bounded by the Miami River and Government Cut to the south

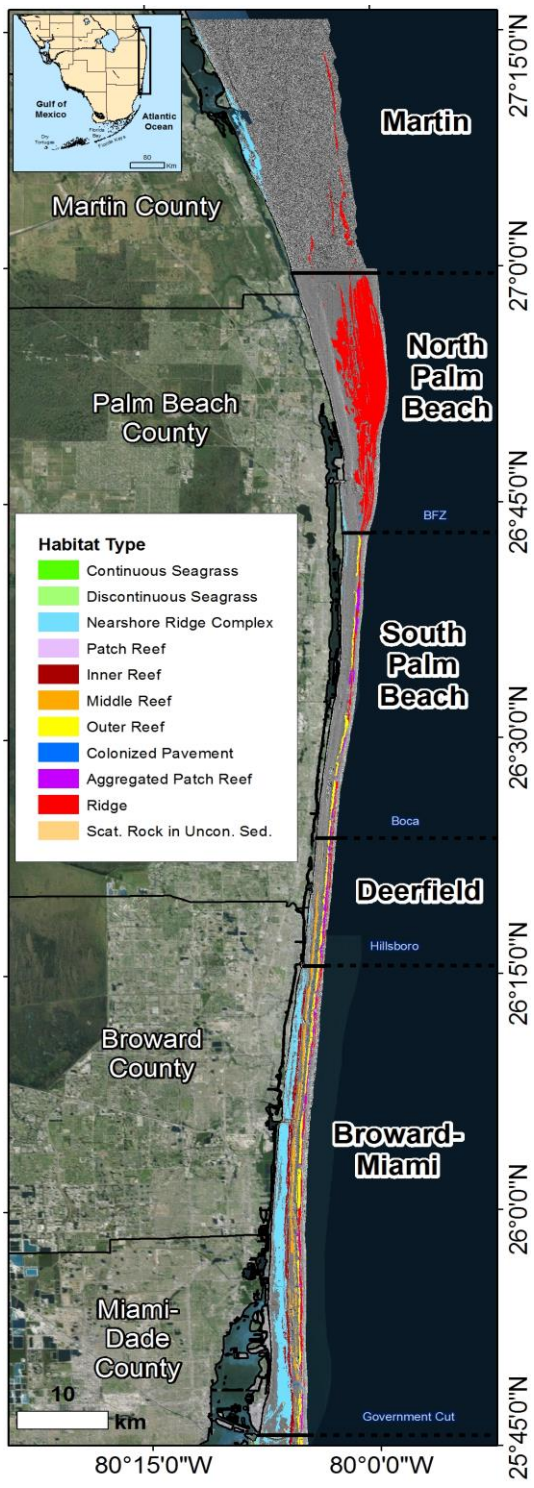


Figure 1. *Map of study area including habitat types and the five ecoregions along the Southeast Florida Reef Tract.*

and the northern terminus of the Linear Reef-Inner (LIRI) habitat at Hillsboro inlet (26°15'32.73"N) (Walker 2012). The nearshore hardbottom is comprised of rock outcrops of colonized pavement and rubble that contains variable sand cover dominated by encrusting zoanthids, corals and macroalgae (Finkl and Andrews 2008; Kilfoyle et al. 2013).

The Deerfield Coral Reef Ecoregion is the smallest of the six coral reef ecoregions and ranges about 15 km of the coastline of mainland SE Florida (25.27 km^2 total mapped area) north from its southern boundary of the Hillsboro inlet to the northern end of the Linear Reef-Middle (LIRM) habitat at Boca Raton (26°23'40"N) (Walker 2012).

The South Palm Beach Coral Reef Ecoregion was the fourth largest coral reef ecoregion and covers roughly 36 km of shoreline (60.05 km^2 total mapped area) reaching north from the Boca Raton boundary to the northern end of the Linear Reef-Outer (LIRO) habitat at the Bahamas Fracture Zone (BFZ) (26°43'4.62"N) (Walker 2012). This ecoregion is relatively narrow and includes the remainder of the coral reefs that are not present in the North Palm Beach Coral Reef Ecoregion (Finkl and Andrews 2008).

The North Palm Beach Coral Reef Ecoregion is the largest, encompassing around 32 km of coastline and 175.48 km^2 of mapped area, it spans from just south of Palm Beach Harbor at the BFZ to the northern extent of the Deep Ridge Complex (DPRC) (Walker 2012). At its southern edge, the Florida current diverges further from the coast (Engle and Summers 1999; Walker 2012) and the coastal shelf widens (Finkl and Andrews 2008). There is a notable lack of ancient coral reef topography in this ecoregion, it is characterized by extensive sand flats and karst topography (Finkl and Andrews 2008). The nearshore hardbottom habitats of the Jupiter area are derived from accretionary ridges of coquina mollusks, sand and shell marl with lithified parallel to ancient shorelines during the Pleistocene interglacial periods (Finkl and Andrews 2008). The habitat complexity of these limestone structures was expanded by colonies of tube-building polychaete worms and other invertebrate and macroalgal species (Lindeman and Snyder 1999) including the present-day coral assemblages.

The Martin Coral Reef Ecoregion extends from southern Martin County just north of the end of the DPRC to the northern border of Martin County (Walker and Gilliam 2013). At the southern end of the county, there are three deep ridge lines that run parallel to the shore (Walker and Gilliam 2013). Most of the shallow hardbottom habitats—both Colonized Pavement-Shallow (CPSH) and Ridge-Shallow (RGSH)—occur near the St. Lucie inlet (Walker and Gilliam 2013). The Martin Coral Reef Ecoregion also contains large mobile sand dunes that appear to be moderately or completely burying portions of the DPRC (Walker and Gilliam 2013).

1.3 Benthic Habitats

The SE FRT has also been divided into specific cross shelf habitat types (Walker 2012; Walker and Gilliam 2013; Walker, Riegl, and Dodge 2008). The benthic habitats used in this project were adopted and modified from the NOAA hierarchical classification scheme used in Puerto Rico and the U.S. Virgin Islands (Kendall et al. 2001; Walker and Gilliam 2013; Walker, Riegl, and Dodge 2008). The habitats used in this project and their descriptions (adopted directly from the sources) are listed from inshore to offshore below

(Walker and Gilliam 2013; Walker 2012; Kendall et al. 2001; Finkl and Andrews 2008; Walker, Riegl, and Dodge 2008; Banks et al. 2008). For the purposes of my study, Shallow habitats occur < 10 m water depth and Deep habitats occur between 10 - 33 m. Furthermore, Reef was defined as a substrate that has historical organic reef growth and Hardbottom as every other type of natural, hard substrate habitat.

1.3.1 Shallow Habitats

Colonized Pavement-Shallow (CPSH) consisted of colonized pavement in water shallower than 10 m. This habitat included rubble in many areas; however, consolidated rubble fields were a less frequent feature in shallow water than found in the Colonized Pavement-Deep habitat. Especially inshore of the Ridge-Shallow habitat, limited rubble was found and a wide contiguous area of pavement was encountered. This area could contain variable sand cover, which shifted according to seasons, wave energy and in response to weather. Thus, some of the colonized pavement was always covered by shifting sand and the density of visible coral and algae was highly variable. This habitat was categorized as Hardbottom and was present in four of the five coral reef ecoregions.

Ridge-Shallow (RGSH) were ridges found in water shallower than 10 m near shore that were geomorphologically distinct, yet their benthic cover remained similar to the shallow colonized pavement assemblages on the surrounding hard grounds. The RGSH habitat was categorized as Hardbottom and was the only habitat present in all five of the coral reef ecoregions.

Linear Reef-Inner (LIRI) was a distinct, relatively continuous, shore-parallel reef that consisted of a rich coral reef assemblage and crested in approximately 8 m depth. The LIRI had an immature reef formation growing atop antecedent shallow colonized pavement that lacked any clearly defined zonation. Acoustic and biological data indicated a distinct benthic assemblage from the Linear Reef-Middle and Linear Reef-Outer (Moyer et al. 2003; Walker, Riegl, and Dodge 2008). LIRI was categorized as Reef and was only present in the Broward-Miami Coral Reef Ecoregion.

Patch Reefs (PTCH) were coral or hardbottom formations (categorized as Reef for this study) that were isolated from other coral reef formations by sand, seagrass, or other habitats and that had no organized structural axis relative to the contours of the shore or shelf edge. PTCH habitats could occur as a single isolated patch or in constellations of patches with varying densities in the four southern coral reef ecoregions. A surrounding halo of sand was often a distinguished feature of this habitat type when it occurred adjacent to submerged vegetation.

Scattered Rock in Unconsolidated Sediment (SCRS) was primarily sand bottom with scattered rocks or small, isolated coral heads that were too small to be delineated individually and were less than 10 percent cover of submerged vegetation. SCRS was present in Broward-Miami and Martin coral reef ecoregions and was categorized as Hardbottom.

1.3.2 Deep Habitats

Linear Reef-Middle (LIRM) was a distinct, relatively continuous, linear, shore-parallel reef that consisted of a rich coral reef assemblage which crested in approximately 15 m depth. Acoustic and biological data indicated that it harbored a distinct benthic assemblage from the LIRI, Linear Reef-Outer and other hardbottom habitats (Moyer et al. 2003; Walker, Riegl, and Dodge 2008). These Reef features followed the contours of the shore/shelf edge and were found in Broward-Miami and Deerfield coral reef ecoregions.

Colonized Pavement-Deep (CPDP) was a flat, low relief habitat, composed of solid carbonate rock with coverage of macroalgae, hard coral, gorgonians, and other sessile invertebrates that were dense enough to partially obscure the underlying substrate in water deeper than 10 m. Also included in the CPDP habitat was a transition zone from colonized pavement to consolidated colonized rubble on the deep reefs. The CPDP was a Hardbottom habitat and was present in all coral reef ecoregions except the Martin Coral Reef Ecoregion.

Linear Reef-Outer (LIRO) was a linear coral formation that was oriented parallel to shore or the shelf edge. These features were distinct, relatively continuous, reefs that

followed the contours of the shore/shelf edge, crest in approximately 16 m depth and were only found in the three southern coral reef ecoregions. The LIRO Reef habitat consisted of a rich coral reef assemblage that lived on relic reef morphology and included a back reef, reef crest, and spur and groove. Acoustic and biological data indicated that it harbored a distinct benthic assemblage (Moyer et al. 2003; Foster, Walker, and Riegl 2009).

Spur and Groove (SPGR) was a Reef habitat that had alternating sand and coral formations that were orientated perpendicular to the shore or bank/shelf escarpment. The coral formations (spurs) of this feature typically had a high vertical relief compared to pavement with sand channels and were separated from each other by 1-5 m of sand or bare hardbottom (grooves), although the height and width of these elements may have varied considerably. This habitat type was found in the three southern coral reef ecoregions and typically occurred in the fore reef or bank/shelf escarpment zone.

Aggregated Patch Reefs-Deep (APRD) were clustered patch reefs that individually were too small or were too close together to map separately. Like the PTCH habitat, APRD was categorized as Reef and was present in all of the coral reef ecoregions except for Martin.

Ridge-Deep (RGDP) was a linear, often shore-parallel, low-relief feature, present in four of the five coral reef ecoregions (absent in North Palm Beach Coral Reef Ecoregion), which mostly occurred deeper than 20 m. It consisted of Hardbottom with sparse benthic assemblages in most parts likely due to variable and shifting rubble and sand cover. Some parts of the RGDP contained exposed ledges where large fish like Goliath Grouper (*Epinephelus itajara*) and Nurse Shark (*Ginglymostoma cirratum*) may have aggregated. Acoustic data indicated a distinct benthic assemblage (Foster, Walker, and Riegl 2009).

Deep Ridge Complex (DPRC) was a complex of Hardbottom ridges found in deep water in the North Palm Beach and Martin coral reef ecoregions. These features resided in depth from 20 m to 35 m and were presumed to be of cemented beach dune origin. Most of this habitat consisted of low cover, deep assemblages dominated by small gorgonians, sponges and macroalgae, but denser areas existed, especially near areas of higher relief.

Some areas, particularly between ridges, may have contained large areas of shifting unconsolidated sediments.

1.4 Previous Regional Fish Studies

While the southern portions of the FRT—which include the Florida Keys and the Dry Tortugas—have been the focus of yearly fish surveys since 1979 and 1999, respectively; the regional distribution of reef fish along the SE FRT has never been investigated in a synoptic way. Localized studies have been performed in Broward and Palm Beach counties for various purposes, but never a full reef-tract-wide scale investigation to assess the reef fish assemblages.

The largest amount of data gathered was between 1998 and 2002 for the National Oceanic and Atmospheric Administration (NOAA). Ettinger et al. (2001) performed the preliminary study with 181 Reef fish Visual Census (RVC) samples over a 5 nm area. The authors surveyed the three reef tracts and recorded a total of 139 species from 39 families. These surveys revealed significant cross-shelf differences with the inshore sites containing significantly less density and species richness than the two outer reef tracts. The 181 initial counts were added into the database of Ferro, Jordan, and Spieler (2005) who sampled east-west transects every quarter nautical mile along the coastline of Broward County. In a total of 667 sites collected over four years, the authors found a total of 211 species from 52 families. The analysis of the data showed significant latitudinal differences within reef tracts—especially with relation to the ports and inlets. The authors also found a significant trend of increasing species richness, total density, and total biomass on each reef tract moving offshore (Ferro, Jordan, and Spieler 2005).

Walker, Jordan, and Spieler (2009) further analyzed Ferro, Jordan, and Spieler's (2005) data using GIS and spatial analyses tools. The spatial analyses tools showed that the maps used by Ferro, Jordan, and Spieler (2005) misclassified some of sample sites leading to an erroneous conclusion of significant differences among the middle and inner reefs. Further analysis showed that reef fish distributions along the SE FRT appear to be influenced by topographic complexity. In general, benthic habitats with the highest mean

densities and species richness exhibited correspondingly higher topographic complexity and vice versa (Walker, Jordan, and Spieler 2009). Cluster analysis indicated the shallow and middle reef habitats were highly variable assemblages and the deeper habitats displayed a less variable species assemblage. While species richness was more reliably homogeneous among benthic habitats than fish density, the relationships between topographic metrics and fish assemblages varied among benthic habitats.

Arena, Jordan, and Spieler (2007) performed a study to analyze the differences in fish populations between natural ledge reef sites and vessel reef sites. The authors used some of the Ferro, Jordan, and Spieler (2005) data from 32 sites on the second and third reef tracts and added 29 sites of their own for a total of 61 point counts. For this study, only reef ledge sites closest to the vessel reefs were chosen because of their proximity and the complexity of reef ledges most closely resembles that of vessel reefs. Their data from the natural reefs showed a statistically higher fish density and mean species richness on the east edge of the middle reef than the western edge of the outer reef. The authors recorded 118 species from 35 families on the natural reefs (Arena, Jordan, and Spieler 2007).

The other studies on the SE FRT have focused on the nearshore hardbottom fish assemblages. Between 1994 and 1996, Lindeman and Snyder (1999) performed a series of 15 m transect counts on the nearshore hardbottom off Jupiter in Palm Beach County and found that over 80% of the individual fish at all of the sites sampled were in early life stages. In the 394 transects performed, the authors found 86 taxa from 36 families. When Lindeman and Snyder (1999)'s species data were compared to a similar study in Broward County, the assemblages were different (Baron, Jordan, and Spieler 2004). In their study in 2001, Baron, Jordan, and Spieler (2004) performed 398 counts and found 164 species from 48 families. More than 85% of the fish in the first 30 m of nearshore hardbottom were juveniles. The authors concluded that the assemblage of fishes throughout the nearshore hardbottom of Broward County is relatively homogeneous due to a weak north-south regression for both species richness and density. Kilfoyle et al. (2013) performed rover diver and transect counts annually between 2004 and 2008 on the nearshore hardbottom

and artificial boulders in Broward County. The authors recorded an overall high diversity with a total of 185 species consisting primarily of juveniles and small cryptic species.

In a literature synthesis on the ecological functions of nearshore hardbottom habitats in Southeastern Florida, a list was compiled of 257 species of fish that had been recorded from nearshore hardbottom habitats (Lindeman et al. 2009). The authors noted that some differences among the fish assemblages were present between the southern and northern areas of the SE FRT in terms of the most abundant species. The authors believe that there is a southern nearshore hardbottom population and a less diverse northern fauna particularly north of the deflection of the Gulf Stream offshore.

In a study in preparation for regional reef fish surveys, Ault et al. (2012) synthesized the data from numerous previous reef fish studies performed on the SE FRT. The authors put together a list of reef fish with 10% or higher frequency of occurrence for each county (Broward, Palm Beach, Martin). Although the methods used and amount of data collected were not the same in all of the counties, a few obvious differences between the 10% frequency of occurrence lists are; 13 species of fish occurred frequently in all three counties, 23 species were listed in both Broward and Palm Beach counties, 5 species made the cut off in Palm Beach and Martin counties, 1 species was on the list for both Broward and Martin counties, 6 species were only in Broward County, 23 were only in Palm Beach County and 8 were only in Martin County.

In 2012, Florida Department of Environmental Protection (FDEP) in concert with NOAA Coral Reef Conservation Program (CRCP) funded a three-year statistically robust tiered fisheries-independent monitoring program along the SE FRT (Kilfoyle et al. 2015; Ault et al. 2012). A main objective of the project was to capture an initial baseline of the reef fish assemblages throughout the region that could then be used to study and compare temporal trends in the future for fisheries management. Data collected has been integrated with the existing Reef fish Visual Census (RVC) program data for the Dry Tortugas and Florida Keys to enable resource managers to holistically examine the FRT, assess the status of the ichthyofaunal resources and conduct system-wide stock assessments.

1.5 Statement of Purpose

My thesis used three years of the most recent regional data to evaluate the spatial distribution of southeast Florida reef fish assemblages and determine fish community differences by habitat types and with previously defined ecological sub-regions. My intention was to quantify reef fish latitudinal and cross-shelf spatial distribution on the southeast Florida Reef Tract and to define where the assemblage shifts from a tropical species dominance to a more cold-tolerant temperature dominance as well as to define new Reef Fish Assemblage Biogeographic Regions related to these spatial patterns.

2.0 Methodology

2.1 Study Area and Design

The study area includes all previously mapped hardbottom habitats shallower than 33 m between Government Cut (25°45”32’N, -80°7”30’W) in Miami-Dade County and the Saint Lucie Inlet (27°9”45’N, -80°9”9’W) in Martin County (Figure 1). The sampling design for this project was created with local stakeholder input in a separate FDEP-CRCP project by Ault et al. (2012). The two stage stratified random sampling design used for selecting locations for these Reef fish Visual Census (RVC) surveys has been proven to dramatically improve the efficiency of sampling (Ault et al. 2005; Smith et al. 2011) and was based on the prior accuracy of the RVC studies performed in the Florida Keys and the Dry Tortugas. The allocation scheme that follows is an established method and is the same reported in Kilfoyle et al. (2015).

The reef-scape was gridded into 100 m cells referred to herein as primary sampling units (PSUs). Each PSU was divided into four 50x50 m grid cells to acquire second-stage randomized data collection locations with the PSU (Figure 2). At each second-stage data collection site, two surveyors performed concurrent fish counts. During the analysis, an arithmetic mean for adjacent counts from each individual surveyor was calculated to determine the fish density per data collection area (177 m^2). This area is referred to herein as a second-stage unit (SSU). A SSU is synonymous with a “site” throughout the remainder

of my project. Each PSU and SSU was characterized by three main strata types, which combined are termed herein as map strata: coral reef ecoregion, benthic habitat type, and topographic slope (Table 1). The coral reef ecoregions as described above in section 1.2 and defined in Walker (2012) and Walker and Gilliam (2013) were used to divide the study area into five ecologically relevant subregions. The grid cells were characterized according to which coral reef ecoregion the majority of the PSU resided. Detailed benthic habitat maps were used to determine the majority habitat type in each PSU and SSU (Riegl et al. 2005; Walker, Riegl, and Dodge 2008; Walker, Jordan, and Spieler 2009; Walker and Gilliam 2013). The benthic habitat maps contained more detail than was practical for the stratification, therefore a priori decisions were made to combine more specific habitats into broader strata (Table 2). Since topographic complexity also affects local fish distributions (Foster, Walker, and Riegl 2009), topographic slope was included in the stratification as a surrogate for larger scale (10s of meters) topographic complexity. The slope was calculated in ArcGIS using high resolution LIDAR (Light Detection and Ranging) data. The LIDAR data were analyzed for slope where all areas greater than 5° were considered "high slope". A single polygon layer of these areas was created and used to determine if the PSU and SSU majority were high or low slope.

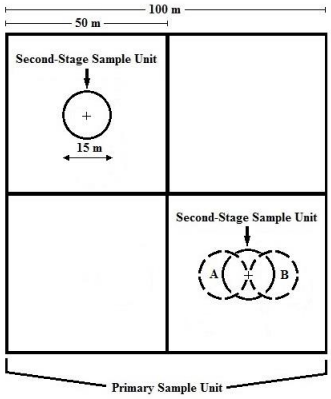


Figure 2. *Illustration of a 100 m Primary Sample Unit (PSU) and the Second-stage Sample Units (SSUs) inside their respective 50 m box. Selection of 2 individual target SSUs is accomplished by a randomization of the 4 cells within the PSU. The dashed circles represent a buddy pair (A and B). [Modified from* (Smith et al. 2011)*].*

Table 1. *Map strata for the site randomization to optimize survey outcomes. The coral reef ecoregions, habitat strata, and slope were used to define a specific map stratum. See Table 2 for habitat strata details. [Adopted from* (Kilfoyle et al. 2015)*]*

Coral Reef Ecoregion	Habitat Strata	Slope
Broward-Miami	INNR	High
Broward-Miami	INNR	Low
Broward-Miami	MIDR	High
Broward-Miami	MIDR	Low
Broward-Miami	NEAR	High
Broward-Miami	NEAR	Low
Broward-Miami	OFFR	High
Broward-Miami	OFFR	Low
Broward-Miami	PTDP	High
Broward-Miami	PTDP	Low
Broward-Miami	PTSH	N/D
Deerfield	MIDR	Low
Deerfield	MIDR	High
Deerfield	NEAR	Low
Deerfield	OFFR	High
Deerfield	OFFR	Low
Deerfield	PTDP	High
Deerfield	PTDP	Low
South Palm Beach	NEAR	High
South Palm Beach	OFFR	Low
South Palm Beach	OFFR	High
South Palm Beach	PTDP	Low
South Palm Beach	PTDP	High
South Palm Beach	PTSH	Low
North Palm Beach	DPRC	High
North Palm Beach	DPRC	Low
North Palm Beach	NEAR	High
Martin	NEAR	Low
Martin	NEAR	High
Martin	RGDP	Low
Martin	RGDP	High

Table 2. *Mapped benthic habitat classes and stratification habitat codes for this study, and major categories for the benthic habitat map in the southeast Florida Reef Tract. * The Ridge-Deep was included in the OFFR strata for the southern portion of the reef tract however, in Martin County it was recognized as distinctly different and was thus kept as a separate stratum. [Adopted from* (Kilfoyle et al. 2015)*]*

Map Habitat Class	**Habitat Strata**
Deep Ridge Complex	DPRC
Linear Reef-Inner	INNR
Linear Reef-Middle	MIDR
Linear Reef-Outer	OFFR
Ridge-Deep	OFFR (RGDP in Martin only)*
Ridge-Shallow	NEAR
Other Delineations (Artificial, dredged inlets, sand borrow areas)	OTHR
Aggregated Patch Reef-Deep	PTDP
Aggregated Patch Reef-Shallow	PTSH
Patch Reef	PTSH <20 m; PTDP>20 m
Colonized Pavement-Deep	OFFR
Colonized Pavement-Shallow	NEAR
Unconsolidated Sediment	SAND
Scattered Coral/Rock in Sand	PTSH <20 m; PTDP>20 m
Seagrass	SGRS
Spur and Grove	OFFR
No Map Data	UNKW

The map strata were used to parse the region into finer categories to optimize sample locations for the eight targeted fishery species *Balistes capriscus, Epinephelus morio, Haemulon plumierii, Haemulon sciurus, Lachnolaimus maximus, Lutjanus analis, Lutjanus griseus,* and *Ocyurus chrysurus*. A simple randomized design would take many more samples to acquire the necessary data on the desired species, whereas a strategically targeted design is much more efficient (Smith et al. 2011). A major aspect of sampling efficiency (balance of precision and cost) of the Florida Keys RVC surveys was the use of environmental features that correlated with the spatial distribution of reef fishes to partition the survey area into strata of low, moderate and high variation in density (Smith et al. 2011; Ault et al. 2012). In the case of the Southeastern Florida Reef Tract (SE FRT), initially

there was not much regional information available about the fisheries species to inform the survey design, thus the proportion of benthic habitats were used to allocate sampling among strata (Ault et al. 2012). Subsequent years used previously collected data to aid in the site allocations by allocating sampling effort according to both stratum size and stratum variance of reef-fish density. When including the coral reef ecoregions, slope, and benthic habitat types, there were too many individual categories to be practical in the stratified random design and many were not thought to pertain to the targeted fish species. For example, the subtle differences between Colonized Pavement-Shallow and Ridge-Shallow benthic communities and geomorphology were not thought to be major factors affecting species distribution. Therefore certain benthic habitats were combined into what were intended to be more relevant strata, such as the nearshore habitats (NEAR). Combining the benthic habitats into habitat strata resulted in thirty-one map strata that were used in the sampling allocations (Table 1). As this project is meant to study hardbottom reef fish populations, grid cells containing 'Other' habitat class (altered natural substrates, dredge channels, artificial reefs, etc.) were excluded from the sample frame, as were cells containing only softbottom habitats (e.g. sand, seagrass, etc.).

It was estimated that 360 PSUs could be visited each year with a combined effort from all partner agencies. PSU allocations for each stratum were guided by the proportional distribution of strata in the sampling frame. Each stratum was given a minimum of five PSUs. Then the remaining PSUs were distributed proportionally by the strata area. Extremely large strata were limited to 50 PSUs. Once the total number of target PSUs for each stratum was determined, the location of the PSUs to be sampled was randomly chosen based on equal probability of selection from the survey frame using NOAA's sampling design tool for ArcGIS (http://coastalscience.noaa.gov/projects/detail?key=185). Then, two of the four SSUs in each chosen PSU were randomly selected. The center location of the two chosen SSUs were the sample sites for that PSU.

Prior to the beginning of field sampling, the target locations were visually inspected with the high-resolution bathymetry and benthic habitat maps in GIS to determine if the

location was within the intended strata. If not, the points were moved (within the SSU where possible) to the designated target habitat. In cases where no suitable habitat was nearby, the point was discarded and a suitable alternate was chosen. Appendix 1 contains four site maps of actual sample locations from the combined 2012-2014 period.

2.2 Point-Count Methodology

The Reef fish Visual Census (RVC) point-count method used in this project is modeled after the original survey design developed by Bohnsack & Bannerot (1986). It is a nondestructive survey method, which provides reliable quantitative estimates of species density, frequency of occurrence, and size structure of reef fish assemblages. This method is based on taking a census of reef fish at a randomly selected stationary point within an imaginary cylinder with a 7.5 m radius (Figure 3).

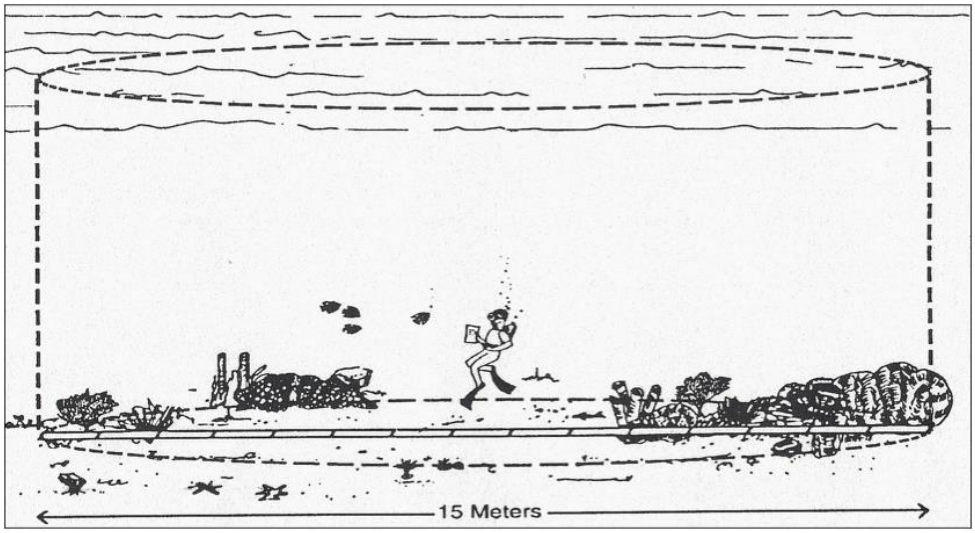


Figure 3. *Diagram of the 15 m cylinder with Reef fish Visual Census surveyor in center. [Reprinted from* (Brandt et al. 2009)*].*

Biological data for this project were collected using non-destructive, *in situ*, fishery-independent, visual monitoring methods by highly trained and experienced surveyors using open circuit Air and Nitrox SCUBA (Ault et al. 2002). Data on non-cryptic, diurnally active marine fishes were collected between May and October when there are minimum winds for better diving logistics and to keep a year-to-year consistency for the more mobile species. A reel with a weight and reef hook was dropped at each of the two Global Positioning System (GPS) located Second-stage Sampling Unit (SSU) sites. The line on the reels was attached to the surface with flag, buoy, and GPS systems. The addition of a GPS attached to the flag was used to document the actual location at the time of the sample. In areas of high current where there was risk of the flag and GPS submerging, a GPS point was taken where the surveyor's bubbles were detected on the bottom using a Fathometer. Once suited up and ready, a buddy team of two surveyors (designated as diver A and diver B) was dropped at each flag. The weighted reel was hooked into the hardbottom using the reef hook—being careful to avoid sensitive species where possible—and served as a mid-point between the two surveyors' cylinders. Each surveyor was responsible for a 15 m diameter imaginary cylinder from the bottom to the limits of vertical visibility or surface (Figure 3). A prefabricated data sheet on a clipboard with an attached pencil was used to assist in ease of recording. Starting in 2013, a new technique was used for the deep, high current sites found in the northern regions of the study frame. One team of surveyors was dropped—with flag and reel—at the SSU that was the furthest up current in the PSU. The buddy team performed one point-count at that SSU, then swam about 50 m with the current in the direction of the second SSU and performed the second point-count for that PSU. The surveyors were told prior to their dive the direction to swim and the projected relief of the two target SSU's (high or low) and attempted, to the best of their ability, to land on the desired SSU. This technique was implemented to save overall dive time as well as give the surveyors' extra surface intervals in between deep dives.

For five minutes, the surveyor wrote down every observed species within the cylinder. The timing was assisted by the use of a stopwatch. After the initial five minutes,

the surveyor then drew a line under the list of species. For each species, the surveyor recorded the density and the estimated maximum, minimum and mean fork lengths to the nearest centimeter (cm). The surveyor worked back up the list in reverse order of recording to reduce potential bias by avoiding counting a species when they were particularly abundant or obvious. For the common families (e.g. *Pomacentridae*, *Labridae*, etc.), one 360° rotation was made for each species. Species with few individuals (e.g. *Pomacanthid*'s, *Sphyraena barracuda*, *Lachnolaimus maximus,* etc.) were counted and their size estimated immediately. Highly mobile fish that were unlikely to remain in the area (e.g. *Elasmobranch*'s, *Carangidae,* etc.) were tabulated when first observed. This was repeated for every species on the list. If another species appeared within the next five minutes which was not previously recorded, the surveyor wrote it down under the five-minute line. For particularly long or species-rich counts, the stopwatch alarm went off again and the surveyor then drew a ten-minute line and continued counting and estimating until the original five minute list was completely filled out. The time required for the surveyor to record each count averaged between 15-20 minutes but ranged between 5-30 minutes depending on the habitat and number of species present.

To aid in correct estimation of sizes and to reduce the apparent magnification errors each surveyor was equipped with an All Purpose Tool (APT). This measuring tool was composed of a meter-long Polyvinyl Chloride (PVC) stick marked at 10 cm increments with a perpendicular 30 cm ruler attached at one end. This APT enabled surveyors to calibrate their length estimates by measuring stationary items such as gorgonians or sponges and comparing these items to the fish swimming by. It also aided in measuring the radius of the cylinder, visibility, distinctive habitat features such as relief, and in keeping the surveyor aware of the center of his or her cylinder. In a couple instances, the APT was also used to ward off unwanted attention from predatory fish.

After the initial data on the fish species were recorded, data were also collected on the depth and benthic habitat features including bottom composition, estimated percent cover, reef morphology (e.g. isolated patch reefs, spur and groove, coral rubble, etc.) and

topography (e.g. maximum height of hard and soft reef structures extending above the seafloor). An underwater camera was used to take four pictures—North, East, South, and West—to further document the benthic habitats. This underwater camera was also used to take photos of unusual or less well-known species to help the surveyors to later fact-check their in-water identifications.

The captain, or data manager, recorded a daily boat log during the field day. This boat log contained the date, daily weather and sea state, the individual SSU's five-digit identification number, the names of each surveyor and their designation (A or B), the GPS location and time at which the surveyors were dropped, the time the surveyors returned to the surface, and other pertinent information to the dives.

2.3 Data Entry and Proofing

Reef fish Visual Census (RVC) sample fish and habitat data were entered into an electronic database using the RVC Data Entry Program (Weinberger 1998; Ault et al. 2002; Brandt et al. 2009). This program was designed to standardize data entry and minimize the potential for errors during the data entry process (Brandt et al. 2009; Ault et al. 2002). The surveyors entered their own data from each of their dives through a three-window data entry program. With a section for comments, each entry contained every detail observed and recorded while performing the sample. The lead data manager entered the information gathered on the daily boat logs into a similar data entry program. The actual SSU locations from the dive flags' hand-held Global Positioning System (GPS) units (or Fathometer readings) were entered as well to indicate the location at which the point-counts took place.

Efforts to ensure maximum quality of the data were maintained throughout all levels of the data collection, entry and verification process in order to create the most accurate database possible (Kilfoyle et al. 2015). There was a two-fold data checking process performed by each of the surveyors. Immediately following each dive, surveyors consulted with their buddies to review the data sheet, fill in missing data, correct any errors, and ensure agreement on subjective data such as habitat type and visibility (Brandt et al. 2009; Kilfoyle et al. 2015). Secondarily, after entering all of their samples, each surveyor

was provided with a scanned copy of their original data sheet and a similar Portable Document Format (PDF) with all of the data that he or she entered. The surveyors went through each sample crosschecking the original with that which was entered into the RVC Data Entry Program. From previous experience in experiments in the Florida Keys and the Dry Tortugas, this two-fold proofing process is critical to the data analysis process as individual entering errors were most likely not caught after the use of the RVC Data Entry Program (Brandt et al. 2009). Once all errors were identified and corrected, the final version of the data (i.e., sample, species, and substrate files, boat log, diver log and environmental data) for each agency was submitted for the final data merge, Quality Assurance/Quality Control (QA/QC) verification procedures (Kilfoyle et al. 2015). Once final data from each agency was compiled, the RVC Annual Master Spreadsheet was created (Kilfoyle et al. 2015). This file consisted of merged (via Merge2.0exe program) ASCII sample, substrate and species data outputs from the RVC data entry program along with a combined version of the Boat/Field and Water Quality/Environmental logs, each of which become one of four individual worksheets within the completed RVC Annual Master Spreadsheet file (Kilfoyle et al. 2015). The next step involved performing an in-depth cross check of each of the four worksheets to locate any missing samples or incorrectly entered data, outliers, unlikely sizes and numbers of particular species, and any other dubious entries (Kilfoyle et al. 2015). Questionable elements discovered during this process were typically resolved by contacting the individual surveyor(s) who collected the data (Kilfoyle et al. 2015). A final rigorous verification procedure followed which scrutinized the habitat and substrate data, comparing the observed results to the GIS database (Kilfoyle et al. 2015).

As the RVC methodology was not designed to accurately assess every fish on a reef, some decisions were made as to what to keep for analysis and what to disregard. In order to keep the data consistently identified to the species level, every fish that was only identified to the genus level was disregarded during statistical analyses. An exception was made for *Jenkinsia spp.* (Herring spp.), which was included in the analyses because it was the only representative of that genus. One other exception was made for fish identified as

Haemulon spp. with the assumption that individual species are very difficult to distinguish at newly settled and early juvenile life stages yet make up an important functional group of the nearshore fish assemblages (Baron, Jordan, and Spieler 2004; Gilliam 1999).

During the QA/QC process, each SSU's actual Global Positioning System (GPS) location (from the boat log) was mapped in Geographic Information Systems (GIS). Due to high current conditions, the surveyors did not always end up at the initially allocated site. The diver's benthic data were cross-referenced with the habitat type to determine the strata of the sample. If the data indicated it was in a different habitat than originally assigned, the habitat classification associated with the SSU was changed to reflect the difference.

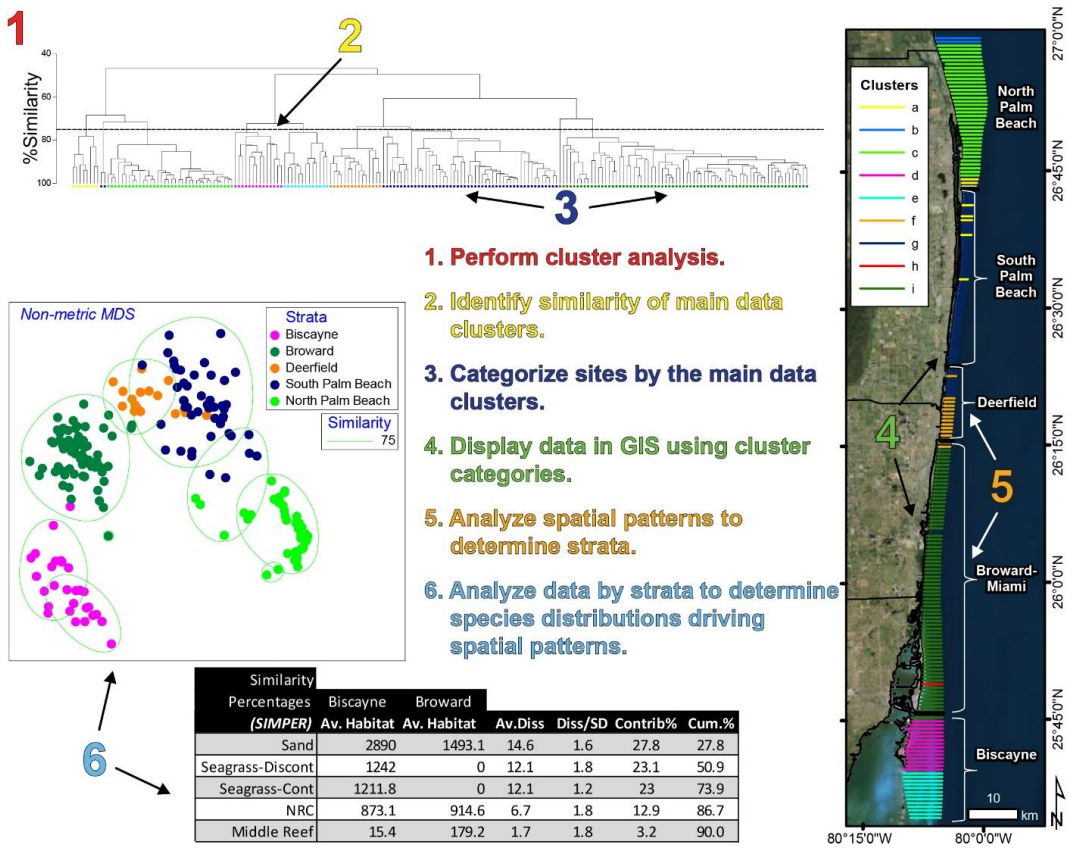
2.4 Statistical Analyses

Once the QA/QC process was complete, the final RVC Annual Master Spreadsheet file from the three years of sampling were compiled into one Microsoft Excel (2011) spreadsheet and each SSU was assigned an individual site number (0001-1676). Microsoft Excel (2011) was used to calculate percent occurrence and formulate graphical displays of the data. The statistical package, Statistica, was used to perform basic analysis of variance (ANOVA) and non-parametric analyses on the species richness and mean fish density data. The species richness data were found to be normally distributed so ANOVA tests were performed and differences were found. Then, using a post-hoc Tukey HSD test with an alpha value of 0.05, statistically significant homogenous groups were determined. The mean fish density data were not found to be normally distributed and transformations did not normalize the data so non-parametric Wilcoxon Matched Pairs Tests ($p<0.05$) were performed to determine statistically significant homogenous groups. Microsoft Excel (2011) was used to collect the data and formulate the graphs.

Characterizing the reef fish assemblage biogeographic regions requires the inclusion of many variables because many habitats are composed of a variety of organisms of different densities or coverage (Costa, Dijkstra, and Walker, in review). Surveys that collect multivariate information can be analyzed spatially to determine larger scale patterns

and site similarities and differences (Costa, Dijkstra, and Walker, in review). Multivariate statistics for this project were conducted in Plymouth Routines in Multivariate Ecological Research (PRIMER) (PRIMER-E, Ltd., Plymouth, UK). First, in order to normalize the density measurements, an overall square root transformation was performed. Then, a Bray-Curtis similarity resemblance matrix was created out of the transformed density data which ranked all of the sites relative to each other.

Figure ***4*** illustrates an example using seafloor habitat data along cross-shelf transects to determine seascape patterns along the coast in Southeast Florida (Costa, Dijkstra, and Walker, in review). The analysis in this project closely followed the steps in the example. After the resemblance matrix was created, differences in the structure of reef fish assemblages between the twelve habitat types (CPSH, RGSH, LIRI, PTCH, SCRS, LIRM, CPDP, RGDP, LIRO, SPGR, APRD, and DPRC) were assessed using MultiDimensional Scaling (MDS). Then, a cluster analysis was performed and a dendrogram showed the similarity of the main data clusters. The data was then displayed in GIS using the two main cluster categories (Cluster A and Cluster B). The two clusters showed spatial patterns and a bar graph showed the habitat types that composed the two clusters fit into a depth strata (shallow and deep). The data was then analyzed by depth strata to determine species distributions driving spatial patterns. Analysis of similarity (ANOSIM) tests were then used to determine whether the reef fish assemblage data fit into the Coral Reef Ecoregions defined by Walker (2012) and Walker and Gilliam (2013). Insignificant differences were found between some of the coral reef ecoregions so these ecoregions were combined into a set of Shallow and Deep Reef Fish Assemblage Biogeographic Regions. MDS and ANOSIM analyses were performed to test if previously determined reef fish strata (General Habitat and Relief) lead to significant differences. After the final Shallow and Deep Reef Fish Assemblage Biogeographic Regions were determined, similarity percentages analyses (SIMPER) were performed to assess the species that contributed the most to the differences in the southernmost and northernmost assemblage regions.



Similarity Percentages (SIMPER)	Biscayne Av. Habitat	Broward Av. Habitat	Av.Diss	Diss/SD	Contrib%	Cum.%
Sand	2890	1493.1	14.6	1.6	27.8	27.8
Seagrass-Discont	1242	0	12.1	1.8	23.1	50.9
Seagrass-Cont	1211.8	0	12.1	1.2	23	73.9
NRC	873.1	914.6	6.7	1.8	12.9	86.7
Middle Reef	15.4	179.2	1.7	1.8	3.2	90.0

Figure 4. *Methods for identifying spatial distribution. Six steps involved in analyzing multivariate data to determine spatial patterns. The colored numbers correspond to the colored list of steps in the middle. The steps go from the top left to the middle right to the bottom left. Example data are from* (Walker 2012). *[image from* (Costa, Dijkstra, and Walker, in review)*]*.

3.0 Results

3.1. General

Three annual surveys were accomplished between July 12 and October 31, 2012; May 23 and October 28, 2013 and between May 6 and October 31, 2014 collecting data at 432, 639, and 605 SSUs respectively (1676 total). Forty-seven surveyors counted a total of 283,644 fish during the three sampling seasons representing 286 species from 69 families (

Appendix ***2***). The total mean density for all sites combined was 170.0 ± 5.9 Standard Error of the Mean (SEM) fishes/site. The total mean species richness for all sites combined was 25.0 ± 0.2 SEM species/site.

3.2 Defining Strata

The analyses to define the fish strata were performed for my project as well as for the Kilfoyle et al. (2015) report. The results that follow in this section (3.2) are the same as those in the report. Multidimensional scaling (MDS) showed patterns in the reef fish assemblages associated with the benthic habitats described above in section 1.3 (Figure 5). Samples in many of the habitats clustered tightly together indicating that these sites were most similar to each other. These included Linear Reef-Middle (LIRM), Colonized Pavement Deep (CPDP), Linear Reef-Outer (LIRO), Spur and Groove (SPGR), and Aggregated Patch Reef Deep (APRD). Other habitats contained more variable but relatively distinct assemblages as indicated by their spread away from each other and the main cluster of points. For example the Ridge-Deep (RGDP) and the Deep Ridge Complex (DPRC) were spread out and mostly separated from samples in other habitats. The Ridge-Shallow (RGSH) and Colonized Pavement-Shallow (CPSH) were also spread out, however they were comingled indicating that the assemblages in these habitats, although variable, are more similar to each other than other habitats.

A cluster analysis illustrated the similarity of each site in a dendrogram (Figure 6). The dendrogram showed a main split in the data at the 36% similarity level indicating the

sites in these two clusters were very different. The sites associated with these clusters were categorized as Cluster A and Cluster B and plotted in GIS to visualize their spatial relationships (Figure 7). There was clear spatial separation in the two clusters where Cluster A was mainly offshore spread from the Broward-Miami Ecoregion through the South Palm Beach Ecoregion. Cluster B was mainly constrained to the nearshore in the Broward-Miami Ecoregion. The samples in clusters A and B were associated with different habitat types (Figure 8). The sites in Cluster A mainly occurred in the deep habitats (LIRM, CPDP, RGDP, LIRO, SPGR, APRD, and DPRC) whereas the sites in Cluster B were associated with mostly shallow habitats (CPSH, RGSH, and LIRI) supporting that depth was strongly correlated with the differences in the regional reef fish assemblage.

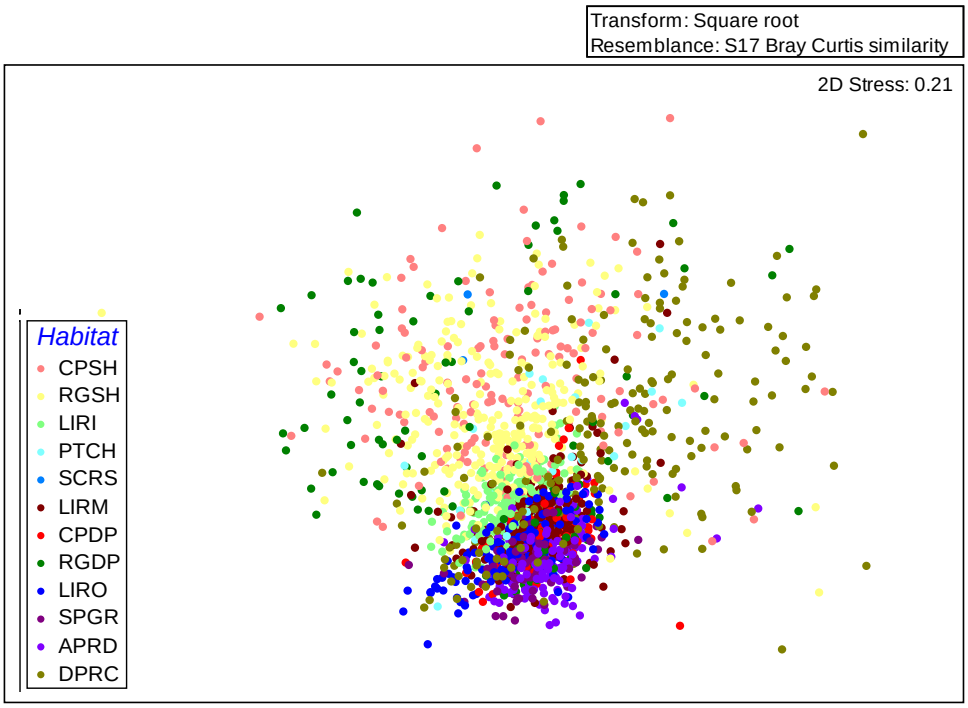


Figure 5. *MDS plot of all sites categorized by Habitat.*

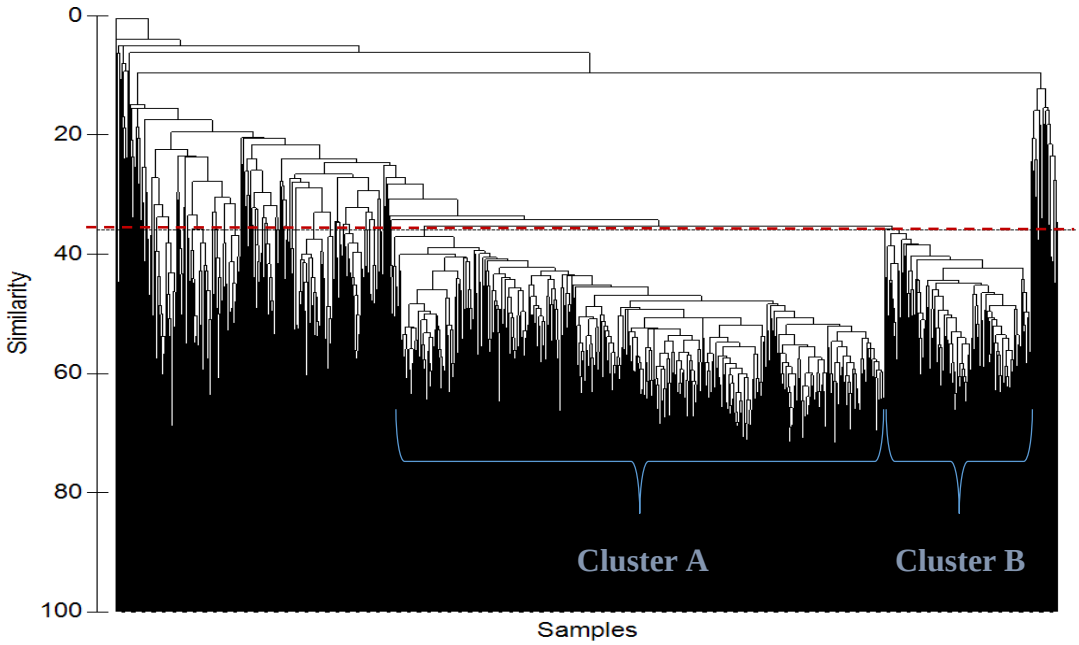


Figure 6. *Cluster dendrogram of all sites. Dashed red line indicates the 36% similarity level which is the main split in the data. All sites linked below the left cluster are Cluster A and all sites linked below the right cluster are Cluster B.*

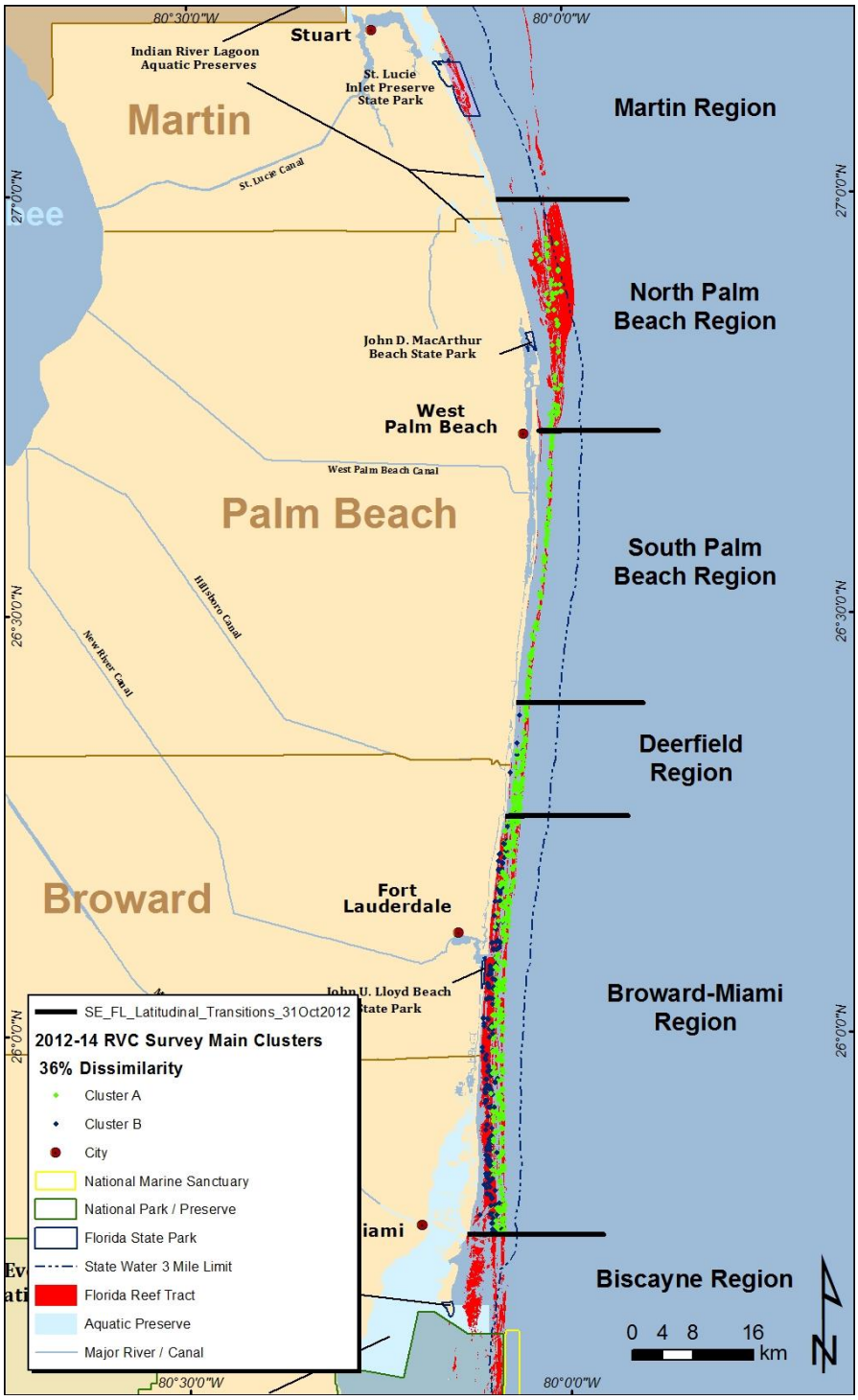


Figure 7. *Map of all sites illustrating the samples within the two main clusters of species densities in the multivariate analysis at 36% similarity.* (Kilfoyle et al. 2015)

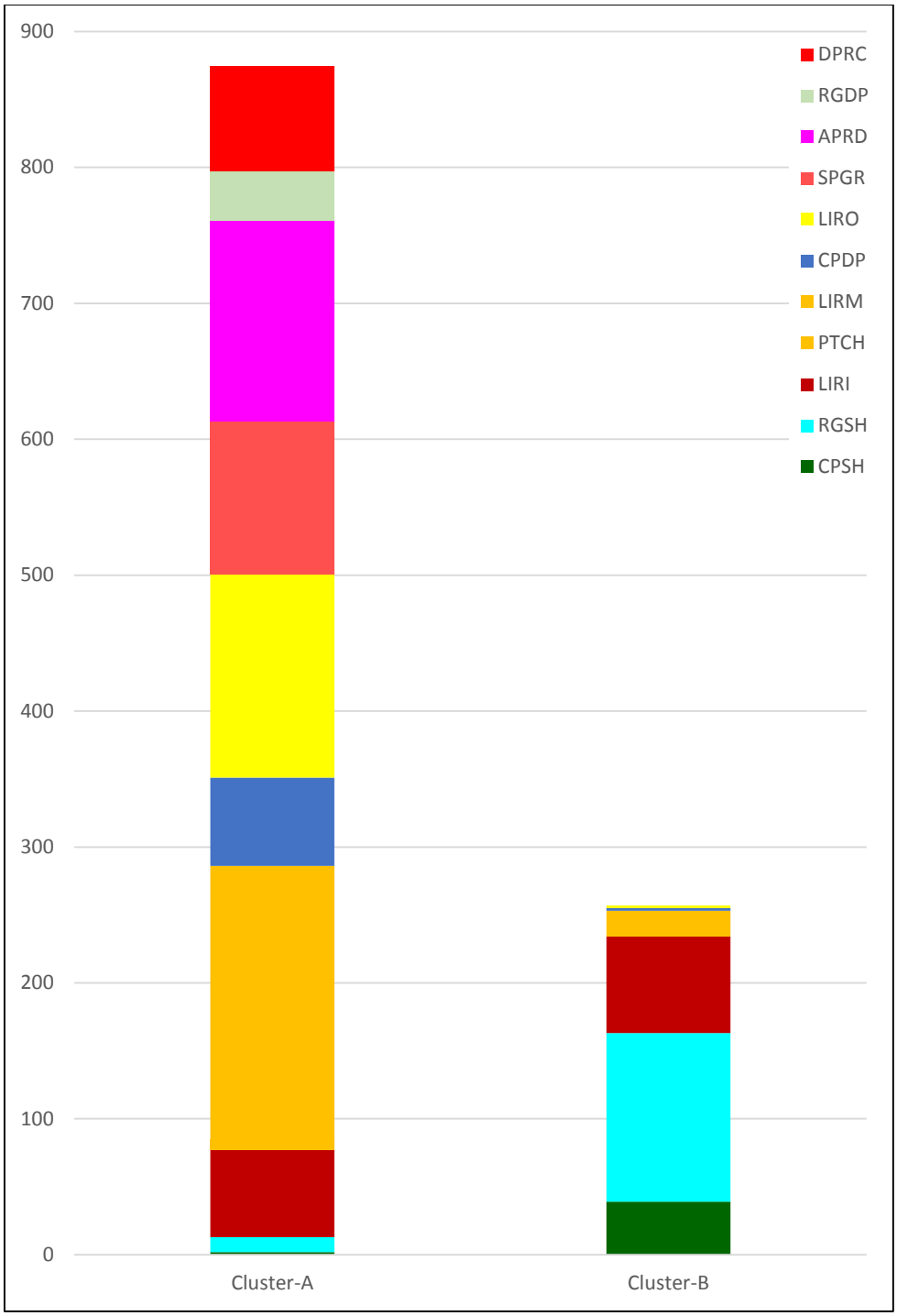


Figure 8. *The number of sites in the two main clusters of species densities in the multivariate analysis at 36% similarity by habitat type.* (Kilfoyle et al. 2015)

When categorized by shallow and deep habitats (Figure 9), the MDS plot illustrated a tight cluster of deep sites and that the shallow sites were mostly separate and considerably spread out indicating high variability. There were many deep sites spread throughout the shallow sites as well, indicating that depth was not the only factor influencing the assemblage composition. When combining habitats into general categories of Reef (LIRI, PTCH, LIRM, LIRO, SPGR, and APRD) and Hardbottom (CPSH, RGSH, SCRS, SCDP, RGDP, DPRC), the MDS revealed that the Reef sites were mostly tightly clustered and the Hardbottom sites were mostly separate and spread throughout the plot where the Deep and Shallow sites mixed (Figure 10). This result indicated that the main differences in habitat associated with regional fish assemblages was whether it was Deep or Shallow and Reef or Hardbottom. When displayed by both depth and general habitat, the MDS plot illustrated good splits between most categories (Figure 11). However, some assemblages on the Deep Hardbottom sites clustered with those on the Deep Reef sites. The MDS was further categorized by Depth, General Habitat and Relief (0=Low= <0.3 m and 1=High= >0.3 m) (Figure 12). The general patterns in Figure 11 remained and high relief helped explain the Deep Hardbottom sites clustering with the Deep Reef sites.

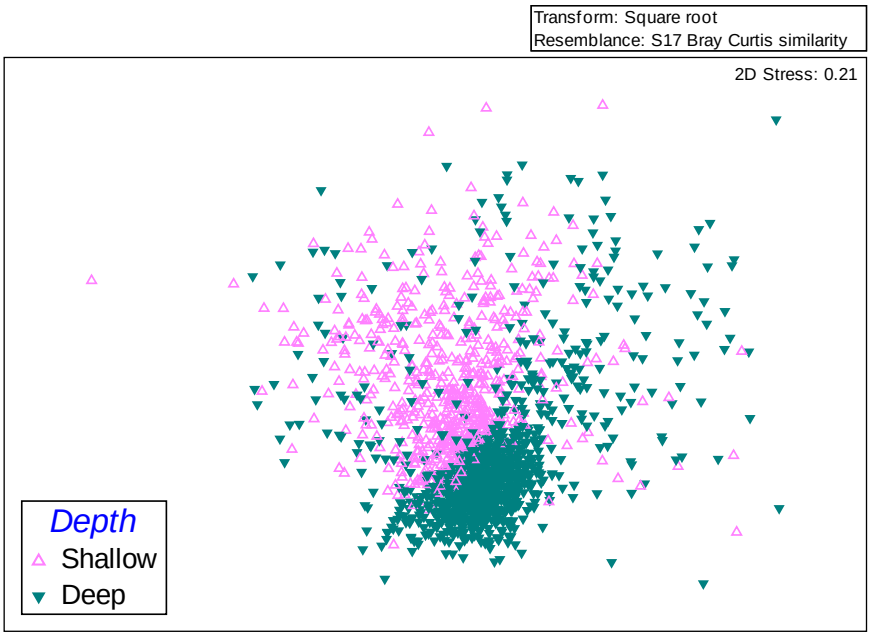


Figure 9. *MDS plot of all sites categorized by Habitat Depth. CPSH, RGSH, LIRI, PTCH and SCRS habitats were categorized as Shallow and all others as Deep.*

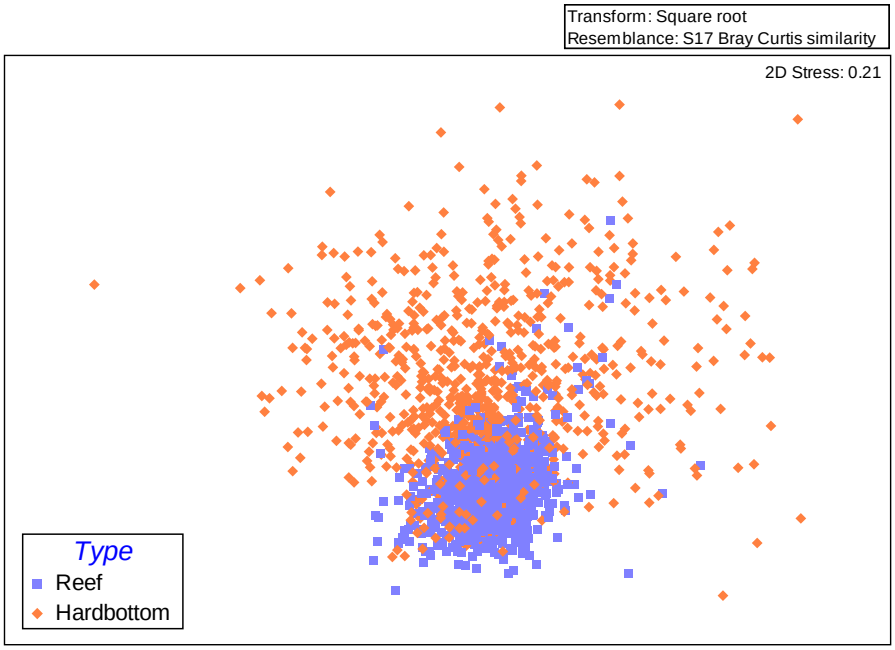


Figure 10. *MDS plot of all sites categorized by General Habitat; Reef (LIRI, PTCH, LIRM, LIRO, SPGR and APRD) or Hardbottom (CPSH, RGSH, SCRS, CPDP, RGDP and DPRC).*

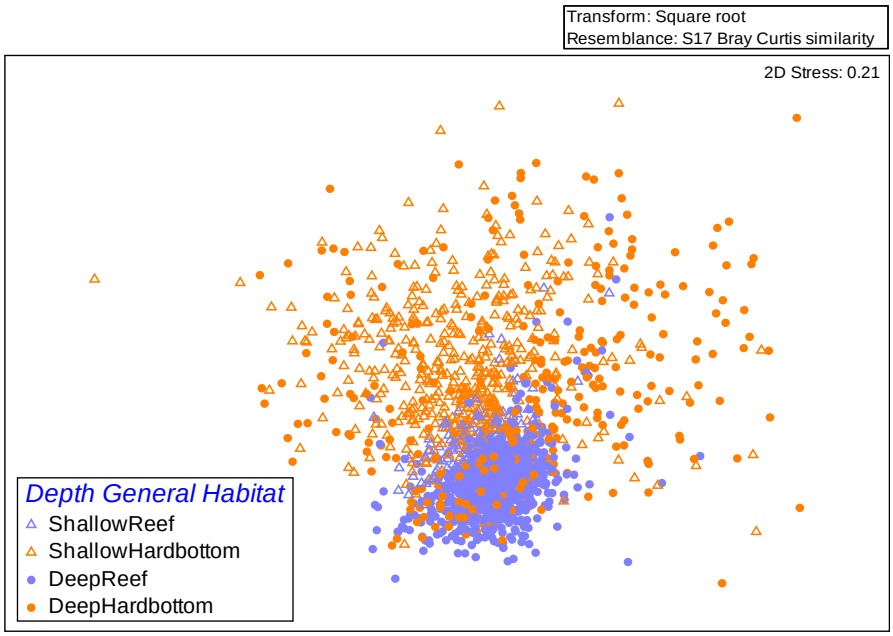


Figure 11. *MDS plot of all sites categorized by Depth (Shallow or Deep) and General Habitat (Reef or Hardbottom).*

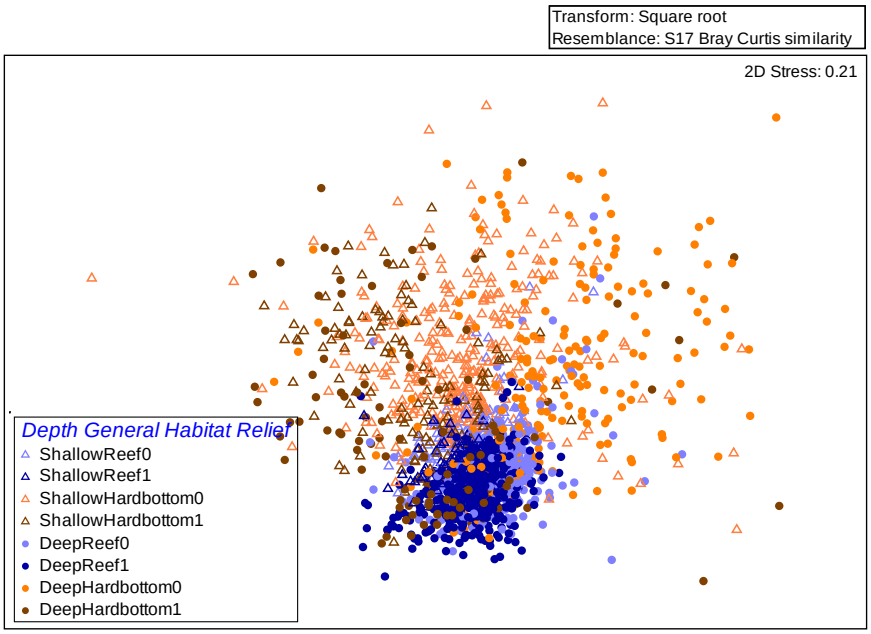


Figure 12. *MDS plot of all sites categorized by Depth (Shallow or Deep), General Habitat (Reef or Hardbottom), and Relief (0=Low or 1=High).*

3.3 Shallow Samples

Analyses were performed on the shallow sites (CPSH, RGSH, LIRI, PTCH and SCRS) to further define shallow reef fish assemblage strata. A MDS between the Coral Reef Ecoregions within the shallow sites showed the Broward-Miami and Martin sites were mostly separate but the other three ecoregions were all mixed together (

Figure ***13***). An ANOSIM further elucidated the differences in the shallow reef fish assemblages between the Coral Reef Ecoregions (Table 3). Broward-Miami Coral Reef Ecoregion was significantly different (R stat = 0.373-0.591) from the northern Coral Reef Ecoregions so the sites within this zone formed the new Shallow Broward-Miami Reef Fish Assemblage Biogeographic Region. A Reef Fish Assemblage Biogeographic Region is synonymous with an "Assemblage Region" throughout the remainder of this document. No significant differences were found between the Deerfield, South Palm Beach and North Palm Beach Coral Reef Ecoregions so these ecoregions were combined into a new Shallow Palm Beach-Deerfield Assemblage Region. All of the southern ecoregions were statistically different from the Martin Coral Reef Ecoregion (R stat 0.482-0.595) so the sites within this zone created the new Shallow Martin Assemblage Region.

Following the separation into the three Shallow Assemblage Regions (Broward-Miami, Palm Beach-Deerfield, and Martin) an ANOSIM was performed to determine if General Habitat and Relief were significant stratification factors in the shallow habitats (Table 4). The largest difference between shallow reef fish strata was between the Broward-Miami High relief Reef and the Martin Low relief Hardbottom (R stat = 0.967). Within the Shallow Broward-Miami Assemblage Region, the majority of the assemblages were not significantly different and the significant ones were not very strong (R stat = 0.181-0.183). The assemblages of the Low Hardbottom and High Hardbottom habitats within the Shallow Palm Beach-Deerfield Assemblage Region were not significantly different. The same was true for assemblages in the Shallow Martin Assemblage Region. Due to the lack of strong significant differences within the individual assemblage regions,

a further stratification by General Habitat and Relief was deemed unnecessary for the shallow sites.

A MDS plot was created using the new Shallow Assemblage Regions (Figure 14). Similar to

Figure ***13***, the Broward-Miami sites clustered on the bottom and the Martin sites clustered on the top. The new Palm Beach-Deerfield Assemblage Region sites overlapped the other two assemblage regions with most of the sites falling in between Broward-Miami and Martin. While the 2D stress was quiet high at 0.24, the MDS clearly illustrated the difference between the shallow Broward-Miami and the Martin assemblages. An ANOSIM further confirmed the difference in assemblage structure between Broward-Miami and Martin (R stat = 0.591) (Table 5). The Broward-Miami assemblage was significantly distinct from the Palm Beach-Deerfield (R stat = 0.429) and the Palm Beach-Deerfield assemblage was significantly different from the Martin Hardbottom (R stat = 0.255).

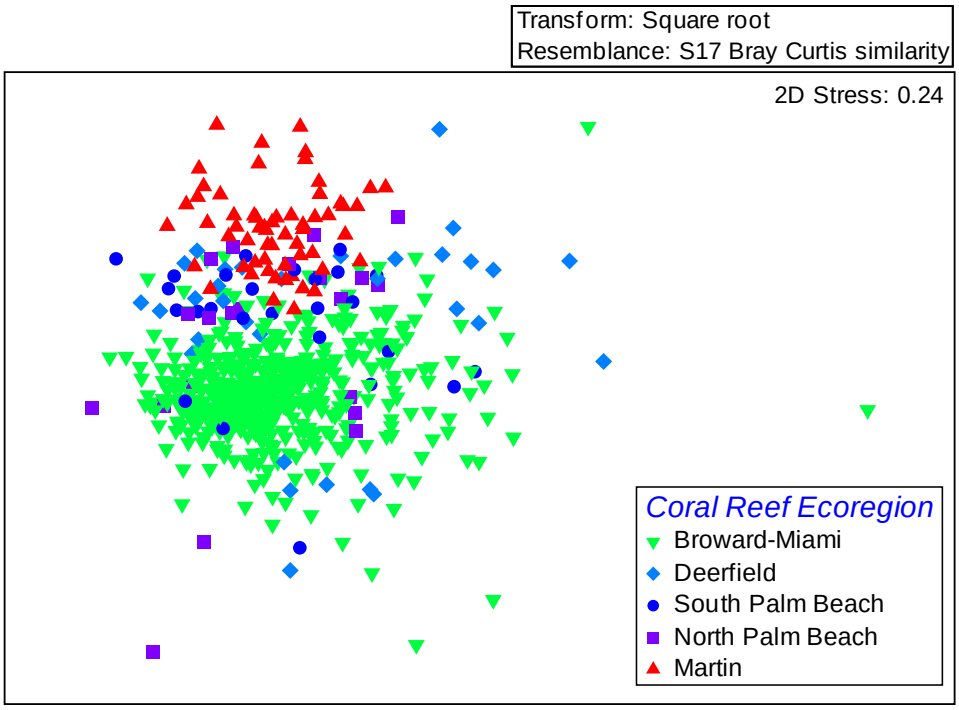


Figure 13. *MDS plot of all samples on shallow habitats only (CPSH, RGSH, LIRI, PTCH and SCRS). Categorized by Coral Reef Ecoregion.*

Table 3. *A summary of the ANOSIM pairwise tests of the shallow sites between the Coral Reef Ecoregions. The R statistic indicates the strength of the difference where 1 is the strongest and 0 is the weakest. The significant differences (0.1%) are in plain text while the non-significant pairings (>0.1%) are in italics.*

Groups (Coral Reef Ecoregion)	**R Statistic**	**Significance Level %**
Broward-Miami, Deerfield	0.52	0.1
Broward-Miami, South Palm Beach	0.373	0.1
Broward-Miami, North Palm Beach	0.408	0.1
Broward-Miami, Martin	0.591	0.1
Deerfield, South Palm Beach	*0.113*	*0.4*
Deerfield, North Palm Beach	*0.106*	*0.7*
Deerfield, Martin	0.595	0.1
South Palm Beach, North Palm Beach	*0.042*	*9.1*
South Palm Beach, Martin	0.489	0.1
North Palm Beach, Martin	0.482	0.1

Table 4. *A summary of the ANOSIM pairwise tests of the shallow sites between the Assemblage Region, General Habitat, and Relief.*

Groups (Assemblage Region, General Habitat, Relief)	R Statistic	Significance Level %	Groups (Assemblage Region, General Habitat, Relief)	R Statistic	Significance Level %
Broward-MiamiReef0, Broward-MiamiHardbottom0	*0.037*	*9.7*	Broward-MiamiHardbottom1, Palm Beach-DeerfieldHardbottom0	0.285	0.1
Broward-MiamiReef0, Broward-MiamiHardbottom1	0.183	0.1	Broward-MiamiHardbottom1, MartinHardbottom1	0.722	0.1
Broward-MiamiReef0, Broward-MiamiReef1	*0.061*	*1*	Broward-MiamiHardbottom1, MartinHardbottom0	0.693	0.1
Broward-MiamiReef0, Palm Beach-DeerfieldHardbottom0	0.491	0.1	*Broward-MiamiHardbottom1, Palm Beach-DeerfieldHardbottom1*	*0.425*	*0.2*
Broward-MiamiReef0, MartinHardbottom1	0.915	0.1	Broward-MiamiReef1, Palm Beach-DeerfieldHardbottom0	0.405	0.1
Broward-MiamiReef0, MartinHardbottom0	0.888	0.1	Broward-MiamiReef1, MartinHardbottom1	0.946	0.1
Broward-MiamiReef0, Palm Beach-DeerfieldHardbottom1	0.637	0.1	Broward-MiamiReef1, MartinHardbottom0	0.967	0.1
Broward-MiamiHardbottom0, Broward-MiamiHardbottom1	*-0.018*	*69.3*	Broward-MiamiReef1, Palm Beach-DeerfieldHardbottom1	0.721	0.1
Broward-MiamiHardbottom0, Broward-MiamiReef1	*0.101*	*1*	Palm Beach-DeerfieldHardbottom0, MartinHardbottom1	0.251	0.1
Broward-MiamiHardbottom0, Palm Beach-DeerfieldHardbottom0	0.333	0.1	*Palm Beach-DeerfieldHardbottom0, MartinHardbottom0*	*0.036*	*31.8*
Broward-MiamiHardbottom0, MartinHardbottom1	0.495	0.1	*Palm Beach-DeerfieldHardbottom0, Palm Beach-DeerfieldHardbottom1*	*-0.015*	*54.3*
Broward-MiamiHardbottom0, MartinHardbottom0	0.429	0.1	*MartinHardbottom1, MartinHardbottom0*	*0.266*	*0.2*
Broward-MiamiHardbottom0, Palm Beach-DeerfieldHardbottom1	*0.335*	*0.4*	MartinHardbottom1, Palm Beach-DeerfieldHardbottom1	0.705	0.1
Broward-MiamiHardbottom1, Broward-MiamiReef1	0.181	0.1	MartinHardbottom0, Palm Beach-DeerfieldHardbottom1	0.459	0.1

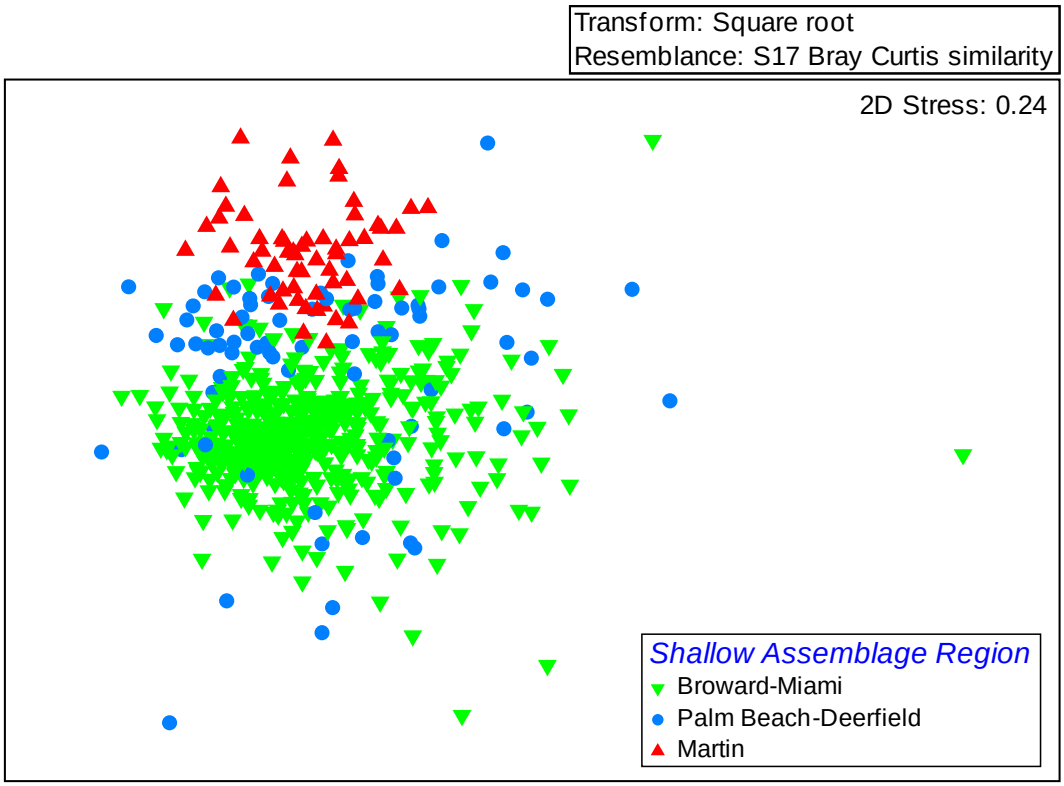


Figure 14. *MDS plot of all samples on shallow habitats only. Categorized by the new Shallow Assemblage Regions.*

Table 5. *A summary of the ANOSIM pairwise tests of the shallow sites between the new Shallow Assemblage Regions.*

Groups (Shallow Assemblage Region)	R Statistic	Significance Level %
Broward-Miami, Palm Beach-Deerfield	0.429	0.1
Broward-Miami, Martin	0.591	0.1
Palm Beach-Deerfield, Martin	0.255	0.1

3.4 Deep Samples

Analyses were performed on the deep sites (LIRM, CPDP, RGDP, LIRO, SPGR, APRD, and DPRC) to further define deep reef fish assemblage strata. An MDS between the Coral Reef Ecoregions (Figure 15) aided in splitting apart the dense cluster present within the deep habitats in Figure 9. The sites in the Broward-Miami, Deerfield, and South Palm Beach Coral Reef Ecoregions all clustered together while the sites in North Palm Beach and Martin were mostly spread apart from the cluster and each other. An ANOSIM numerically demonstrated the relationships of the deep habitat assemblages within the Coral Reef Ecoregions (Table 6). Since the R stat values between Broward-Miami, Deerfield and South Palm Beach were very low (R stat < 0.198), these three were combined to make a new Deep South Palm Beach-Miami Assemblage Region. While the assemblages of South Palm Beach and North Palm Beach were weakly similar (R stat 0.169), the decision to create a separate Deep North Palm Beach Assemblage Region was made because the assemblages as a whole between the southern three ecoregions were more similar to each other (R stat = 0.054-0.198) than to the North Palm Beach assemblage (R stat = 0.169-0.532). The differences between the assemblages of the southern four ecoregions and those of the Martin Coral Reef Ecoregion were strong enough to separate them into the new Deep Martin Assemblage Region.

An ANOSIM was performed using the Deep reef fish strata (Assemblage Regions, General Habitat and Relief) to further elucidate the differences in the assemblages (Table 7). The strongest difference between the deep reef fish strata was South Palm Beach-Miami High relief Reef and Martin Low relief Hardbottom (R stat = 0.981). Of the six reef fish strata comparisons within the South Palm Beach Assemblage Region, only two sets of assemblages were significantly different from each other. The High relief Reef and the Low relief Hardbottom, were moderately dissimilar (R stat = 0.339) while the comparison between the Low relief Reef and the High relief Reef was not strong (R stat = 0.098). Because the majority of the assemblages were similar, the strata of South Palm Beach-Miami were considered a single Deep South Palm-Deerfield Assemblage Region. The

North Palm Beach Low relief and High relief Hardbottom assemblages were also similar (R stat = 0.16) so the strata were considered a single Deep North Palm Beach Assemblage Region. The Martin Low relief and High relief Hardbottom assemblages were moderately dissimilar (R stat = 0.342) so this assemblage region was split into two regions, Deep Martin Low Assemblage Region and Deep Martin High Assemblage Region.

An MDS plot was created using the new Deep Assemblage Regions (Figure 16). The South Palm Beach-Miami sites clustered densely at the top of the plot. Some of the North Palm Beach sites were also clustered in with the South Palm Beach sites but the majority were spread across the right side of the plot. The Martin High sites were spread in between the main cluster and the Martin Low sites at the bottom left. An ANOSIM (Table 8) further confirmed the difference in assemblage structure between South Palm Beach-Miami and North Palm Beach (R stat = 0.588), Martin Low (R stat = 0.957) and Martin High (R stat = 0.93). The assemblage structure of North Palm Beach was significantly different from Martin Low (R stat = 0.402) and Martin High (R stat = 0.364).

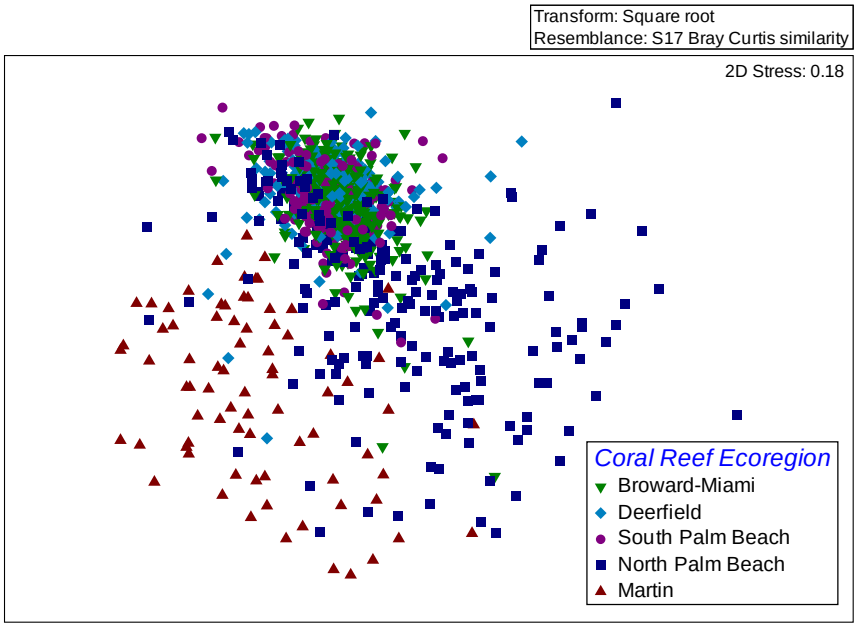


Figure 15. *MDS plot of all samples on deep habitats only (LIRM, CPDP, RGDP, LIRO, SPGR, APRD, and DPRC). Categorized by Coral Reef Ecoregion.*

Table 6. *A summary of the ANOSIM pairwise tests of the deep sites between the ecoregions.*

Groups (Coral Reef Ecoregion)	R Statistic	Significance Level %
Broward-Miami, Deerfield	0.101	0.1
Broward-Miami, South Palm Beach	0.198	0.1
Broward-Miami, North Palm Beach	0.532	0.1
Broward-Miami, Martin	0.938	0.1
Deerfield, South Palm Beach	0.054	0.1
Deerfield, North Palm Beach	0.256	0.1
Deerfield, Martin	0.858	0.1
South Palm Beach, North Palm Beach	0.169	0.1
South Palm Beach, Martin	0.831	0.1
North Palm Beach, Martin	0.37	0.1

Table 7. *A summary of the ANOSIM pairwise tests of the deep sites between the Reef Fish Strata (Assemblage Region, General Habitat, and Relief).*

Groups (Assemblage Region, General Habitat, Relief)	R Statistic	Significance Level %	Groups (Assemblage Region, General Habitat, Relief)	R Statistic	Significance Level %
South Palm Beach-MiamiReef0, South Palm Beach-MiamiReef1	0.098	0.1	*South Palm Beach-MiamiHardbottom0, North Palm BeachReef1*	*0.125*	*28*
South Palm Beach-MiamiReef0, South Palm Beach-MiamiHardbottom0	*0.15*	*1.5*	*South Palm Beach-MiamiHardbottom1, North Palm BeachHardbottom0*	*0.103*	*10*
South Palm Beach-MiamiReef0, South Palm Beach-MiamiHardbottom1	*-0.072*	*78.5*	*South Palm Beach-MiamiHardbottom1, North Palm BeachHardbottom1*	*0.045*	*28.7*
South Palm Beach-MiamiReef0, North Palm BeachHardbottom0	0.555	0.1	South Palm Beach-MiamiHardbottom1, MartinHardbottom0	0.555	0.1
South Palm Beach-MiamiReef0, North Palm BeachHardbottom1	0.396	0.1	South Palm Beach-MiamiHardbottom1, MartinHardbottom1	0.565	0.1
South Palm Beach-MiamiReef0, MartinHardbottom0	0.929	0.1	South Palm Beach-MiamiHardbottom1, North Palm BeachReef0	0.649	0.1
South Palm Beach-MiamiReef0, MartinHardbottom1	0.899	0.1	*South Palm Beach-MiamiHardbottom1, North Palm BeachReef1*	*0.558*	*4.2*
South Palm Beach-MiamiReef0, North Palm BeachReef0	0.402	0.1	North Palm BeachHardbottom0, North Palm BeachHardbottom1	0.16	0.1
South Palm Beach-MiamiReef0, North Palm BeachReef1	*0.166*	*23.1*	North Palm BeachHardbottom0, MartinHardbottom0	0.397	0.1
South Palm Beach-MiamiReef1, South Palm Beach-MiamiHardbottom0	0.339	0.1	North Palm BeachHardbottom0, MartinHardbottom1	0.451	0.1
South Palm Beach-MiamiReef1, South Palm Beach-MiamiHardbottom1	*-0.027*	*59.6*	*North Palm BeachHardbottom0, North Palm BeachReef0*	*-0.123*	*87*
South Palm Beach-MiamiReef1, North Palm BeachHardbottom0	0.722	0.1	*North Palm BeachHardbottom0, North Palm BeachReef1*	*0.019*	*43*
South Palm Beach-MiamiReef1, North Palm BeachHardbottom1	0.413	0.1	North Palm BeachHardbottom1, MartinHardbottom0	0.674	0.1
South Palm Beach-MiamiReef1, MartinHardbottom0	0.981	0.1	North Palm BeachHardbottom1, MartinHardbottom1	0.549	0.1
South Palm Beach-MiamiReef1, MartinHardbottom1	0.963	0.1	*North Palm BeachHardbottom1, North Palm BeachReef0*	*0.264*	*2.1*
South Palm Beach-MiamiReef1, North Palm BeachReef0	0.617	0.1	*North Palm BeachHardbottom1, North Palm BeachReef1*	*-0.101*	*58.1*
South Palm Beach-MiamiReef1, North Palm BeachReef1	*0.329*	*8.3*	MartinHardbottom0, MartinHardbottom1	0.342	0.1
South Palm Beach-MiamiHardbottom0, South Palm Beach-MiamiHardbottom1	*0.077*	*12.7*	*MartinHardbottom0, North Palm BeachReef0*	*0.215*	*0.8*
South Palm Beach-MiamiHardbottom0, North Palm BeachHardbottom0	*-0.007*	*53.6*	*MartinHardbottom0, North Palm BeachReef1*	*0.268*	*6.2*
South Palm Beach-MiamiHardbottom0, North Palm BeachHardbottom1	0.229	0.1	MartinHardbottom1, North Palm BeachReef0	0.523	0.1
South Palm Beach-MiamiHardbottom0, MartinHardbottom0	0.576	0.1	*MartinHardbottom1, North Palm BeachReef1*	*0.277*	*13.5*
South Palm Beach-MiamiHardbottom0, MartinHardbottom1	0.593	0.1	*North Palm BeachReef0, North Palm BeachReef1*	*0*	*40*
South Palm Beach-MiamiHardbottom0, North Palm BeachReef0	*0.246*	*3.2*			

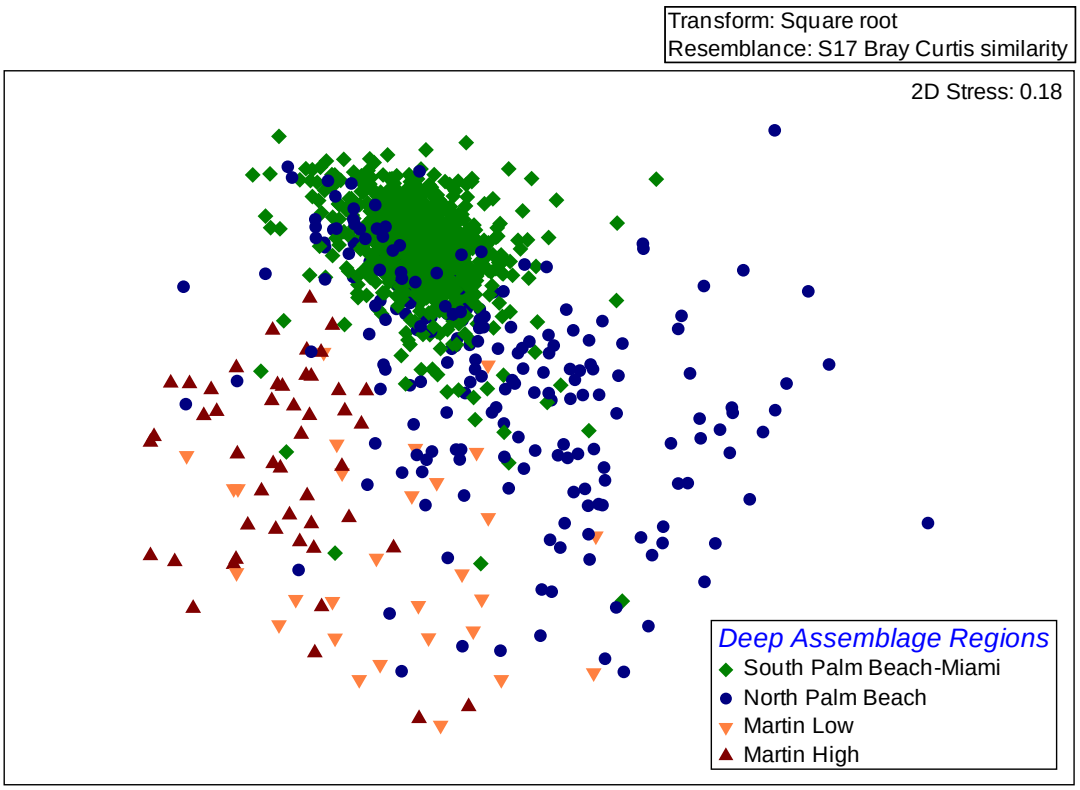


Figure 16. *MDS plot of all samples on deep habitats only. Categorized by the new Deep Assemblage Region.*

Table 8. *A summary of the ANOSIM pairwise tests of the deep sites between the new Deep Assemblage Regions.*

Groups (Deep Assemblage Region)	R Statistic	Significance Level %
South Palm Beach-Miami, North Palm Beach	0.588	0.1
South Palm Beach-Miami, Martin Low	0.957	0.1
South Palm Beach-Miami, Martin High	0.93	0.1
North Palm Beach, Martin Low	0.402	0.1
North Palm Beach, Martin High	0.364	0.1
Martin Low, Martin High	0.342	0.1

3.5 Southeast Florida Reef Fish Assemblage Biogeographic Regions

Once the Reef Fish Assemblage Biogeographic Regions were determined within each depth stratum, the deep and shallow data were analyzed together to examine if differences between latitudes is stronger than the difference between shallow and deep assemblages. An MDS plot was created with all of the sites divided by shallow and deep assemblage regions (Figure 17). While it is hard to interpret because the sites in the middle latitudes are highly variable, there is a clear difference between Broward-Miami sites and the Martin sites. An ANOSIM better shows the differences in the latitudes (Table 9). All assemblages were determined to be significantly different from each other with some showing stronger differences than others. The strongest difference in assemblage structure was between the Deep South Palm Beach-Miami and the Shallow Martin assemblage regions (R stat = 0.966). The smallest differences in assemblage structure was between the Shallow Palm Beach-Deerfield and the Deep North Palm Beach assemblage regions (R stat = 0.238).

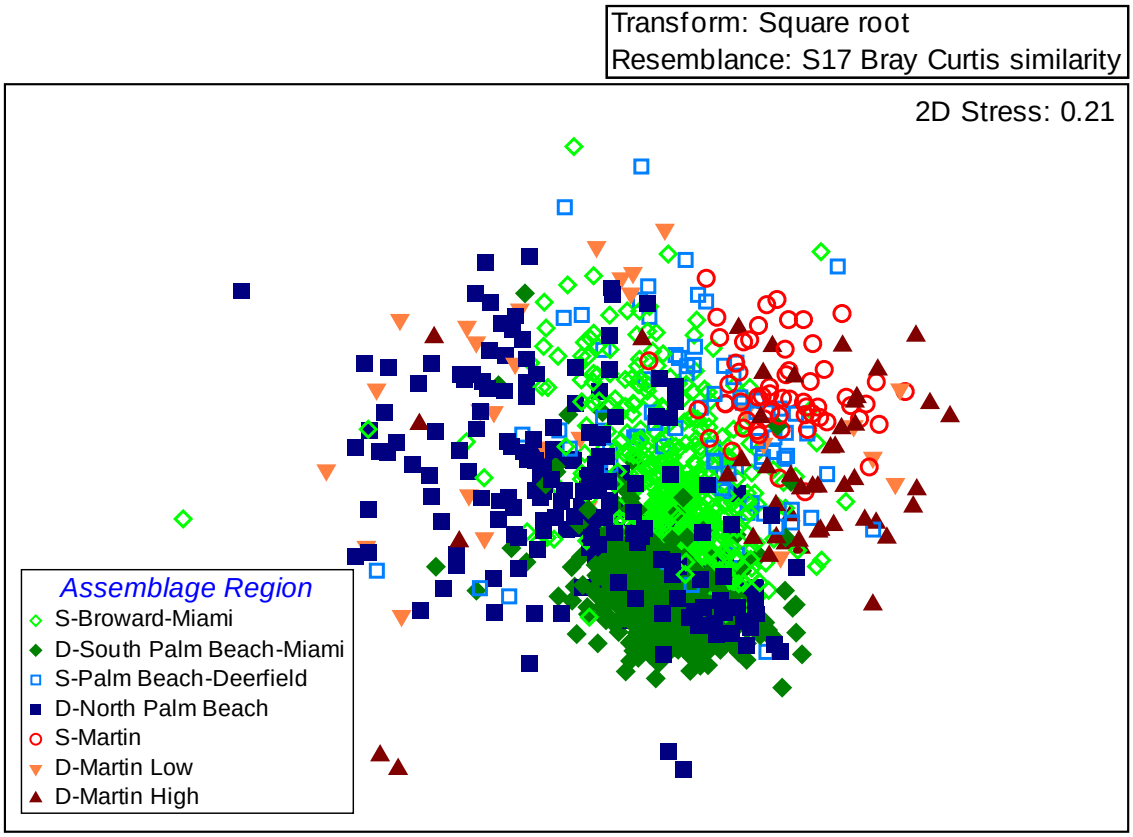


Figure 17. *MDS plot of all sites categorized by Assemblage Region. "S" indicates Shallow and "D" indicates Deep Assemblage Regions. Shallow sites are denoted by hollow shapes and the Deep sites are solid.*

Table 9. *A summary of the ANOSIM pairwise tests of all sites categorized by Assemblage Regions. "S" indicates Shallow and "D" indicates Deep Assemblage Regions.*

Groups (Assemblage Region)	R Statistic	Significance Level %	Groups (Assemblage Region)	R Statistic	Significance Level %
S-Broward-Miami, D-South Palm Beach-Miami	0.441	0.1	S-Palm Beach-Deerfield, D-North Palm Beach	0.238	0.1
S-Broward-Miami, S-Palm Beach-Deerfield	0.429	0.1	S-Palm Beach-Deerfield, S-Martin	0.255	0.1
S-Broward-Miami, D-North Palm Beach	0.37	0.1	S-Palm Beach-Deerfield, D-Martin Low	0.493	0.1
S-Broward-Miami, S-Martin	0.591	0.1	S-Palm Beach-Deerfield, D-Martin High	0.401	0.1
S-Broward-Miami, D-Martin Low	0.798	0.1	D-North Palm Beach, S-Martin	0.411	0.1
S-Broward-Miami, D-Martin High	0.724	0.1	D-North Palm Beach, D-Martin Low	0.402	0.1
D-South Palm Beach-Miami, S-Palm Beach-Deerfield	0.856	0.1	D-North Palm Beach, D-Martin High	0.364	0.1
D-South Palm Beach-Miami, D-North Palm Beach	0.588	0.1	S-Martin, D-Martin Low	0.752	0.1
D-South Palm Beach-Miami, S-Martin	0.966	0.1	S-Martin, D-Martin High	0.552	0.1
D-South Palm Beach-Miami, D-Martin Low	0.957	0.1	D-Martin Low, D-Martin High	0.342	0.1
D-South Palm Beach-Miami, D-Martin High	0.93	0.1			

3.6 Mean Species Richness and Mean Density

Comparisons of mean species richness and density among the assemblage regions were statistically significant. The Shallow Broward-Miami Assemblage Region contained significantly more species and fish on average than the Shallow Palm Beach-Deerfield and Martin assemblage regions which contained a statistically similar mean number of species and fish (Figure 18 andFigure ***19***).

The Deep South Palm Beach-Miami sites had significantly higher mean species richness than the rest of the deep sites (Figure 20). The Deep Martin Low sites contained significantly lower mean species richness than the rest of the deep sites. The deep sites in the North Palm Beach and Martin High assemblage regions contained a similar number of species on average. The deep sites in the South Palm Beach-Miami and Martin High assemblage regions contained similar mean density of fish which was higher than the deep sites in the North Palm Beach and Martin Low assemblage regions (Figure 21).

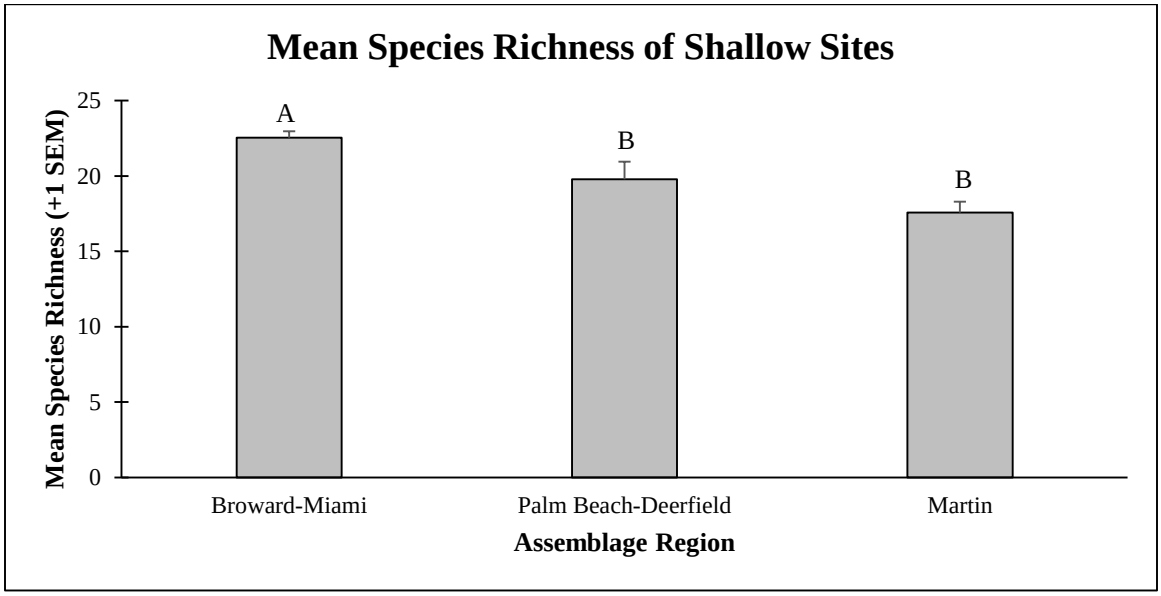


Figure 18. *Comparisons of mean reef fish species richness by Shallow Assemblage Region. The lines above the bars indicate one standard error measurement (SEM). The letters represent significantly different homogenous groups as determined by a post-hoc Tukey HSD test with an alpha value of 0.05.*

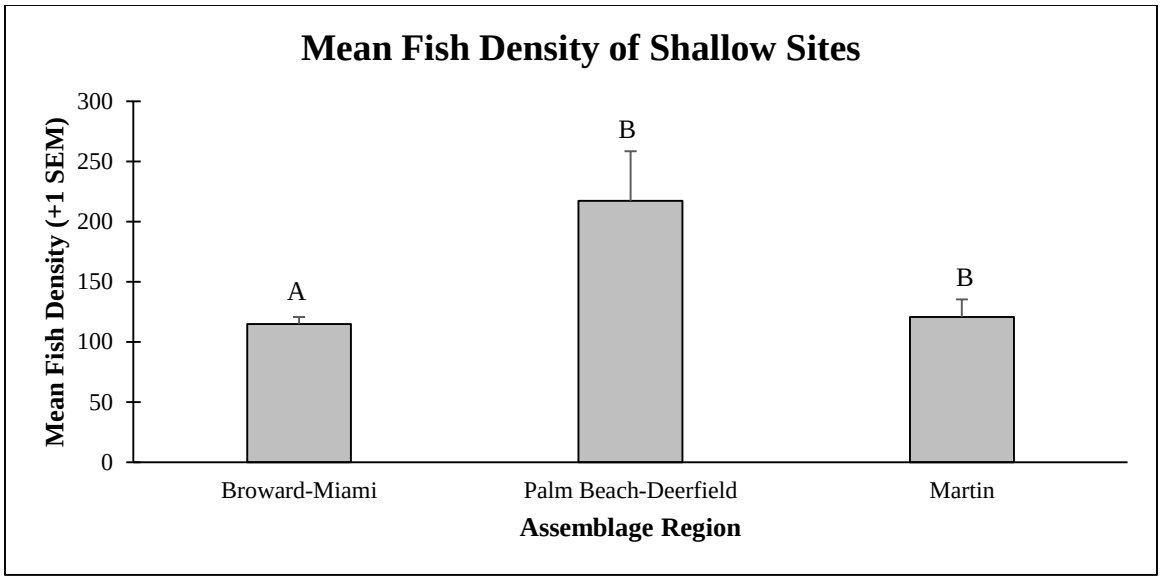


Figure 19. *Comparisons of mean reef fish density by Shallow Assemblage Region. The lines above the bars represent one standard error measurement (SEM). The letters represent significant homogenous groups as determined by a non-parametric Wilcoxon Matched Pairs Test ($p<0.05$).*

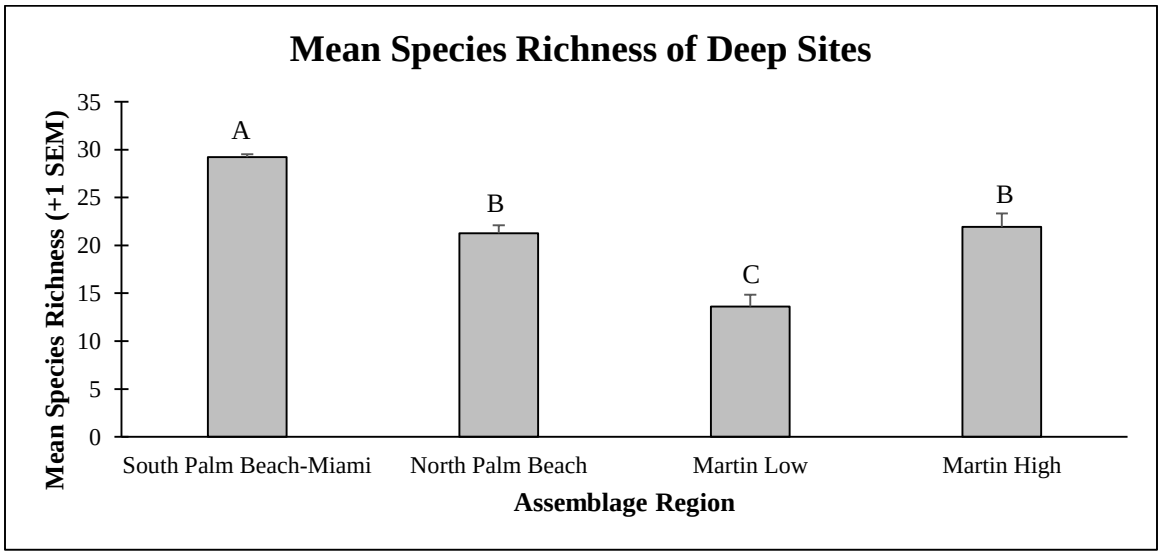


Figure 20. *Comparisons of mean reef fish species richness by Deep Assemblage Region. The lines above the bars indicate one standard error measurement (SEM). The letters represent significantly different homogenous groups as determined by a post-hoc Tukey HSD test with an alpha value of 0.05.*

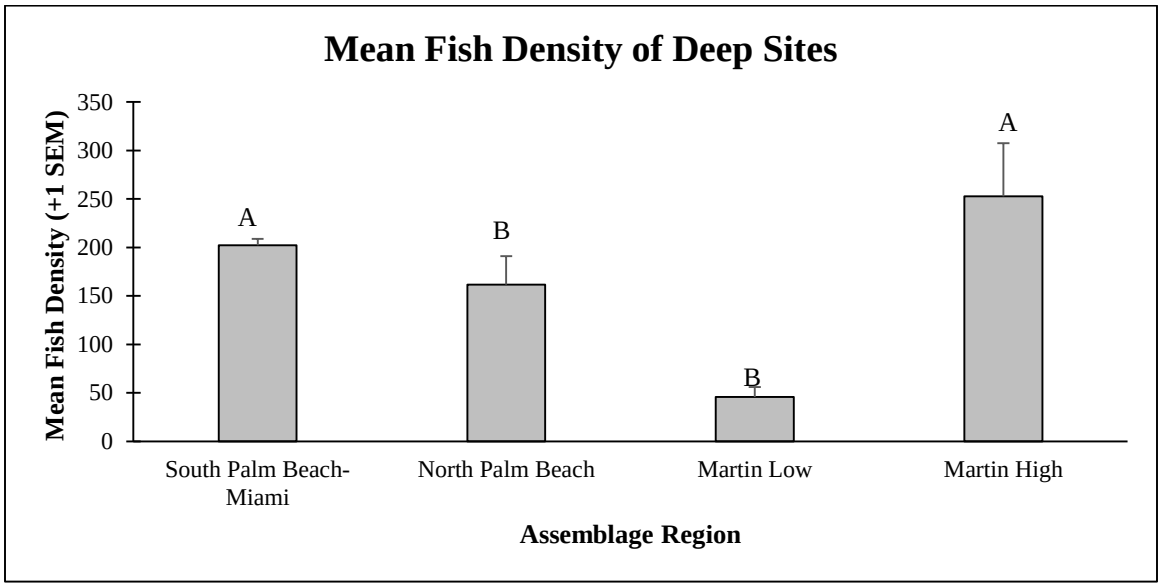


Figure 21. *Comparisons of mean reef fish density by Deep Assemblage Region. The lines above the bars represent one standard error measurement (SEM). The letters represent significant homogenous groups as determined by a non-parametric Wilcoxon Matched Pairs Test ($p<0.05$).*

3.7 Assemblage variations with latitude

Between Shallow reef fish strata, the High relief Broward-Miami Reef and Low relief Martin Hardbottom ANOSIM showed the greatest dissimilarity (Table 4). These sites were separated by the greatest latitudinal difference, thus an analysis of similar percentages (SIMPER) test was run to analyze the species that contributed the most to the differences in assemblages with latitude (Table 10). These two reef fish strata had an average dissimilarity of 81.69%. *Stegastes partitus, Thalassoma bifasciatum, Coryphopterus personatus, Sparisoma aurofrenatum, Halichoeres garnoti, Haemulon flavolineatum, Acanthurus bahianus, Acanthurus coeruleus* and *Scarus iseri* had a higher percentage of density in the Broward-Miami High relief Reef than in the Martin Low relief Hardbottom. *Haemulon aurolineatum*, juvenile *Haemulon spp., Halichoeres bivittatus, Anisotremus virginicus, and Acanthurus chirurgus,* had higher percentages in the Martin Low relief Hardbottom and the Broward-Miami High relief Reef. Percent occurrence comparisons

between Shallow Assemblage Regions also showed patterns with latitude, where *S. partitus, T. bifasciatum, S. aurofrenatum,* and *A. bahianus* decreased in percent occurrence to the north and *H. aurolineatum, A. virginicus,* and *Diplodus holbrookii* increased (Figure 22). *Diplodus holbrookii* in particular showed an exaggerated pattern with < 7% frequency of occurrence in Broward-Miami and Palm Beach-Deerfield assemblage regions but > 71% frequency of occurrence in the Martin Assemblage Region.

The ANOSIM showed the greatest dissimilarity within the Deep reef fish strata between the South Palm Beach-Miami High relief Reef and the Martin Low relief Hardbottom. The SIMPER test showed an average dissimilarity of 89.16% in the assemblages between these two Deep reef fish strata (Table 11). Like in the Shallow reef fish strata, *S. partitus, T. bifasciatum, C. personatus, H. garnoti, S. aurofrenatum, A. bahianus* and *A. coeruleus* had a higher percentage of density in the South Palm Beach-Miami High relief Reef than in the Martin Low relief Hardbottom. In addition to the shared species, *Canthigaster rostrata, Chromis cyanea, Chromis insolata,* and *Clepticus parrae* were also present in higher densities in the south than in the north. Only *H. aurolineatum* and *H. bivittatus* shared spots with the shallow in the top 50% of species with higher densities in the northern than in the southern reef fish strata. In addition, *Centropristis striata* and *Balistes capriscus* were present in high densities in the Deep Martin Low relief Hardbottom sites than in the Deep South Palm Beach-Miami High relief Reef sites. Percent occurrence comparisons between Deep Assemblage Regions showed similar patterns with latitude (Figure 23). *Stegastes partitus*, *T. bifasciatum*, *H. garnoti* and *C. rostrata,* decreased in occurrence with latitude while *H. aurolineatum, C. striata*, *B. capriscus*, and *Caranx crysos* showed an increase in occurrence with latitude. *Centropristis striata* specifically had an exaggerated pattern with < 1% frequency of occurrence in Broward-Miami and Palm Beach-Deerfield assemblage regions and an > 58% frequency of occurrence in Martin Low and Martin High assemblage regions.

Table 10. *A summary of the SIMPER test performed on the transformed species density data on Shallow reef fish strata up to 52% cumulative percentage between the Broward-Miami High relief Reef sites and the Martin Low relief Hardbottom sites. For abbreviations, see*

Appendix **2***.*

Species	Group Broward-Miami Reef High Av.Abund	Group Martin Hardbottom Low Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
STE_PART	5.3	0.05	6.04	2.65	7.4	7.4
THA_BIFA	5.04	0.89	5.02	1.87	6.15	13.54
HAE_AURO	0.9	3.56	4.33	0.84	5.3	18.84
COR_PERS	3.94	0.05	4.03	1.01	4.93	23.77
SPA_AURO	2.69	0	3.18	2.65	3.89	27.66
HAE_SPE_	0.34	2.39	2.77	0.53	3.39	31.06
HAL_GARN	2.13	0	2.41	2.22	2.95	34.01
HAE_FLAV	2.32	0.24	2.38	0.98	2.92	36.93
HAL_BIVI	1.9	3.47	2.35	1.33	2.88	39.8
ACA_BAHI	2.37	1.08	2.24	1.47	2.74	42.55
ANI_VIRG	0.79	1.56	1.95	0.81	2.39	44.94
ACA_CHIR	1.16	1.36	1.83	1.12	2.24	47.18
ACA_COER	1.64	0.05	1.79	1.56	2.19	49.37
SCA_ISER	1.66	0.16	1.78	1.33	2.17	51.54

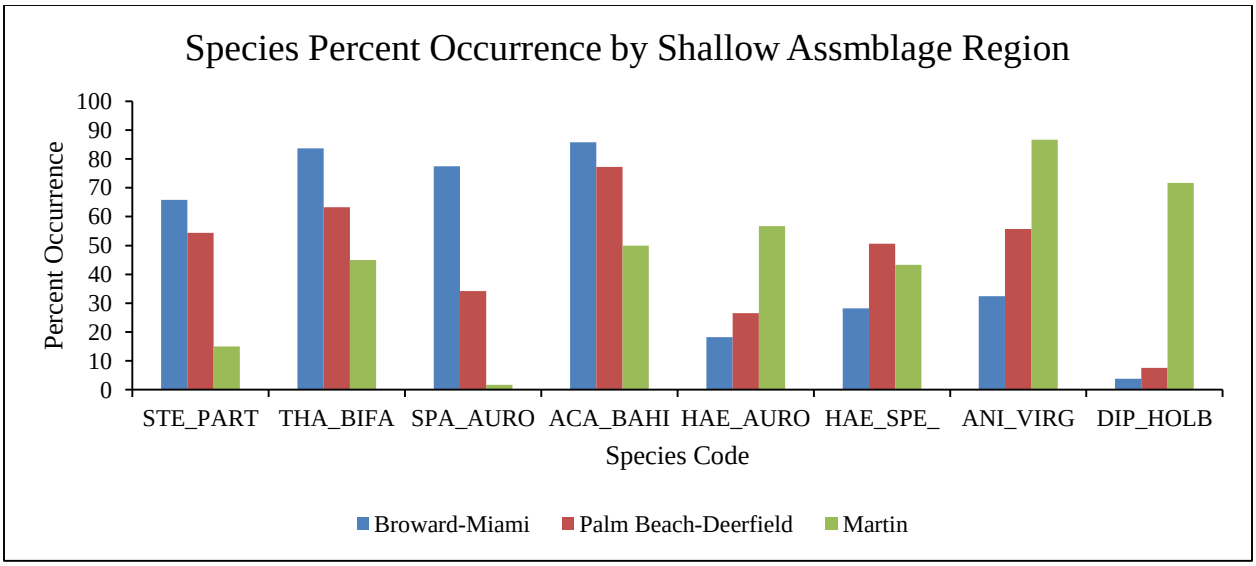


Figure 22. *Percent occurrence comparison between Shallow Assemblage Region for commonly occurring species. Species on the left occur more frequently in the southern assemblages while species on the right occur more frequently in the northern assemblages. For abbreviations, see Appendix 2.*

Table 11. *A summary of the SIMPER test performed on the transformed species density data on the Deep reef fish strata up to 51% cumulative percentage between the South Palm Beach-Miami High relief Reef and the Martin Low relief Hardbottom. For abbreviations, see Appendix* **2**

Species	Group South Palm Beach-Miami High Reef Av.Abund	Group Martin Low Hardbottom Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
STE_PART	6.61	0.91	7.67	2.35	8.6	8.6
THA_BIFA	4.91	0.73	5.52	1.82	6.19	14.79
COR_PERS	3.68	0	4.41	0.88	4.95	19.73
HAL_GARN	2.86	0.2	3.6	1.83	4.04	23.77
SPA_AURO	2.47	0.06	3.16	1.84	3.55	27.32
ACA_BAHI	2.11	0.21	2.64	1.39	2.96	30.28
CAN_ROST	1.86	0.33	2.11	1.65	2.37	32.65
HAE_AURO	0.53	1.55	2.08	0.66	2.34	34.98
ACA_CHIR	1.62	0.4	2.08	1.08	2.33	37.32
CHR_CYAN	1.66	0	1.97	0.91	2.21	39.53
CEN_STRI	0	1.23	1.68	0.77	1.88	41.41
ACA_COER	1.25	0	1.62	1.34	1.82	43.23
CHR_INSO	1.06	0.43	1.62	0.71	1.82	45.05
HAL_BIVI	0.5	1.17	1.6	1.02	1.8	46.85
CLE_PARR	1.53	0	1.58	0.56	1.77	48.62
BAL_CAPR	0.31	1.15	1.54	1.06	1.73	50.34

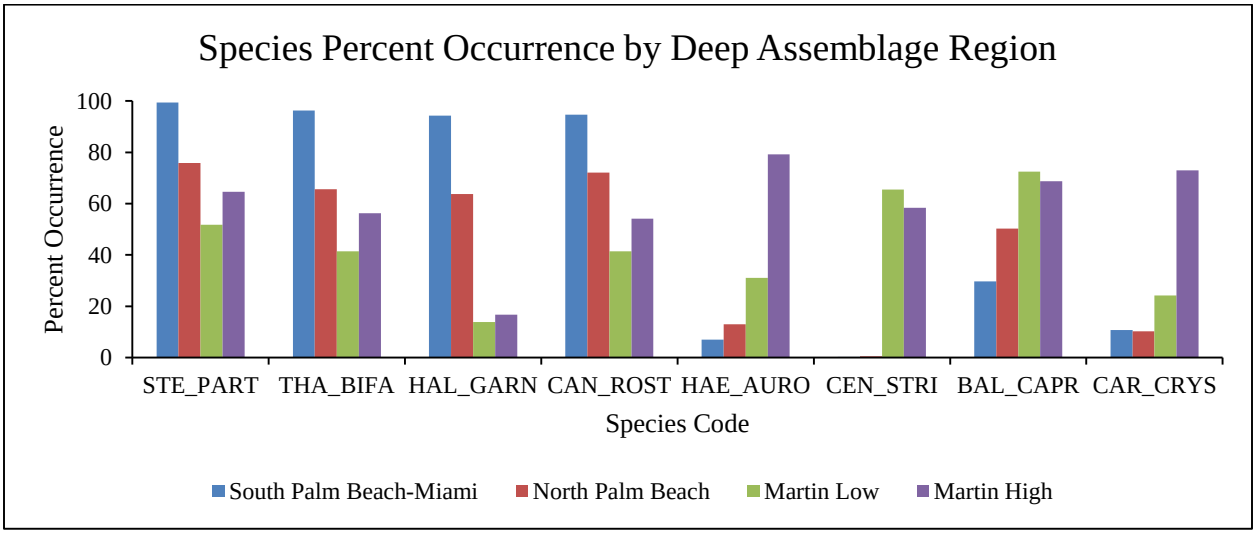


Figure 23. *Percent occurrence comparison between Deep Assemblage Regions for commonly occurring species. Species on the left occur more frequently in the southern assemblages while species on the right occur more frequently in the northern assemblages. For abbreviations, see Appendix 2.*

4.0 Discussion

This study defines biogeographic regions for coral reef fish assemblages in southeast Florida (Figure 24). Reef fish assemblages' species richness, distribution and density are structured by the regional pool of available species and the numerous factors that guide these species' ability to settle and persist (Ebeling and Hixon 1991; Sale 1980). The Florida Current provides the regional pool of planktonic larvae for the Florida Reef tract from upstream sources (Yeung and Lee 2002; Gilmore et al. 1981). Most reef fishes are dependent on the substrate for many purposes (avoiding predation, seeking nourishment, etc.) accordingly, the structure and makeup of the substrate will most likely influence the local assemblage (Luckhurst and Luckhurst 1978). Therefore, it is crucial to analyze the data at the finest habitat strata categorization possible to best comprehend the relationships with associated reef fish assemblages (Pittman, Costa, and Battista 2009; Walker, Jordan, and Spieler 2009). Reef fish distributions may not directly equate to the finest level of benthic habitat classification though and the numerous variables involved in determining the spatial relationships of reef fish sometimes complicate predicting and analyzing their distributions (Walker 2008). However, my study illustrates that analyses can be used to define statistically meaningful reef fish assemblage biogeography at a regional scale.

Depth was the first large-scale habitat strata which correlated highly with the reef fish assemblage structure along the southeast Florida Reef Tract (SE FRT) in this study and in others (Walker, Jordan, and Spieler 2009; Gilliam et al. 2014; Ferro, Jordan, and Spieler 2005). Correlations between fish assemblage attributes (i.e. density and/or species richness) and depth of habitat have also been documented on other coral reef habitats around the world (Gilmore et al. 1981; Aguilar-Perera and Appeldoorn 2008; Grober-Dunsmore et al. 2004; Luckhurst and Luckhurst 1978; Friedlander and Parrish 1998;

Newman and Williams 2001). Similar to the findings of Walker et al. (2009) and Ferro et al. (2005), my study found that fish assemblages were more variable in the shallow habitats and more tightly clustered in the deeper habitats. So, in order to eliminate the depth variable

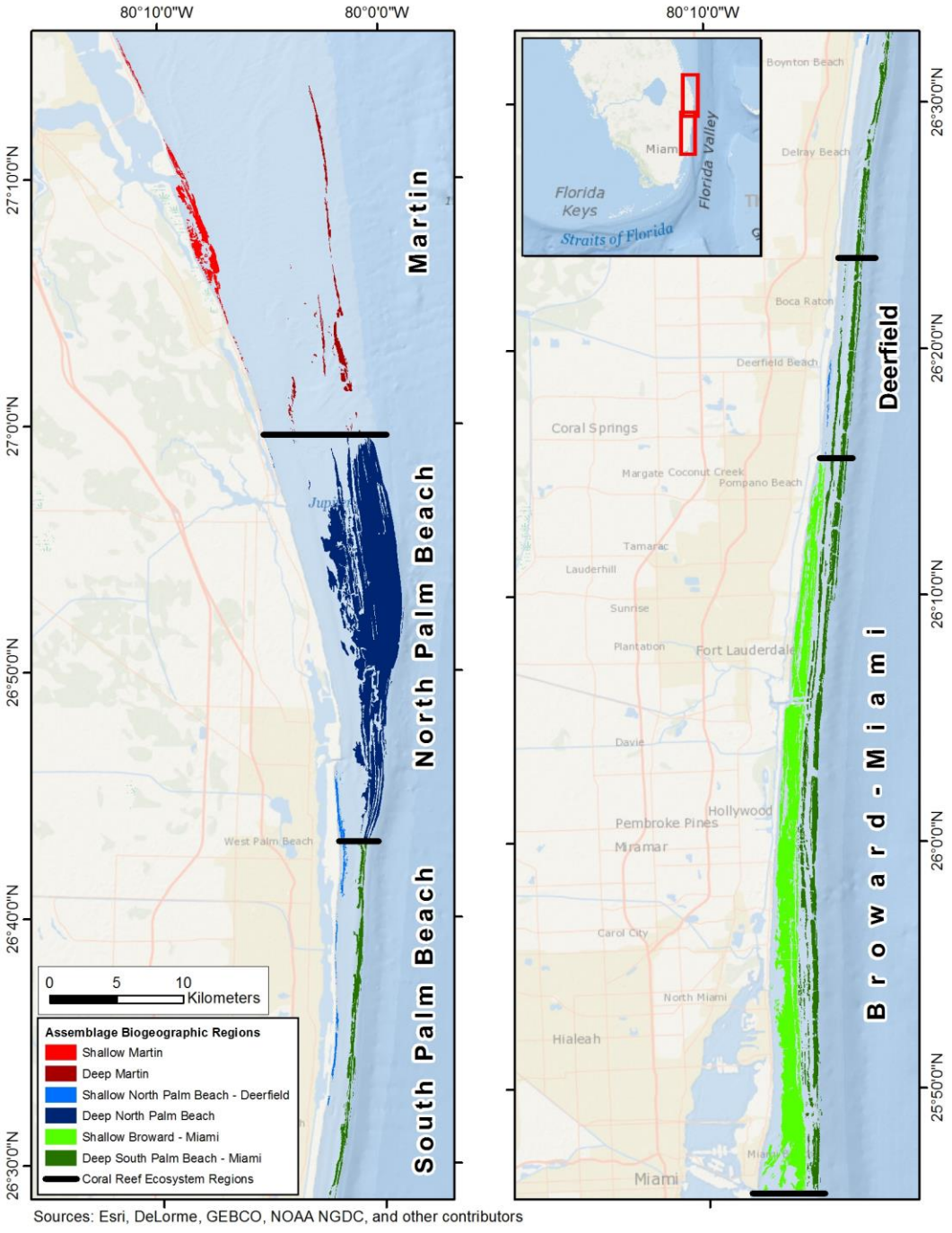


Figure 24. *Map of the Southeast Florida Reef Tract with Reef Fish Assemblage Biogeographic Regions indicated by color. Shallow sites are lighter shades and Deep sites are darker shades. The Coral Reef Ecoregions of Walker (2012) and Walker and Gilliam (2013) are labeled and divisions are indicated by dark bars.*

from obfuscating the analysis of reef fish assemblage biogeographic regions, the data in this study were initially analyzed separately by shallow (< 10 m) and deep (10 – 33 m) habitats. After determining the shallow and deep assemblage regions, the data were combined to analyze the relative importance of depth. While strong differences between depths within similar regions were present, the latitudinal differences in assemblages, regardless of depth, were stronger.

Along the SE FRT, the amount and extent of distinct benthic habitats attenuates northward (Walker 2012) and the benthic macroalgal (Lapointe 2007) and coral (Walker and Gilliam 2013; Moyer et al. 2003) assemblages vary with latitude as well. The data from the present study show the fish assemblages of the SE FRT also vary with latitude. Many studies have related habitat structure to the structure of the reef fish assemblages (Jones and Syms 1998; Tuya, Wernberg, and Thomsen 2011; Friedlander and Parrish 1998). Since habitat type greatly affects the assemblage structure, the presence or absence of habitat in a region helped define the reef fish assemblage biogeography of the SE FRT. The primary shallow reef habitat, the Linear Reef-Inner, runs along the entire near-shore shelf in the Broward-Miami Coral Reef Ecoregion terminating approximately at the Hillsboro inlet (Banks et al. 2008; Walker 2012). The Broward-Miami Assemblage Region was the only shallow region to contain both Reef and Hardbottom habitats. The shallow habitats north of Hillsboro inlet were found to be formed by processes other than historical organic reef growth (i.e. exposed rock outcrops, karstified terrains, etc.) (Banks et al. 2008; Walker, Riegl, and Dodge 2008; Finkl and Andrews 2008) so they were considered Hardbottom. Similarly, the deep reef habitats, the Linear Reef-Middle and Linear Reef-Outer, are present only in the three southern coral reef ecoregions (Walker 2012). The combination of the reef fish assemblages of the southern three coral reef ecoregions into one South Palm

Beach-Miami Assemblage Region corresponded to the presence of mapped reef and hardbottom habitats.

The correlation of relief with a range of coral reef fish metrics in coral reef ecosystems has been documented and spans multiple habitats and/or depths (Luckhurst and Luckhurst 1978; Friedlander and Parrish 1998; Pittman et al. 2007; Pittman, Costa, and Battista 2009; Walker, Jordan, and Spieler 2009; Parrish, Callahan, and Norris 1985). Intricacies in substrate can provide many benefits to a variety of reef fishes. Live coral and other invertebrates living in the substrate can serve as a food source for some fish (Friedlander and Parrish 1998; Parrish, Callahan, and Norris 1985) while the structural complexity can serve as protection from physical or predatory stress (Hixon 1991). The strongest difference in assemblages between low and high relief was between the Martin Low and Martin High assemblage regions where the Martin Low sites exhibited lower density and richness than the Martin High sites. In all other assemblage regions, relief did not play a significant role in differentiating assemblage biogeography. While the general habitat and relief helped to parse out the differences in the assemblage regions, they did not fully explain the strong latitudinal differences between the assemblage regions.

Along continental coasts, north-south faunal latitudinal boundaries fluctuate as warm-temperate and cold-temperate regions overlap in zones of transition. In these zones species of different faunas mingle to various extents depending on yearly shifts in the oceanographic climate (Ebeling and Hixon 1991). Variation in thermal regimes—either seasonal or with depth—may enhance local diversity in transitional zones between temperate and subtropical waters by promoting the co-occurrence of cool and warm water species (Stephens and Zerba 1981). Southeast Florida is located at the convergence of the subtropical and temperate climate zones (Chen and Gerber 1990; Lugo et al. 1999). Prior studies of the benthos have found that the assemblages of the SE FRT show a substantial decrease in the number of tropical coral species and a relative dominance of cold-tolerant coral species in the northern assemblages (Martin County) (Walker and Gilliam 2013). The authors found that the shift in benthic assemblages was explained by differences in

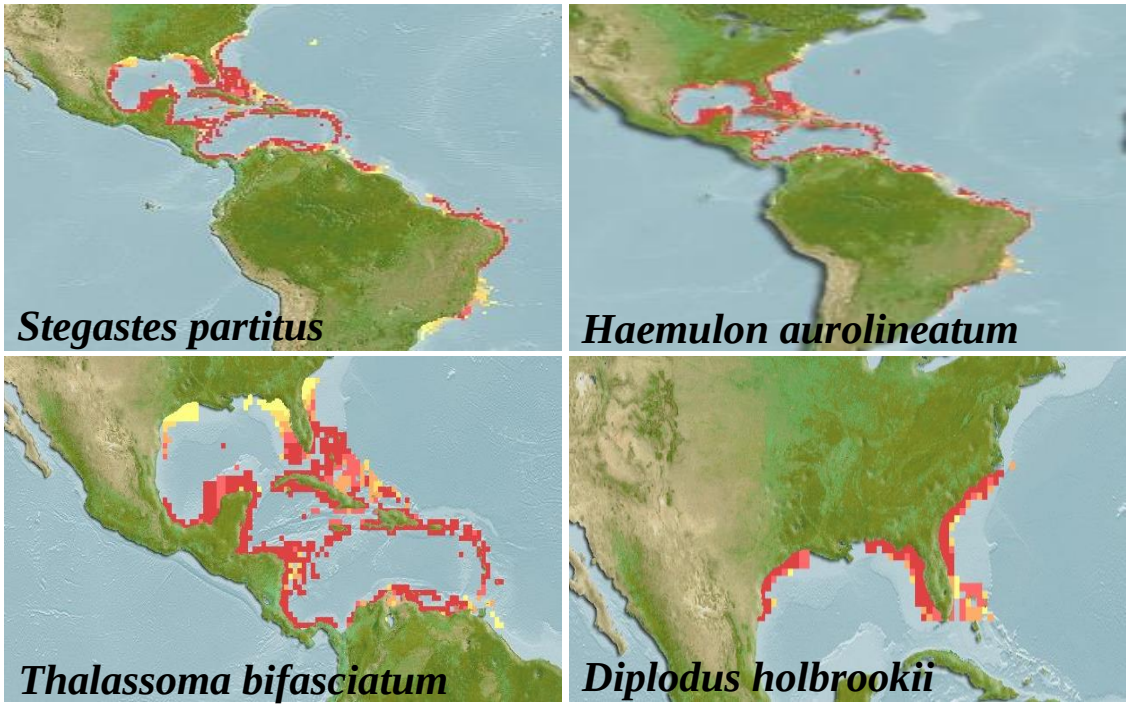
temperature regimes along the southeast Florida coast. Analyses of bottom temperature differences along the reef tract showed significant cold-water upwelling occurs more frequently and with higher intensity in the regions north of an area referred to as the Bahamas Fracture Zone (BFZ) (Walker, Gilliam, and Gramer, in prep), a geological feature that coincides with the end of historical outer reef growth and where the Florida Current diverges from the coast (Klitgord, Popenoe, and Schouten 1984). The division between the deep South Palm Beach-Miami and the North Palm Beach assemblage regions is situated along the BFZ, above which, the continental shelf widens and the Florida Current diverges from the coast. This divergence carries the warm tropical waters into the Gulf Stream and boundary eddies form causing the frequent episodes of cold water upwelling (Walker and Gilliam 2013). In my study, the deep assemblages south of the BFZ were more similar to each other while the assemblages north of the BFZ were separate from the southern assemblages and widely dispersed indicating they were highly variable in species composition and density.

Among the deep assemblages, the southernmost Broward-Miami Assemblage Region and the northernmost Martin High Assemblage Region contained similar fish density but the number of species was significantly lower in the Martin High sites. The shallow assemblage regions also showed a significant decrease in species richness between the Broward-Miami sites and the Martin sites. My results of increasing species richness with decreasing latitude agree with previous studies (Ebeling and Hixon 1991; Willig, Kaufman, and Stevens 2003; Macpherson 2002; Walker 2012; Moyer et al. 2003; Stephens and Zerba 1981). This is not surprising since fish diversity can be related to coral diversity (Smith, Chave, and Kam 1973), and Walker and Gilliam (2013) found that coral species richness decreased poleward along the coast. Furthermore, in a study of the fishes of Palm Beach County performed between 1997 and 2007, more species were recorded in the southern half of the county than in the northern half with the most frequently occurring species differing markedly between the two as well (Banks et al. 2008).

This latitudinal decrease in the richness of the assemblages of tropical fauna may be due to a decrease in the level of environmental variability through which reef species are able to survive and persist (Ebeling and Hixon 1991; Stephens and Zerba 1981). Tropical to temperate latitudinal differences in reef fish assemblages have been reported along the northern coast of Florida in the Indian river lagoon system (Gilmore et al. 1981). While their study includes inland habitats and assemblages north of the present study area, Gilmore et al. (1981) note that the warm-temperate Carolinian and the tropical Caribbean fish faunas overlap considerably in the east central aquatic fish assemblages they studied. They propose that the fishes of the Indian river lagoon region in east central Florida originated in the Caribbean faunal province and apparently came into the region via the Florida Current while the warm-temperate Carolinian fishes distribution must be explained by adult migration with some aid from larval fishes transported via southbound counter-currents of the Florida Current and other inshore water mass movements (Gilmore et al. 1981). My study demonstrates that the transition between these two climate zones within the ichthyofaunal assemblages is present in habitats further south than the Gilmore et al. (1981) study covered. Typical coral reef fishes live among existing coral in relatively shallow tropical water where temperatures rarely drop below 20°C (Ebeling and Hixon 1991). Over the course of a two year study, the temperature recorded in Martin County was below 20°C for about 2100 hours whereas the temperature recorded in the southern areas of the SE FRT was below 20°C for approximately 300 hours (Walker, Gilliam, and Gramer, *in prep*). This temperature regime difference is likely affecting the assemblage constituents.

Examples of known ranges (Www.aquamaps.org 2013) for some of the species driving the differences in assemblages between the southernmost Shallow Broward-Miami and Deep South Palm Beach-Miami assemblage regions and the northernmost Shallow Martin, Deep Martin Low and High assemblage regions are displayed in Figure 25. The species found in high densities at the northernmost sites (right) have ranges that extend much farther north indicating they live in a broader range of colder water temperatures. The ranges of the species found in much higher densities farther south (left) diminish rapidly to the north indicating they are less tolerant of colder conditions (i.e. more tropical).

For example, two of the species that have higher densities in the Shallow Martin, Deep Martin Low and High assemblage regions, *Haemulon aurolineatum* (tomtate grunt) and *Diplodus holbrookii* (spottail seabream), are found from 43° N to 33° S and 40° N to 20° N respectively whereas two of the species with higher densities in the South Palm Beach, and Broward-Miami assemblage regions, *Thalassoma bifasciatum* (bluehead) and



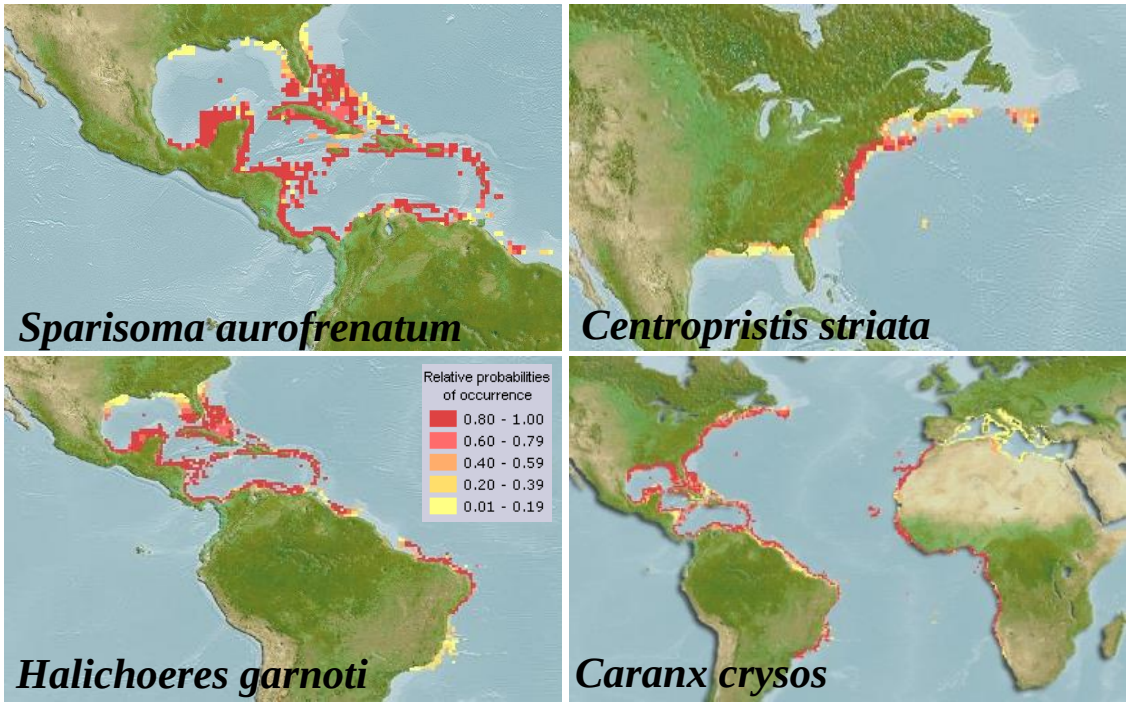


Figure 25. *Examples of known ranges for some of the species driving the differences in assemblages between the southernmost Broward-Miami region and the northernmost Martin region* (Www.aquamaps.org 2013).

Sparisoma aurofrenatum (redband parrotfish) are only found 33° N to 8° N and 32° N to 7° N respectively (Robins and Ray 1986). One species, *Centropristis striata* (black seabass), was observed 47 times in the Deep Martin Low and High assemblage regions combined and only three times in the North Palm Beach and South Palm Beach-Miami assemblage regions combined. The black seabass is described as a temperate fish with a range from Maine to northeastern Florida that can reach extreme southern Florida during cold winters (Robins and Ray 1986). Interestingly, none of the samples were conducted in winter, but cold-water upwelling is known to occur.

Sea surface temperatures along the world's major coastlines decrease with increasing latitude. Sea Surface temperatures are expected to rise over the next century (Pratchett et al. 2011; Munday et al. 2007; Booth, Bond, and MacReadie 2011; Fodrie et al. 2010; Hobday and Lough 2011). Baumann and Doherty (2013) demonstrate how these

large scale thermoclines along the continental coasts have changed over the past three decades. This has direct influence on the ability of fish species to live at different latitudes because water temperature is one of the most important abiotic factors influencing fish geographic distribution (Baumann and Doherty 2013; Fodrie et al. 2010; Booth, Bond, and MacReadie 2011). As noted above, many of the reef fish dominating the southern regions of the SE FRT have ranges that do not span as far into the more temperate northern latitudes than those found in the northern regions. If the warm sea surface temperatures move north as predicted, there could be an increase in opportunities for more tropical warm-water species to survive in the northern portions of the SE FRT and a shift in the center of biomass of tropical species could occur (Baumann and Doherty 2013; Perry et al. 2005; Holbrook, Schmitt, and Stephens 1997; Nye et al. 2009). Studies of marine and coastal studies at middle and high latitudes have suggested biogeographical shifts are possible with locally increased numbers of warm-water species and decreased numbers of cold-water species (Perry et al. 2005; Weinberg, Dahlgren, and Halanych 2002; Precht and Aronson 2004; Nye et al. 2009). Perry et al. (2005) for example, found that the latitudinal boundaries of roughly half of the species they studied in the North Sea moved significantly northward with warming ocean temperatures. Likewise, Nye et al. (2009) demonstrated clear shifts in spatial distribution in 24 of the 36 fish stocks they examined on the continental shelf of the northeastern United States. This shift in specific species' boundaries could lead to a shift in the species composition and relative density in local assemblages to those able to better adapt to warmer water temperatures (Holbrook, Schmitt, and Stephens 1997). Figueira and Booth (2010) demonstrated that the ability of four commonly occurring species of tropical pacific damselfishes to overwinter at temperate latitudes increases with increasing average winter temperatures. With the frequency of warm winters increasing, the possibility grows for poleward populations of certain reef fish species to become established year-round (Figueira and Booth 2010). Tropical species poleward range expansion have been suggested for corals (Precht and Aronson 2004) along the FRT but thus far contemporary range expansions for fish or corals have yet to be documented.

"For a species to expand its present range the new area must meet a minimum set of biophysical requirements" (Figueira and Booth 2010). Thus, a holistic approach is needed to look at the changes in reef fish distribution as these changes may also be influenced by variations in the distribution and density of other organisms that also live on and around coral reefs and might follow the corals' migration poleward as well as habitat like mangroves for nurseries (Nye et al. 2009). The study of local systems is important to understanding how fish will respond to global temperature changes because local controls will ultimately dictate their potential distribution. The availability of suitable habitat may drastically restrict a shift in species range (Munday et al. 2007). The unique geomorphology of Florida, for example, could prevent projected range shifts from occurring along the eastern seaboard. Walker (2012) proposed that poleward expansions of tropical systems on the coast of Florida may be limited by the present habitat geomorphology and hydrography. Walker and Gilliam (2013) suggested that the frequent cold water upwelling events may be affecting the northernmost benthic communities. The unique local geomorphology may have been controlling the northern limit of coral reef growth since the Holocene (Walker and Gilliam 2013; Walker, Gilliam, and Gramer, *in prep*) when temperatures were similarly warm (Ziegler et al. 2008). It is possible that if the Florida current continues to pull the warm water offshore and the cold-water upwelling persists, a temperature boundary will continue to limit the range expansion of the more tropical Caribbean reef fishes. My study provides a baseline for future comparisons of global climate change's effects on the fish assemblages of the SE FRT. A long term continuation of this study will be necessary to determine if the more warm-water tolerant species that dominate the assemblages of the southern assemblage regions will settle in the northern assemblage regions in higher densities with warming waters.

The Assemblage Regions match with the Coral Reef Ecoregions of Walker (2012) and Walker and Gilliam (2013) in some ways and not in others. One big distinction is that the Assemblage Regions vary by habitat depth. The Shallow Broward-Miami Assemblage Region aligns with the Broward-Miami Ecoregion and the Martin Assemblage Region aligns with the Martin Ecoregion. The Deep South Palm Beach – Miami Assemblage

Region spans the Broward-Miami, Deerfield, and South Palm Beach Ecoregions, yet it transitions at the BFZ similar to the South Palm Beach Ecoregion. The Deep North Palm and Deep Martin assemblage regions match the North Palm and Martin Ecoregions. The Coral Reef Ecoregions were not defined by one particular species or group, thus it is not surprising that certain groups conform in some places and not others. Klug (2015) found that in the shallow habitats, coral communities and benthic cover supported the Biscayne and Broward-Miami separation. A comprehensive regional benthic assessment has yet to be conducted on a scale that would facilitate a similar benthic analyses as those conducted herein. It is possible that some major benthic functional groups (corals, algae, gorgonian) are arranged similar to the Reef Fish Assemblage Regions defined herein.

5.0 Conclusions

In conclusion, this study defines seven new reef fish assemblage biogeographic regions. The three shallow, Broward-Miami, Palm Beach-Deerfield and Martin, and four deep, South Palm Beach-Miami, North Palm Beach, and Martin Low and Martin High, assemblage regions are defined by differences in assemblage structure. The structures of the assemblages were driven by a higher concentration of more cold-tolerant species in the northern latitudes and a more tropical species dominance in the southern latitudes of the Southeast Florida Reef Tract (SE FRT). The Bahamas Fracture Zone (BFZ) appears to play an important role in shaping the local communities. The frequent upwelling events that occur north of the BFZ coincide with the poleward limit of tropical species. The study of local systems is important to understanding how coral reefs will respond to global temperature changes because local controls will ultimately dictate their potential distribution. Even if sea surface temperatures along the coast increase, the BFZ might impede a range shift along the SE FRT.

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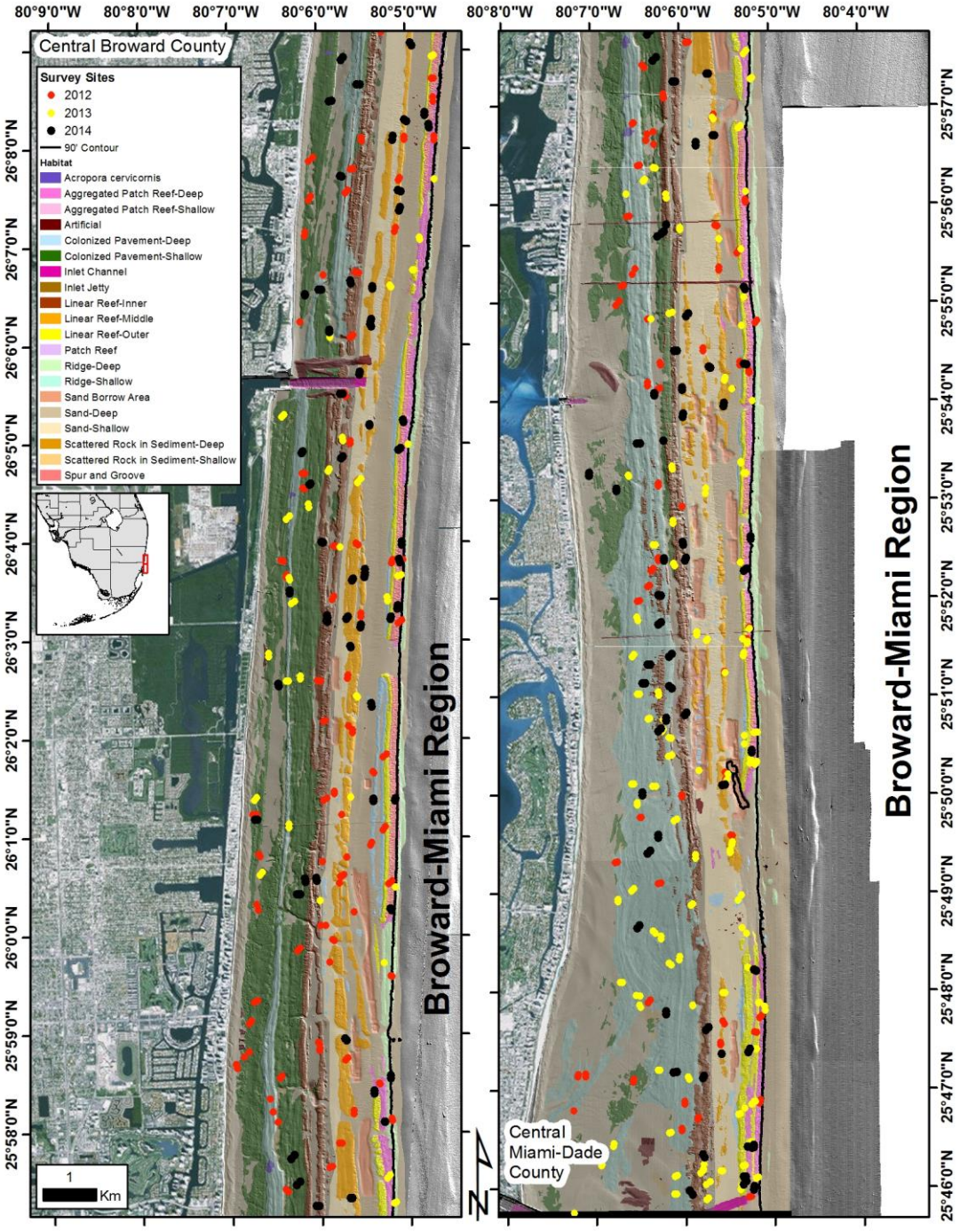
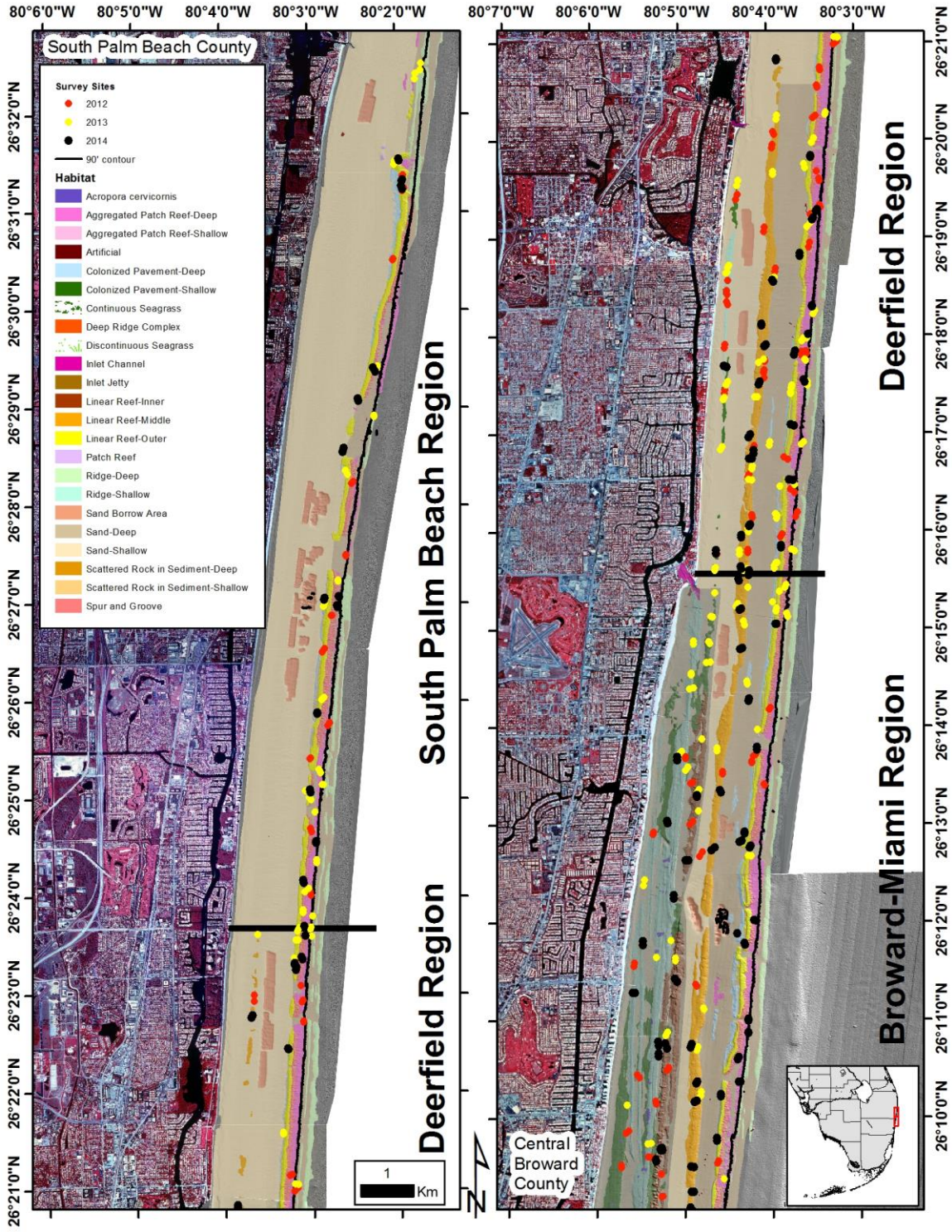
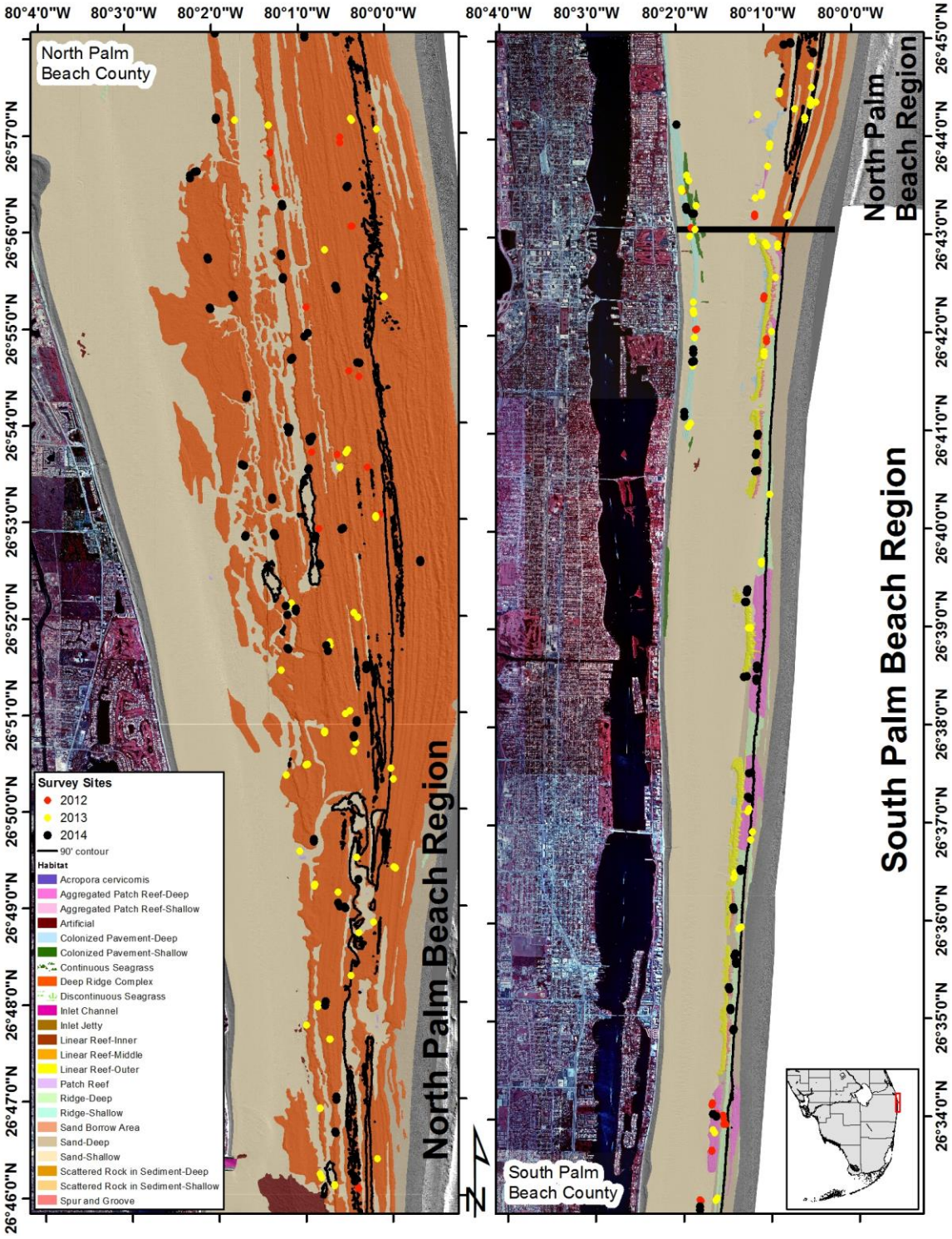
Appendices

Appendix 1. *Maps of locations of all study sites. Red dots indicate sites sampled in 2012, yellow dots indicate sites sampled in 2013 and black dots indicate sites sampled in 2014.*




South Palm Beach County
Survey Sites
2012
2013
2014
90' contour
Habitat
Acropora cervicornis
Aggregated Patch Reef-Deep
Aggregated Patch Reef-Shallow
Artificial
Colonized Pavement-Deep
Colonized Pavement-Shallow
Continuous Seagrass
Deep Ridge Complex
Discontinuous Seagrass
Inlet Channel
Inlet Jetty
Linear Reef-Inner
Linear Reef-Middle
Linear Reef-Outer
Patch Reef
Ridge-Deep
Ridge-Shallow
Sand Borrow Area
Sand-Deep
Sand-Shallow
Scattered Rock in Sediment-Deep
Scattered Rock in Sediment-Shallow
Spur and Groove
South Palm Beach Region
Deerfield Region
Deerfield Region
Broward-Miami Region
Central Broward County
1 Km
N
80°6'0"W
80°5'0"W
80°4'0"W
80°3'0"W
80°2'0"W
80°7'0"W
80°6'0"W
80°5'0"W
80°4'0"W
80°3'0"W
26°32'0"N
26°31'0"N
26°30'0"N
26°29'0"N
26°28'0"N
26°27'0"N
26°26'0"N
26°25'0"N
26°24'0"N
26°23'0"N
26°22'0"N
26°21'0"N
26°21'0"N
26°20'0"N
26°19'0"N
26°18'0"N
26°17'0"N
26°16'0"N
26°15'0"N
26°14'0"N
26°13'0"N
26°12'0"N
26°11'0"N
26°10'0"N


North Palm Beach County
North Palm Beach Region
South Palm Beach Region
South Palm Beach County
Survey Sites
2012
2013
2014
90' contour
Habitat
Acropora cervicornis
Aggregated Patch Reef-Deep
Aggregated Patch Reef-Shallow
Artificial
Colonized Pavement-Deep
Colonized Pavement-Shallow
Continuous Seagrass
Deep Ridge Complex
Discontinuous Seagrass
Inlet Channel
Inlet Jetty
Linear Reef-Inner
Linear Reef-Middle
Linear Reef-Outer
Patch Reef
Ridge-Deep
Ridge-Shallow
Sand Borrow Area
Sand-Deep
Sand-Shallow
Scattered Rock in Sediment-Deep
Scattered Rock in Sediment-Shallow
Spur and Groove
80°4'0"W
80°3'0"W
80°2'0"W
80°1'0"W
80°0'0"W
26°57'0"N
26°56'0"N
26°55'0"N
26°54'0"N
26°53'0"N
26°52'0"N
26°51'0"N
26°50'0"N
26°49'0"N
26°48'0"N
26°47'0"N
26°46'0"N
26°45'0"N
26°44'0"N
26°43'0"N
26°42'0"N
26°41'0"N
26°40'0"N
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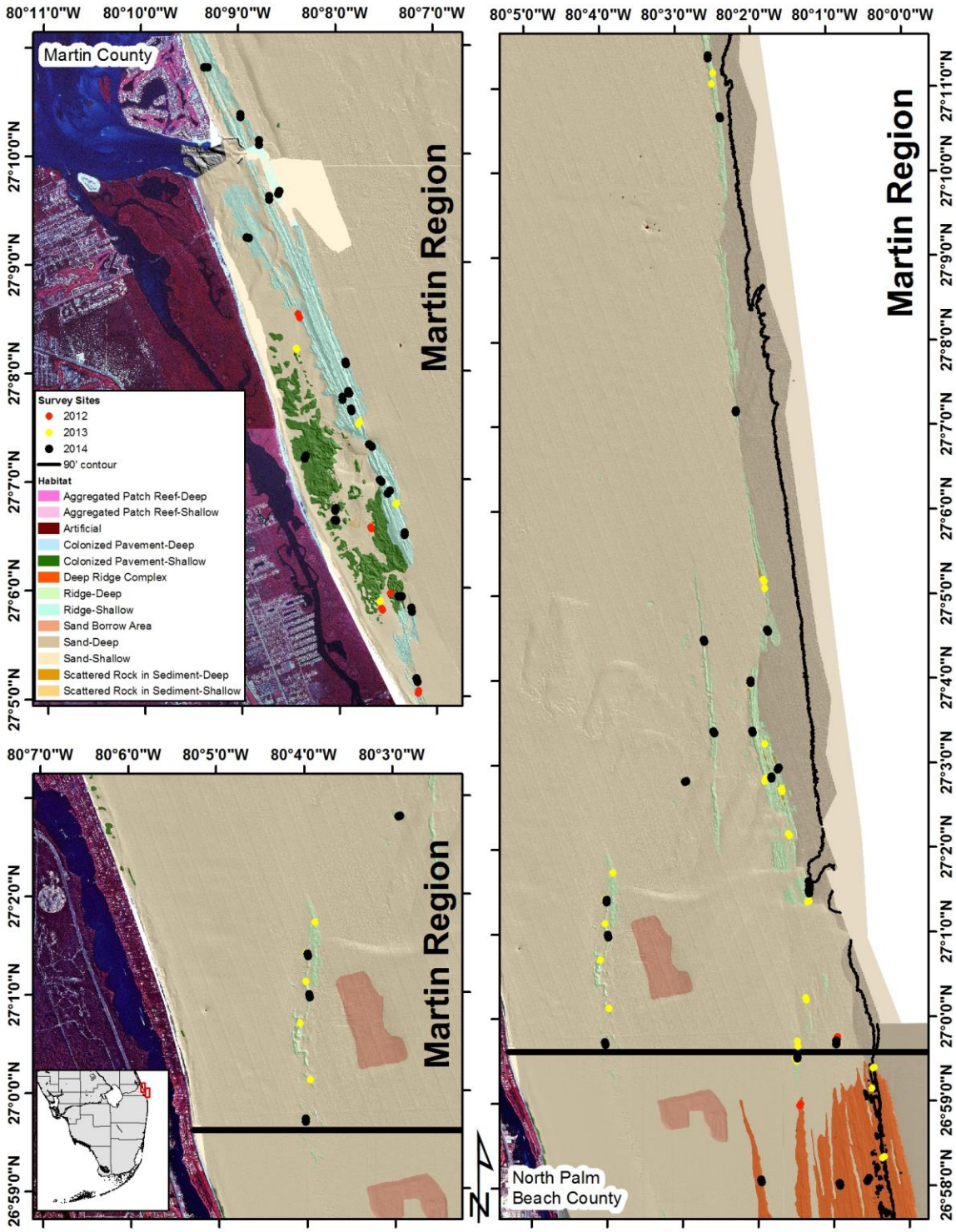
26°38'0"N
26°37'0"N
26°36'0"N
26°35'0"N
26°34'0"N


Martin County
Martin Region
Survey Sites
2012
2013
2014
90' contour
Habitat
Aggregated Patch Reef-Deep
Aggregated Patch Reef-Shallow
Artificial
Colonized Pavement-Deep
Colonized Pavement-Shallow
Deep Ridge Complex
Ridge-Deep
Ridge-Shallow
Sand Borrow Area
Sand-Deep
Sand-Shallow
Scattered Rock in Sediment-Deep
Scattered Rock in Sediment-Shallow
Martin Region
Martin Region
North Palm
Beach County
N

Appendix 2. *All observed species listed alphabetically by family name. Species codes were created using the first three letters from the genus and the first four letters from the species. *Species that were removed for multivariate tests in PRIMER and all richness calculations. **Species that were removed for all richness calculations.*

	Species Code	Scientific Name	Common Name	Family Name
	ACA BAHI	*Acanthurus bahianus*	Ocean Surgeon	Acanthuridae
	ACA CHIR	*Acanthurus chirurgus*	Doctorfish	Acanthuridae
	ACA COER	*Acanthurus coeruleus*	Blue Tang	Acanthuridae
*	ACA SPE.	*Acanthurus* sp.	Surgeonfish species	Acanthuridae
	APO BINO	*Apogon binotatus*	Barred Cardinalfish	Apogonidae
	APO MACU	*Apogon maculatus*	Flamefish	Apogonidae
	APO PSEU	*Apogon pseudomaculatus*	Twospot Cardinalfish	Apogonidae
	APO QUAD	*Apogon quadrisquamatus*	Sawcheek Cardinalfish	Apogonidae
	APO TOWN	*Apogon townsendi*	Belted Cardinalfish	Apogonidae
*	AST SPE.	*Astrapogon* sp.	Cardinalfish species	Apogonidae
	AUL MACU	*Aulostomus maculatus*	Atlantic Trumpetfish	Aulostomidae
	BAL CAPR	*Balistes capriscus*	Gray Triggerfish	Balistidae
	BAL VETU	*Balistes vetula*	Queen Triggerfish	Balistidae
	CAN SUFF	*Canthidermis sufflamen*	Ocean Triggerfish	Balistidae
	MEL NIGE	*Melichthys niger*	Black Durgon	Balistidae
	OPS TAU.	*Opsanus tau*	Oyster Toadfish	Batrachoididae
*	BLE SPE.	*Blenniidae* sp.	Blenny species	Blenniidae
	HYP BERM	*Hypleurochilus bermudensis*	Barred Blenny	Blenniidae
	OPH MACC	*Ophioblennius macclurei*	Redlip Blenny	Blenniidae
	PAR MARM	*Parablennius marmoreus*	Seaweed Blenny	Blenniidae
	SCA CRIS	*Scartella cristata*	Molly Miller	Blenniidae
	BOT LUNA	*Bothus lunatus*	Peacock Flounder	Bothidae
	BOT OCEL	*Bothus ocellatus*	Eyed Flounder	Bothidae
	STY LATE	*Stygnobrotula latebricola*	Black Brotula	Bythitidae
	PAR BAIR	*Paradiplogrammus bairdi*	Lancer Dragonet	Callionymidae
	ALE CILI	*Alectis ciliaris*	African Pompano	Carangidae
	CAR BART	*Caranx bartholomaei*	Yellow Jack	Carangidae
	CAR CRYS	*Caranx crysos*	Blue Runner	Carangidae
	CAR HIPP	*Caranx hippos*	Crevalle Jack	Carangidae
	CAR LATU	*Caranx latus*	Horse-Eye Jack	Carangidae
	CAR LUGU	*Caranx lugubris*	Black Jack	Carangidae
	CAR RUBE	*Caranx ruber*	Bar Jack	Carangidae
*	CAR SPE.	*Caranx* sp.	Jack species	Carangidae

Appendix 2 continued

	CHL CHRY	*Chloroscombrus chrysurus*	Atlantic Bumper	Carangidae
	DEC MACA	*Decapterus macarellus*	Mackerel Scad	Carangidae
	DEC PUNC	*Decapterus punctatus*	Round Scad	Carangidae
*	DEC SPE.	*Decapterus* sp.	Jack species	Carangidae
	ELA BIPI	*Elagatis bipinnulata*	Rainbow Runner	Carangidae
	OLI SAUR	*Oligoplites saurus*	Leatherjack	Carangidae
	SER DUME	*Seriola dumerili*	Greater Amberjack	Carangidae
	SER RIVO	*Seriola rivoliana*	Almaco Jack	Carangidae
*	SER SPE.	*Seriola* sp.	Jack species	Carangidae
	SER ZONA	*Seriola zonata*	Banded Rudderfish	Carangidae
	TRA FALC	*Trachinotus falcatus*	Permit	Carangidae
	TRA GOOD	*Trachinotus goodei*	Palometa	Carangidae
	TRA LATH	*Trachurus lathami*	Rough Scad	Carangidae
	CAR LEUC	*Carcharhinus leucas*	Bull Shark	Carcharhinidae
	CAR PERE	*Carcharhinus perezii*	Reef Shark	Carcharhinidae
	GAL CUVI	*Galeocerdo cuvier*	Tiger Shark	Carcharhinidae
	NEG BREV	*Negaprion brevirostris*	Lemon Shark	Carcharhinidae
	CEN UNDE	*Centropomus undecimalis*	Common Snook	Centropomidae
	ACA ASPE	*Acanthemblemaria aspera*	Roughhead Blenny	Chaenopsidae
	ACA MARI	*Acanthemblemaria maria*	Secretary Blenny	Chaenopsidae
	CHA LIMB	*Chaenopsis limbaughi*	Yellowface Pikeblenny	Chaenopsidae
	EMB PAND	*Emblemaria pandionis*	Sailfin Blenny	Chaenopsidae
	HEM SIMU	*Hemiemblemaria simula*	Wrasse Blenny	Chaenopsidae
	CHA CAPI	*Chaetodon capistratus*	Foureye Butterflyfish	Chaetodontidae
	CHA OCEL	*Chaetodon ocellatus*	Spotfin Butterflyfish	Chaetodontidae
	CHA SEDE	*Chaetodon sedentarius*	Reef Butterflyfish	Chaetodontidae
	CHA STRI	*Chaetodon striatus*	Banded Butterflyfish	Chaetodontidae
	PRO ACUL	*Prognathodes aculeatus*	Longsnout Butterflyfish	Chaetodontidae
	AMB PINO	*Amblycirrhitus pinos*	Redspotted Hawkfish	Cirrhitidae
**	JEN SPE.	*Jenkinsia spp.*	Herring species	Clupeidae
	SAR AURI	*Sardinella aurita*	Spanish Sardine	Clupeidae
	HET LONG	*Heteroconger longissimus*	Brown Garden Eel	Congridae
	DAC VOLI	*Dactylopterus volitans*	Flying Gurnard	Dactylopteridae
	DAS AMER	*Dasyatis americana*	Southern Stingray	Dasyatidae
	CHI ANTE	*Chilomycterus antennatus*	Bridled Burrfish	Diodontidae
	CHI ATIN	*Chilomycterus atinga*	Spotted Burrfish	Diodontidae
	CHI SCHO	*Chilomycterus schoepfii*	Striped Burrfish	Diodontidae

Appendix 2 continued

	DIO HOLO	*Diodon holocanthus*	Balloonfish	Diodontidae
	DIO HYST	*Diodon hystrix*	Porcupinefish	Diodontidae
*	DIO SPE.	*Diodon* sp.	Puffer species	Diodontidae
	ECH NAUC	*Echeneis naucrates*	Sharksucker	Echeneidae
	ECH NEUC	*Echeneis neucratoides*	Whitefin Sharksucker	Echeneidae
	REM REMO	*Remora remora*	Remora	Echeneidae
*	ELA SPE.	*Charcharhinidae* sp.	Shark species	Elasmobranchiomorphi
	ANC LYOL	*Anchoa lyolepis*	Dusky Anchovy	Engraulidae
	CHA FABE	*Chaetodipterus faber*	Atlantic Spadefish	Ephippidae
	FIS TABA	*Fistularia tabacaria*	Bluespotted Cornetfish	Fistulariidae
	EUC LEFR	*Eucinostomus lefroyi*	Mottled Mojarra	Gerreidae
	GER CINE	*Gerres cinereus*	Yellowfin Mojarra	Gerreidae
	GIN CIRR	*Ginglymostoma cirratum*	Nurse Shark	Ginglymostomatidae
	COR DICR	*Coryphopterus dicrus*	Colon Goby	Gobiidae
	COR EIDO	*Coryphopterus eidolon*	Pallid Goby	Gobiidae
	COR GLAU	*Coryphopterus glaucofraenum*	Bridled Goby	Gobiidae
	COR LIPE	*Coryphopterus lipernes*	Peppermint Goby	Gobiidae
	COR PERS	*Coryphopterus personatus*	Masked Goby	Gobiidae
*	COR SPE.	*Coryphopterus* sp.	Goby species	Gobiidae
	CTE SAEP	*Ctenogobius saepepallens*	Dash Goby	Gobiidae
	ELA EVEL	*Elacatinus evelynae*	Sharknose Goby	Gobiidae
	ELA HORS	*Elacatinus horsti*	Yellowline Goby	Gobiidae
	ELA OCEA	*Elacatinus oceanops*	Neon Goby	Gobiidae
	ELA XANT	*Elacatinus xanthiprora*	Yellowprow Goby	Gobiidae
	GNA THOM	*Gnatholepis thompsoni*	Goldspot Goby	Gobiidae
*	GOB SPE.	*Gobiidae* sp.	Goby species	Gobiidae
	MIC CARR	*Microgobius carri*	Seminole Goby	Gobiidae
	PRI HIPO	*Priolepis hipoliti*	Rusty Goby	Gobiidae
	ANI SURI	*Anisotremus surinamensis*	Black Margate	Haemulidae
	ANI VIRG	*Anisotremus virginicus*	Porkfish	Haemulidae
	HAE ALBU	*Haemulon album*	Margate	Haemulidae
	HAE AURO	*Haemulon aurolineatum*	Tomtate	Haemulidae
	HAE CARB	*Haemulon carbonarium*	Caesar Grunt	Haemulidae
	HAE CHRY	*Haemulon chrysargyreum*	Smallmouth Grunt	Haemulidae
	HAE FLAV	*Haemulon flavolineatum*	French Grunt	Haemulidae
	HAE MACR	*Haemulon macrostomum*	Spanish Grunt	Haemulidae
	HAE MELA	*Haemulon melanurum*	Cottonwick	Haemulidae

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	HAE PARR	*Haemulon parra*	Sailors Choice	Haemulidae
	HAE PLUM	*Haemulon plumierii*	White Grunt	Haemulidae
	HAE SCIU	*Haemulon sciurus*	Bluestriped Grunt	Haemulidae
**	HAE SPE.	*Haemulon* sp.	Juvenile mixed grunts	Haemulidae
	HAE STRI	*Haemulon striatum*	Striped Grunt	Haemulidae
	ORT CHRY	*Orthopristis chrysoptera*	Pigfish	Haemulidae
	HEM BRAS	*Hemiramphus brasiliensis*	Ballyhoo	Hemiramphidae
	HOL ADSC	*Holocentrus adscensionis*	Squirrelfish	Holocentridae
	HOL RUFU	*Holocentrus rufus*	Longspine Squirrelfish	Holocentridae
*	HOL SPE.	*Holocentrus* sp.	Squirrelfish species	Holocentridae
	MYR JACO	*Myripristis jacobus*	Blackbar Soldierfish	Holocentridae
	SAR CORU	*Sargocentron coruscum*	Reef Squirrelfish	Holocentridae
	SAR VEXI	*Sargocentron vexillarium*	Dusky Squirrelfish	Holocentridae
	INE VITT	*Inermia vittata*	Boga	Inermiidae
	IST PLAT	*Istiophorus platypterus*	Sailfish	Istiophoridae
	KYP SECT	*Kyphosus sectatrix*	Bermuda Chub	Kyphosidae
	BOD PULC	*Bodianus pulchellus*	Spotfin Hogfish	Labridae
	BOD RUFU	*Bodianus rufus*	Spanish Hogfish	Labridae
	CLE PARR	*Clepticus parrae*	Creole Wrasse	Labridae
	HAL BIVI	*Halichoeres bivittatus*	Slippery Dick	Labridae
	HAL CAUD	*Halichoeres caudalis*	Painted Wrasse	Labridae
	HAL CYAN	*Halichoeres cyanocephalus*	Yellowcheek Wrasse	Labridae
	HAL GARN	*Halichoeres garnoti*	Yellowhead Wrasse	Labridae
	HAL MACU	*Halichoeres maculipinna*	Clown Wrasse	Labridae
	HAL PICT	*Halichoeres pictus*	Rainbow Wrasse	Labridae
	HAL POEY	*Halichoeres poeyi*	Blackear Wrasse	Labridae
	HAL RADI	*Halichoeres radiatus*	Puddingwife	Labridae
	LAC MAXI	*Lachnolaimus maximus*	Hogfish	Labridae
	THA BIFA	*Thalassoma bifasciatum*	Bluehead	Labridae
	XYR MART	*Xyrichtys martinicensis*	Rosy Razorfish	Labridae
	XYR NOVA	*Xyrichtys novacula*	Pearly Razorfish	Labridae
*	XYR SPE.	*Xyrichtys* sp.	Razorfish species	Labridae
	XYR SPLE	*Xyrichtys splendens*	Green Razorfish	Labridae
*	LAB SPE.	*Labrisomid* sp.	Labrisomid Blenny species	Labrisomidae
	LAB KALI	*Labrisomus kalisherae*	Downy Blenny	Labrisomidae
	LAB NUCH	*Labrisomus nuchipinnis*	Hairy Blenny	Labrisomidae
	MAL AURO	*Malacoctenus aurolineatus*	Goldline Blenny	Labrisomidae

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	MAL GILL	*Malacoctenus gilli*	Dusky Blenny	Labrisomidae
	MAL MACR	*Malacoctenus macropus*	Rosy Blenny	Labrisomidae
	MAL TRIA	*Malacoctenus triangulatus*	Saddled Blenny	Labrisomidae
	LUT ANAL	*Lutjanus analis*	Mutton Snapper	Lutjanidae
	LUT APOD	*Lutjanus apodus*	Schoolmaster	Lutjanidae
	LUT BUCC	*Lutjanus buccanella*	Blackfin Snapper	Lutjanidae
	LUT CAMP	*Lutjanus campechanus*	Red Snapper	Lutjanidae
	LUT CYAN	*Lutjanus cyanopterus*	Cubera Snapper	Lutjanidae
	LUT GRIS	*Lutjanus griseus*	Gray Snapper	Lutjanidae
	LUT JOCU	*Lutjanus jocu*	Dog Snapper	Lutjanidae
	LUT MAHO	*Lutjanus mahogoni*	Mahogany Snapper	Lutjanidae
*	LUT SPE.	*Lutjanus* sp.	Snapper species	Lutjanidae
	LUT SYNA	*Lutjanus synagris*	Lane Snapper	Lutjanidae
	OCY CHRY	*Ocyurus chrysurus*	Yellowtail Snapper	Lutjanidae
	RHO AURO	*Rhomboplites aurorubens*	Vermilion Snapper	Lutjanidae
	MAL PLUM	*Malacanthus plumieri*	Sand Tilefish	Malacanthidae
	MEG ATLA	*Megalops atlanticus*	Tarpon	Megalopidae
	MAN BIRO	*Manta birostris*	Giant Manta	Mobulidae
	ALU MONO	*Aluterus monoceros*	Unicorn Filefish	Monacanthidae
	ALU SCHO	*Aluterus schoepfii*	Orange Filefish	Monacanthidae
	ALU SCRI	*Aluterus scriptus*	Scrawled Filefish	Monacanthidae
*	ALU SPE.	*Aluterus* sp.	Filefish species	Monacanthidae
	CAN MACR	*Cantherhines macrocerus*	Whitespotted Filefish	Monacanthidae
	CAN PULL	*Cantherhines pullus*	Orangespotted Filefish	Monacanthidae
	MON CILI	*Monacanthus ciliatus*	Fringed Filefish	Monacanthidae
	MON TUCK	*Monacanthus tuckeri*	Slender Filefish	Monacanthidae
	STE HISP	*Stephanolepis hispidus*	Planehead Filefish	Monacanthidae
	MUL MART	*Mulloidichthys martinicus*	Yellow Goatfish	Mullidae
	PSE MACU	*Pseudupeneus maculatus*	Spotted Goatfish	Mullidae
	UPE PARV	*Upeneus parvus*	Dwarf Goatfish	Mullidae
	ENC CARY	*Enchelycore carychroa*	Chestnut Moray	Muraenidae
	ENC NIGR	*Enchelycore nigricans*	Viper Moray	Muraenidae
	GYM FUNE	*Gymnothorax funebris*	Green Moray	Muraenidae
	GYM MILI	*Gymnothorax miliaris*	Goldentail Moray	Muraenidae
	GYM MORI	*Gymnothorax moringa*	Spotted Moray	Muraenidae
	GYM VICI	*Gymnothorax vicinus*	Purplemouth Moray	Muraenidae
	AET NARI	*Aetobatus narinari*	Spotted Eagle Ray	Myliobatidae

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	NAR BANC	*Narcine bancroftii*	Lesser Electric Ray	Narcinidae
	OGC NASU	*Ogcocephalus nasutus*	Shortnose Batfish	Ogcocephalidae
*	OGC SPE.	*Ogcocephalus* sp.	Batfish species	Ogcocephalidae
	MYR BREV	*Myrichthys breviceps*	Sharptail Eel	Ophichthidae
	OPI AURI	*Opistognathus aurifrons*	Yellowhead Jawfish	Opistognathidae
	OPI MACR	*Opistognathus macrognathus*	Banded Jawfish	Opistognathidae
*	OPI SPE.	*Opistognathus* sp.	Jawfish species	Opistognathidae
	OPI WHIT	*Opistognathus whitehursti*	Dusky Jawfish	Opistognathidae
	ACA POLY	*Acanthostracion polygonia*	Honeycomb Cowfish	Ostraciidae
	ACA QUAD	*Acanthostracion quadricornis*	Scrawled Cowfish	Ostraciidae
	LAC BICA	*Lactophrys bicaudalis*	Spotted Trunkfish	Ostraciidae
	LAC TRIG	*Lactophrys trigonus*	Trunkfish	Ostraciidae
	LAC TRIQ	*Lactophrys triqueter*	Smooth Trunkfish	Ostraciidae
	PAR ALBI	*Paralichthys albigutta*	Gulf Flounder	Paralichthyidae
	PEM SCHO	*Pempheris schomburgkii*	Glassy Sweeper	Pempheridae
	CEN ARGI	*Centropyge argi*	Cherubfish	Pomacanthidae
	HOL BERM	*Holacanthus bermudensis*	Blue Angelfish	Pomacanthidae
	HOL CILI	*Holacanthus ciliaris*	Queen Angelfish	Pomacanthidae
	HOL TRIC	*Holacanthus tricolor*	Rock Beauty	Pomacanthidae
	HOL TOWN	*Holocanthus sp.*	Townsend Angelfish	Pomacanthidae
	POM ARCU	*Pomacanthus arcuatus*	Gray Angelfish	Pomacanthidae
	POM PARU	*Pomacanthus paru*	French Angelfish	Pomacanthidae
	ABU SAXA	*Abudefduf saxatilis*	Sergeant Major	Pomacentridae
	CHR CYAN	*Chromis cyanea*	Blue Chromis	Pomacentridae
	CHR ENCH	*Chromis enchrysura*	Yellowtail Reeffish	Pomacentridae
	CHR INSO	*Chromis insolata*	Sunshinefish	Pomacentridae
	CHR MULT	*Chromis multilineata*	Brown Chromis	Pomacentridae
	CHR SCOT	*Chromis scotti*	Purple Reeffish	Pomacentridae
	MIC CHRY	*Microspathodon chrysurus*	Yellowtail Damselfish	Pomacentridae
	STE ADUS	*Stegastes adustus*	Dusky Damselfish	Pomacentridae
	STE DIEN	*Stegastes diencaeus*	Longfin Damselfish	Pomacentridae
	STE LEUC	*Stegastes leucostictus*	Beaugregory	Pomacentridae
	STE PART	*Stegastes partitus*	Bicolor Damselfish	Pomacentridae
	STE PLAN	*Stegastes planifrons*	Threespot Damselfish	Pomacentridae
*	STE SPE.	*Stegastes* sp.	Damselfish species	Pomacentridae
	STE VARI	*Stegastes variabilis*	Cocoa Damselfish	Pomacentridae
	HET CRUE	*Heteropriacanthus cruentatus*	Glasseye Snapper	Priacanthidae

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	PRI AREN	*Priacanthus arenatus*	Bigeye	Priacanthidae
	PTE CALL	*Ptereleotris calliura*	Blue Dartfish	Ptereleotridae
	PTE HELE	*Ptereleotris helenae*	Hovering Dartfish	Ptereleotridae
	RAC CANA	*Rachycentron canadum*	Cobia	Rachycentridae
	RHI LENT	*Rhinobatos lentiginosus*	Atlantic Guitarfish	Rhinobatidae
	CRY ROSE	*Cryptotomus roseus*	Bluelip Parrotfish	Scaridae
	NIC USTA	*Nicholsina usta*	Emerald Parrotfish	Scaridae
	SCA COEL	*Scarus coelestinus*	Midnight Parrotfish	Scaridae
	SCA COER	*Scarus coeruleus*	Blue Parrotfish	Scaridae
	SCA GUAC	*Scarus guacamaia*	Rainbow Parrotfish	Scaridae
	SCA ISER	*Scarus iseri*	Striped Parrotfish	Scaridae
*	SCA SPE.	*Scarus* sp.	Parrotfish species	Scaridae
	SCA TAEN	*Scarus taeniopterus*	Princess Parrotfish	Scaridae
	SCA VETU	*Scarus vetula*	Queen Parrotfish	Scaridae
	SPA ATOM	*Sparisoma atomarium*	Greenblotch Parrotfish	Scaridae
	SPA AURO	*Sparisoma aurofrenatum*	Redband Parrotfish	Scaridae
	SPA CHRY	*Sparisoma chrysopterum*	Redtail Parrotfish	Scaridae
	SPA RADI	*Sparisoma radians*	Bucktooth Parrotfish	Scaridae
	SPA RUBR	*Sparisoma rubripinne*	Yellowtail Parrotfish	Scaridae
*	SPA SPE.	*Sparisoma* sp.	Parrotfish species	Scaridae
	SPA VIRI	*Sparisoma viride*	Stoplight Parrotfish	Scaridae
	EQU LANC	*Equetus lanceolatus*	Jackknife Fish	Sciaenidae
	EQU PUNC	*Equetus punctatus*	Spotted Drum	Sciaenidae
	ODO DENT	*Odontoscion dentex*	Reef Croaker	Sciaenidae
	PAR ACUM	*Pareques acuminatus*	High-hat	Sciaenidae
	PAR UMBR	*Pareques umbrosus*	Cubbyu	Sciaenidae
*	SCI SPE.	*Sciaenidae* sp.	Drum species	Sciaenidae
	EUT ALLE	*Euthynnus alletteratus*	Little Tunny	Scombridae
	SCO CAVA	*Scomberomorus cavalla*	King Mackerel	Scombridae
	SCO MACU	*Scomberomorus maculatus*	Spanish Mackerel	Scombridae
	SCO REGA	*Scomberomorus regalis*	Cero	Scombridae
	PTE VOLI	*Pterois volitans*	Red Lionfish	Scorpaenidae
	SCO PLUM	*Scorpaena plumieri*	Spotted Scorpionfish	Scorpaenidae
	ALP AFER	*Alphestes afer*	Mutton Hamlet	Serranidae
	CEN OCYU	*Centropristis ocyurus*	Bank Sea Bass	Serranidae
	CEN STRI	*Centropristis striata*	Black Sea Bass	Serranidae
	CEP CRUE	*Cephalopholis cruentata*	Graysby	Serranidae

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	CEP FULV	*Cephalopholis fulva*	Coney	Serranidae
	DIP FORM	*Diplectrum formosum*	Sand Perch	Serranidae
	EPI ADSC	*Epinephelus adscensionis*	Rock Hind	Serranidae
	EPI GUTT	*Epinephelus guttatus*	Red Hind	Serranidae
	EPI ITAJ	*Epinephelus itajara*	Goliath Grouper	Serranidae
	EPI MORI	*Epinephelus morio*	Red Grouper	Serranidae
	HYP GEMM	*Hypoplectrus gemma*	Blue Hamlet	Serranidae
	HYP GUTT	*Hypoplectrus guttavarius*	Shy Hamlet	Serranidae
	HYP INDI	*Hypoplectrus indigo*	Indigo Hamlet	Serranidae
	HYP PUEL	*Hypoplectrus puella*	Barred Hamlet	Serranidae
*	HYP SPE.	*Hypoplectrus* sp.	Hamlet species	Serranidae
	HYP TANN	*Hypoplectrus tann*	Tan Hamlet	Serranidae
	HYP UNIC	*Hypoplectrus unicolor*	Butter Hamlet	Serranidae
	LIO EUKR	*Liopropoma eukrines*	Wrasse Basslet	Serranidae
	LIO RUBE	*Liopropoma rubre*	Peppermint Basslet	Serranidae
	MYC BONA	*Mycteroperca bonaci*	Black Grouper	Serranidae
	MYC MICR	*Mycteroperca microlepis*	Gag	Serranidae
	MYC PHEN	*Mycteroperca phenax*	Scamp	Serranidae
	PAR FURC	*Paranthias furcifer*	Atlantic Creolefish	Serranidae
	RYP BIST	*Rypticus bistrispinus*	Freckled Soapfish	Serranidae
	RYP MACU	*Rypticus maculatus*	Whitespotted Soapfish	Serranidae
	RYP SAPO	*Rypticus saponaceus*	Greater Soapfish	Serranidae
	SCH BETA	*Schultzea beta*	School Bass	Serranidae
*	SRR SPE	*Serranidae* sp.	Grouper-Sea Bass species	Serranidae
	SER ANNU	*Serranus annularis*	Orangeback Bass	Serranidae
	SER BALD	*Serranus baldwini*	Lantern Bass	Serranidae
	SER PHOE	*Serranus phoebe*	Tattler	Serranidae
	SER SUBL	*Serranus subligarius*	Belted Sandfish	Serranidae
	SER TABA	*Serranus tabacarius*	Tobaccofish	Serranidae
	SER TIGR	*Serranus tigrinus*	Harlequin Bass	Serranidae
	SER TORT	*Serranus tortugarum*	Chalk Bass	Serranidae
	ARC PROB	*Archosargus probatocephalus*	Sheepshead	Sparidae
	ARC RHOM	*Archosargus rhomboidalis*	Sea Bream	Sparidae
	CAL BAJO	*Calamus bajonado*	Jolthead Porgy	Sparidae
	CAL CALA	*Calamus calamus*	Saucereye Porgy	Sparidae
	CAL LEUC	*Calamus leucosteus*	Whitebone Porgy	Sparidae
	CAL NODO	*Calamus nodosus*	Knobbed Porgy	Sparidae

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	CAL PENN	*Calamus penna*	Sheepshead Porgy	Sparidae
	CAL PROR	*Calamus proridens*	Littlehead Porgy	Sparidae
*	CAL SPE.	*Calamus* sp.	Porgy species	Sparidae
	DIP ARGE	*Diplodus argenteus*	Silver Porgy	Sparidae
	DIP HOLB	*Diplodus holbrookii*	Spottail Pinfish	Sparidae
	LAG RHOM	*Lagodon rhomboides*	Pinfish	Sparidae
	SPH BARR	*Sphyraena barracuda*	Great Barracuda	Sphyraenidae
	SPH PICU	*Sphyraena picudilla*	Southern Sennet	Sphyraenidae
	SPH LEWI	*Sphyrna lewini*	Scalloped Hammerhead	Sphyrnidae
	SPH TIBU	*Sphyrna tiburo*	Bonnethead	Sphyrnidae
*	SYG SPE.	*Syngnathus* sp.	Pipefish species	Syngnathidae
	SYN FOET	*Synodus foetens*	Inshore Lizardfish	Synodontidae
	SYN INTE	*Synodus intermedius*	Sand Diver	Synodontidae
	SYN SYNO	*Synodus synodus*	Red Lizardfish	Synodontidae
	CAN ROST	*Canthigaster rostrata*	Sharpnose Puffer	Tetraodontidae
	SPH NEPH	*Sphoeroides nephelus*	Southern Puffer	Tetraodontidae
	SPH SPEN	*Sphoeroides spengleri*	Bandtail Puffer	Tetraodontidae
	SPH TEST	*Sphoeroides testudineus*	Checkered Puffer	Tetraodontidae
	PRI OPHR	*Prionotus ophryas*	Bandtail Searobin	Triglidae
	PRI RUBI	*Prionotus rubio*	Blackwing Searobin	Triglidae
*	UNK SPE.	unknown species	Unknown species	unknown
	URO JAMA	*Urobatis jamaicensis*	Yellow Stingray	Urolophidae