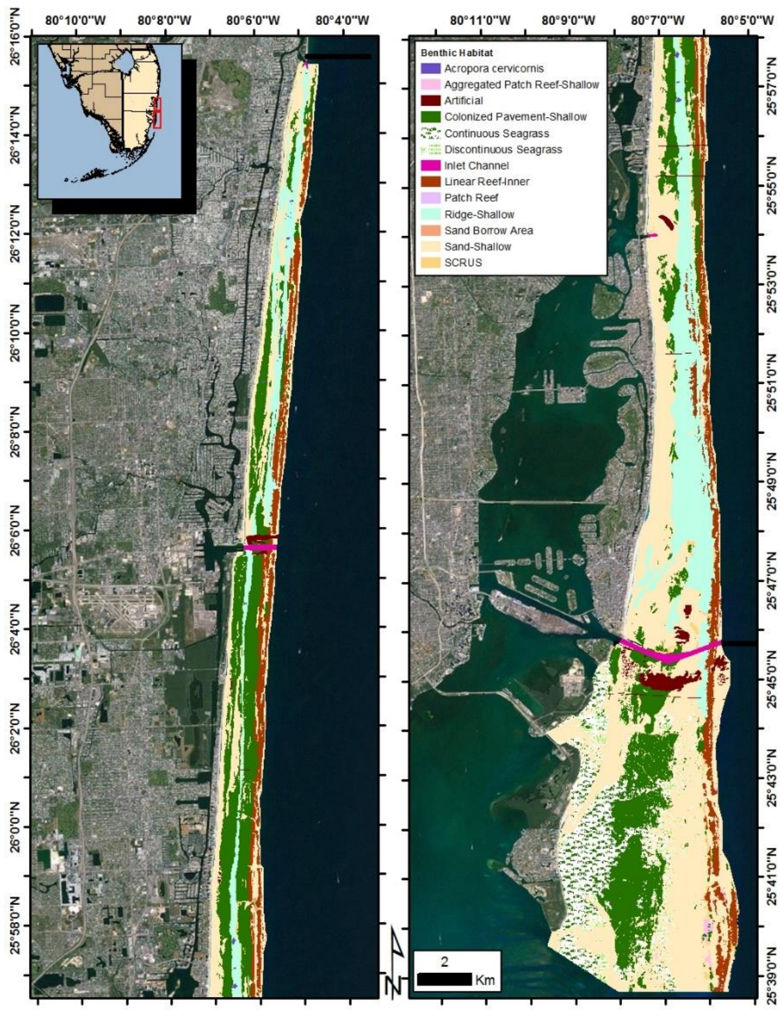
Southeast Florida shallow-water habitat mapping & coral reef community characterization



Florida Department of Environmental Protection
Coral Reef Conservation Program

Southeast Florida shallow-water habitat mapping & coral reef community characterization

Final Report

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Executive Summary

Baseline mapping and quantitative assessment data are required prior to future permitted or un-permitted impacts in order to determine the pre-existing state of the benthic resources; therefore, it is imperative that these data be collected on the ecologically sensitive and economically valuable shallow-water coral reef habitats in southeast Florida. In southeast Florida, the nearshore reef habitats are most vulnerable to coastal construction activities and other anthropogenic impacts, therefore these habitats were the focus for this study. The study goals were to provide a spatially appropriate map of increased resolution and a regional quantitative characterization of nearshore benthic resources to evaluate differences in benthic communities between habitats and with latitude for the southeast Florida region of the Florida Reef Tract. This study is a snapshot habitat characterization providing the current status of shallow-water coral reef community composition. Additionally, these data can be used to reduce un-permitted impacts by informing marine zoning efforts and aid in the creation of new no-anchor zones.

Detailed 1ft resolution overlapping aerial photographs were collected for the Nearshore Ridge Complex (NRC) and Inner Reef from Key Biscayne to Hillsboro Inlet, 68.5km of coastline by PhotoScience, Inc. on March 8, 2013. The imagery and recent bathymetry were visually interpreted into benthic habitat maps. Quantitative groundtruthing of 265 targeted and randomized sites was conducted between April and June 2014. Five 1km wide cross-shelf corridors were placed as evenly as possible across the mapped space while maintaining consistent habitat types and amounts between corridors and avoiding any major anthropogenic influences like shipping channels and proximity to inlets and outfalls. Survey site locations were stratified across three main habitats within each corridor: Colonized Pavement-Shallow, Ridge-Shallow, and Linear Reef-Inner. Percent cover data at each site was collected. Additionally, species, colony size (length, width, height), percent mortality, condition (pale or bleached), and presence of disease was recorded for stony corals. Gorgonians were categorized by morphology (rod, plume, fan) and counted in four size classes (4-10, 11-25, 26-50, and >50cm). *Xestospongia muta* and *Cliona spp*. were also counted. Then an accuracy assessment was performed where drop camera video with GPS data were collected at 494 locations randomly stratified across all habitat types. The overall accuracy was 97.9% at the Major Habitat level.

Of the 172.73km² seafloor mapped, the polygon totals indicated 41.34% was Sand, 47.07% was Coral Reef and Colonized Pavement, 9.35% was Seagrass, and 2.25% was Other Delineations. These totals are estimates due to some habitats having a large mix of sand within. Three habitat types dominated the mapped hardbottom area. The largest was Colonized Pavement (38.36km²), followed by Ridge-Shallow (25.52km²), and Linear Reef-Inner (14.99km²). These comprised 97% of the hardbottom habitats. Seagrass accounted for 9.35% of the map and was solely contained south of Government Cut. Sand comprised 41.34% of the map and Other Delineations accounted for 2.25%.

The clear, high-resolution images enabled the delineation of thirty-five dense *Acropora cervicornis* patches. Some of these corresponded to known locations of dense patches.

These are the largest dense patches in the continental United States. Using aerial photography delineations area estimates, the seven patches near the known existing locations totaled approximately 46,000m² whereas the 28 newly confirmed areas exceed 110,000m². Dense *Acropora cervicornis* comprised 1% of the mapped hardbottom habitats.

Significant differences in percent benthic cover between habitats occurred in all corridors, however some comparisons were stronger than others. Corridor 1 exhibited clear differences between the colonized pavement and inner reef sites due to the high percentages of seagrass on the colonized pavement that did not occur on the Inner Reef sites (nor any other habitat in the region). Corridor 2 showed much weaker differences between habitat types, however the colonized pavement sites were significantly distinct from the inner reef and ridge sites due to the comparatively high percentage of sand on the colonized pavement versus the inner reef and ridge. Corridor 3 ridge was significantly distinct from the colonized pavement and inner reef sites mostly due to lower percentage of *Palythoa spp*. on the ridge. Corridor 4 inner reef sites were significantly different from the others driven by much higher percentage of macroalgae and higher *Palythoa spp*. Corridor 5 exhibited significant differences between all habitat types. Inner reef sites had higher percentages of *Palythoa* spp., gorgonians, and sponges than any other habitat. Colonized pavement sites had the lowest percentages of gorgonians and *Palythoa* spp. while having the highest percentages of sand.

Comparisons of benthic cover percentages between all sites in a given habitat type were conducted to evaluate latitudinal community differences. Among colonized pavement sites, Corridor 1 was significantly different from all other corridors due to the presence of seagrass which only occurred in Corridor 1 colonized pavement. Corridor 5 was also significantly distinct from all other corridors due to a low percentage of gorgonians, stony corals, and *Palythoa spp*. with a high percentage of turf algae. The ridge sites comparisons showed distinct clustering of corridors 2, 3, and 5 in the MDS indicating that there are latitudinal differences in benthic cover in the ridge habitat. The main dissimilarity contributors in corridor 2 were lower percentages of palythoa spp. and macroalgae than corridors 3 and 5 and higher percentages of gorgonians and stony corals than corridor 5. Corridor 3 had higher percentages of macroalgae, stony corals, and gorgonians than corridor 5. The inner reef sites also exhibited latitudinal differences in benthic cover. Corridors 1 and 5 separated out from the other corridors and each other. The main cover classes driving the clustering of corridor 1 sites were high percentages of gorgonians and *Palythoa spp*, while the main contributor to the corridor 4 cluster was high macroalgae percentages in that corridor.

A total of 4,568 stony coral colonies were identified, counted, and measured. Twenty-two species were found, but *Porites astreoides* (29.7%), *Siderastrea siderea* (17.5%), and *Acropora cervicornis* (10.3%) comprised 57.5% of the total number of stony corals measured in this study. The largest coral measured in the study was a *Siderastrea siderea* located in corridor 4 which measured 225 cm long, 200 cm wide, 140 cm tall and an estimated 4.1 m² of live tissue. Stony coral density pooled for the entire surveyed area of 4,200m² was 1.09 corals/m². Mean coral density was lowest in the colonized pavement sites and highest in the inner reef sites, however this also varied by corridor. The colonized pavement coral density in Corridors 1 and 5 was lowest and highest in Corridors 3 and 4. Coral density on ridge habitat had a similar pattern to colonized pavement with corridor 3 having the highest density. Conversely coral density on the inner reef was highest in corridor 1 and corridor 4. *Acropora cervicornis* was found in higher densities than *S. siderea* on the colonized pavement but it only occurred in corridors 3 and 4. It was also found in higher density on ridge habitat except for corridor 5. Of the 471 *A. cervicornis* colonies counted, only 5.3% occurred on the inner reef. Two hundred and thirty-five (49.9%) were found in the colonized pavement and 211 (44.8%) at the ridge sites.

The mean number of coral species (richness) varied by corridor and habitat. Colonized pavement sites had the lowest richness and it was highest on inner reef. Mean richness also varied by corridor within habitats. Among the colonized pavement sites, corridor 3 and corridor 4 had the highest mean richness and corridor 5 the lowest. Similarly, among the ridge site, mean coral richness was highest in corridor 3 and lowest in corridor 5. Mean richness among inner reef sites were not very different however corridor 1 was significantly higher than corridor 3.

A total of 30,076 gorgonians were counted, classified by morpho-type (Fan, Plume, Rod), and binned into size classes. Rods were the most abundant comprising almost 72% of the total number counted and plumes were second-most comprising 24% of the total. This varied by corridor and habitat. With all size classes combined, fans were lowest on the colonized pavement and highest on the ridge. Plumes were higher on the inner reef than the colonized pavement and ridge. Conversely rods were lower on the inner reef than the colonized pavement and ridge. Gorgonians also varied within habitat types by corridor. In colonized pavement, fans were highest in corridors 3 and 4 whereas plumes were more abundant in the southern corridors. Rods were dominantly abundant throughout the colonized pavement except for corridor 5 where they were conspicuously absent. In the ridge habitat, fans varied among corridors without a clear latitudinal pattern. Plumes were more abundant in the southern corridors, while rods were dominantly abundant throughout. The inner reef habitats generally had a higher abundance of plumes and a more even ratio of rod and plume abundance throughout all corridors. Plumes were the most abundant type in corridor 1, but were also high in corridors 3 and 5.

Xestospongia muta colonies were predominantly found at the inner reef sites. Of the 262 total colonies counted, 87.7% were at inner reef sites. Densities were lower than gorgonians and stony corals throughout the study. Mean *X. muta* abundance varied between corridors. In colonized pavement and ridge habitats, *X. muta* predominantly occurred on corridor 4 however mean abundance was very low. At the inner reef sites, *X. muta* was much lower in corridor 1 than all other corridors, which did not significantly vary.

This study elucidated new data on the extent of the Endangered Species Act threatened coral species, *Acropora cervicornis*. Only approximately 30% of the discovered dense patches were identified as previously known and the total regional area of *A. cervicornis* dense patches is now estimated at 156,000 m^2. The condition of the coral in these patches cannot be surmised from the images. Additionally, the polygons depicted in the habitat map are likely under-representative of the shape and sizes of these patches due to their fuzzy boundaries. A detailed study to map their boundaries and characterize their condition is needed to properly inventory these patches and their condition. Furthermore, the only way to fully understand if the net amount is increasing is to investigate it on a regional level. Previous imagery must be identified and used to determine the timing of when these patches came into existence. Unfortunately no consistent data sets have been identified that can be used for this purpose at this time. A compilation of local imagery has been helpful in some cases. It is recommended that a regional set of imagery be repeatedly collected in the future to elucidate the dynamics of dense patches of *A. cervicornis* and document the current extent of nearshore resources. This is especially important after large storm events.

This study has expanded the present knowledge on the amount, location, and species type of ecologically important large coral colonies. Although smaller than the minimum mapping unit for this study (and thus not in this study's scope and funded separately), 187 blips in the LIDAR associated with dark specs in the imagery were identified and a portion investigated. Of the 53 that were visited, 47 were stony corals estimated between 2 and 5 m in diameter. Twenty-three (43%) were alive in various conditions. These were predominantly *Orbicella faveolata* (20), but 2 were *Siderastrea siderea* and one was a *Montastrea cavernosa*. Corals of this size are likely to be hundreds of years old, meaning they have persisted through the multitude of anthropogenic impacts that have occurred in the region. Large coral colonies are more fecund, giving an exponentially increased amount of reproductive output making these colonies particularly important in the restoration of the reef system. It is recommended that a host of important studies be conducted to understand the full extent, size, condition of these large, resilient corals and to monitor them through time, investigate their reproduction and genetic diversity, and perhaps use them to help propagate naturally resilient corals in restoration efforts.

Acknowledgements

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List of Acronyms

AA	Accuracy Assessment
ABGPS	Airborne GPS
AGD	Acoustic Ground Discrimination
ANOSIM	Analysis of Similarity
ANOVA	Analysis of Variance
AT	Analytical Triangulation
CCMA	Center for Coastal Monitoring & Assessment
CRCP	Coral Reef Conservation Program
DEM	Digital Elevation Model
DMC	Digital Mapping Camera
EO	Exterior Orientation
ESRI	Environmental Systems Research Institute
FDEP	Florida Department of Environmental Protection
FGDC	Federal Geographic Data Committee
FRT	Florida Coral Reef Tract
FWRI	Florida Fish and Wildlife Research Institute
GIS	Geographic Information Systems
GPS	Global Positioning System
GSD	Ground Sample Distance
IMU	Inertial Measuring Unit
LADS	Laser And Depth Sounder
LAS	Local Action Strategy
LIDAR	Light Detection and Ranging
MDS	Multi-Dimensional Scaling
MMU	Minimum Mapping Unit
NAVD	North American Vertical Datum
NCCOS	National Centers for Coastal Ocean Science
NCRI	National Coral Reef Institute
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NRC	Nearshore Ridge Complex
NSRS	National Spatial Reference System
NSSDA	National Standard for Spatial Data Accuracy
NSUOC	Nova Southeastern University Oceanographic Center
OCS	Office of Coast Survey
PSM	Professional Surveyor and Mapper

QA/QC	Quality assurance and quality control
RGB	Red, Green, Blue
RMSE	Root Mean Squared Error
SCRUS	Scattered Coral/Rock in Sand
SECREMP	Southeast Coral Reef Evaluation and Monitoring Program
SEFCRI	Southeast Florida Coral Reef Initiative
SE FL	Southeast Florida
SEM	Standard Error of Mean
SIMPER	Similarity Percentages
USGS	United States Geological Society
WAAS	Wide Area Augmentation System

1. INTRODUCTION

1.1. Project Background

The goal of this project is to provide a spatially appropriate map and characterization of nearshore benthic resources for the southeast Florida region of the Florida Reef Tract. While the annual Southeast Coral Reef Evaluation and Monitoring Program (SECREMP) provides status and trends of reef health, this project documents and maps baseline quantitative data on the shallow-water (2m – 10m) southeast Florida coral reef and hardbottom communities using the latest high resolution bathymetry and aerial photography. This study is a snapshot habitat characterization providing the current status of shallow-water coral reef community composition and health.

These data support the recently developed Florida's Coral Reef Management Priorities. These include Goal A1, Objectives 2 & 3; Goal A3; Goal B3, Objectives 3; Goal C3, Objective 4; Goal C4, Objective 3; Goal D2, Objective 1, and; Goal D4, Objective 1.

As stated in the National Oceanic and Atmospheric Association Coral Reef Conservation Program's (NOAA CRCP) National Goals and Objectives 2010-2015 report, all three (Climate Change, Fishing, and LBSP) threat-based strategies require data to identify changes to the resource. This project provides managers with nearshore data required to develop appropriate management strategies, track the effectiveness of these strategies, and support outreach activities which increase stakeholder involvement. This project supports a number of the Florida Department of Environmental Protection Coral Reef Conservation Program's (FDEP CRCP) programmatic strategies as well as Local Action Strategies for the Southeast Florida Coral Reef Initiative (SEFCRI).

1.2. Identification of Issues

The southeast Florida coast contains significant, valuable coral reef communities existing in shallow water between 2m and 10m depths along the shoreline from Key Biscayne north to Hillsboro Inlet (Figure 1). These habitats house many significant coral reef resources, including octocorals, sponges, and threatened and endangered scleractinian coral species. Many individual assessments and monitoring projects have been conducted in the region over the years, but most had much smaller, focused study areas and none were designed for impact assessment at a regional scale. Baseline mapping and quantitative assessment data are required prior to future permitted or un-permitted impacts in order to determine the pre-existing state of the benthic resources; therefore, it is imperative that these data be collected on the ecologically sensitive and economically valuable shallow-water coral reef habitats in southeast Florida.

A current snapshot of shallow-water coral community health is essential to determining impacts from both permitted (e.g. coastal construction) and un-permitted (e.g. groundings, oil spills, etc.) impacts. These data types have been identified as a need by multiple managers in southeast Florida and will be used to directly reduce impacts to coral reef and hardbottom resources from local coastal construction projects (e.g. beach nourishment) through the design and review of permit applications. Additionally, these data can be used to reduce un-permitted impacts by informing marine zoning efforts and aid in the creation of new no-anchor zones.

Mapping activities in Southeast Florida have progressed substantially in the last decade (Banks, Riegl, Shinn, Piller, & Dodge, 2007; Foster, Walker, & Riegl, 2009; Riegl, Walker, Foster, & Foster, 2005; Walker, 2009; Walker, 2012; Walker & Gilliam, 2013; Walker, Riegl, & Dodge, 2008). The previous benthic habitat mapping efforts employed a combined-technique approach incorporating a variety of data types including laser bathymetry, aerial photography, acoustic ground discrimination (AGD), video groundtruthing, limited subbottom profiling, and expert knowledge as available (Walker, et al., 2008). Nova Southeastern University's Oceanographic Center (NSUOC) and the National Coral Reef Institute (NCRI) led this effort with interagency funding by National Oceanic and Atmospheric Administration (NOAA), Florida Department of Environmental Protection (FDEP), and Florida Fish and Wildlife Research Institute (FWRI). The maps were produced by outlining the features in the high resolution bathymetric data and aerial photography, classifying the features based on their geomorphology and benthic fauna. *In situ* data, video camera groundtruthing, and acoustic ground discrimination were used to help substantiate the classification of the habitats using aerial photography and geomorphology. Accuracy assessment of the maps showed high levels of accuracy comparable to that of using aerial photographs in clear water (Riegl, et al., 2005; Walker, 2009; Walker & Gilliam, 2013; Walker, et al., 2008).

The current maps provide a good and accurate understanding of where features are at a large scale, yet they do not provide quantitative *in situ* data on the benthic communities in those mapped areas. Further, many of these maps were based on bathymetric data collected in 2001 and 2002 limiting their ability to capture the most recent depiction of the seafloor habitats. Since the creation of these maps several higher resolution datasets have been conducted in Broward and Miami-Dade counties. In 2008, Broward County collected bathymetric LIDAR using the Laser And Depth Sounder (LADS) system. These data were collected at a higher resolution than the 2001 survey and used better post-processing algorithms to reduce survey artifacts. In 2009, NOAA Office of Coast Survey used the same system to collect higher resolution data over a large area in Miami-Dade County around Government Cut and northern Biscayne Bay for charting purposes. When combined with new high resolution aerial photography, these data would facilitate a more accurate, higher resolution benthic habitat map. The images also provide a new baseline for the state of the resources.

In southeast Florida, the nearshore reef habitats are most vulnerable to coastal construction activities and other anthropogenic impacts, therefore these habitats were the focus for this study. Detailed 1ft resolution overlapping aerial photographs were collected for the Nearshore Ridge Complex (NRC) and Inner Reef from Key Biscayne to Hillsboro Inlet, 68.5km of coastline (Figure 1). The images visually documented existing condition of resources and were used as the primary data for the detailed habitat mapping. The imagery and recent bathymetry were visually interpreted into benthic habitat maps using similar techniques as present regional mapping at a much finer resolution (0.1ha versus the previous 0.4ha). Additionally, a baseline habitat characterization was performed to obtain the current status of coral reef community composition and health.

1.3. Project Objectives

The ultimate goal of this project was to provide managers with:

- **Increased map resolution-** Previous Broward maps were created at a 1:3000 scale and a minimum mapping unit of 0.4ha (1acre). This study increases the mapping resolution fourfold to 0.1ha (0.247acre).

- **Quantitative information on nearshore habitats-** Existing maps are based on reef morphology and inferred associated communities from a multitude of previous projects, local diver knowledge, and qualitative video. Those maps used mostly qualitative video estimations and monitoring data which were designed to monitor change over time, not to characterize the region. This study provides quantitative data on the major functional groups, including corals, on the nearshore habitats. A systematic regional scale quantitative assessment of the SE FL coral communities has never been performed. This work enables estimations of functional group cover at a level relevant to management needs (e.g. determining if management decisions have impacted reef health).

- **Data on the latitudinal differences in coral communities-** Quantitative data are statistically compared between five cross-shelf corridors in two coral reef ecosystem regions to better understand how the benthic communities change with latitude along the SE Florida coast.

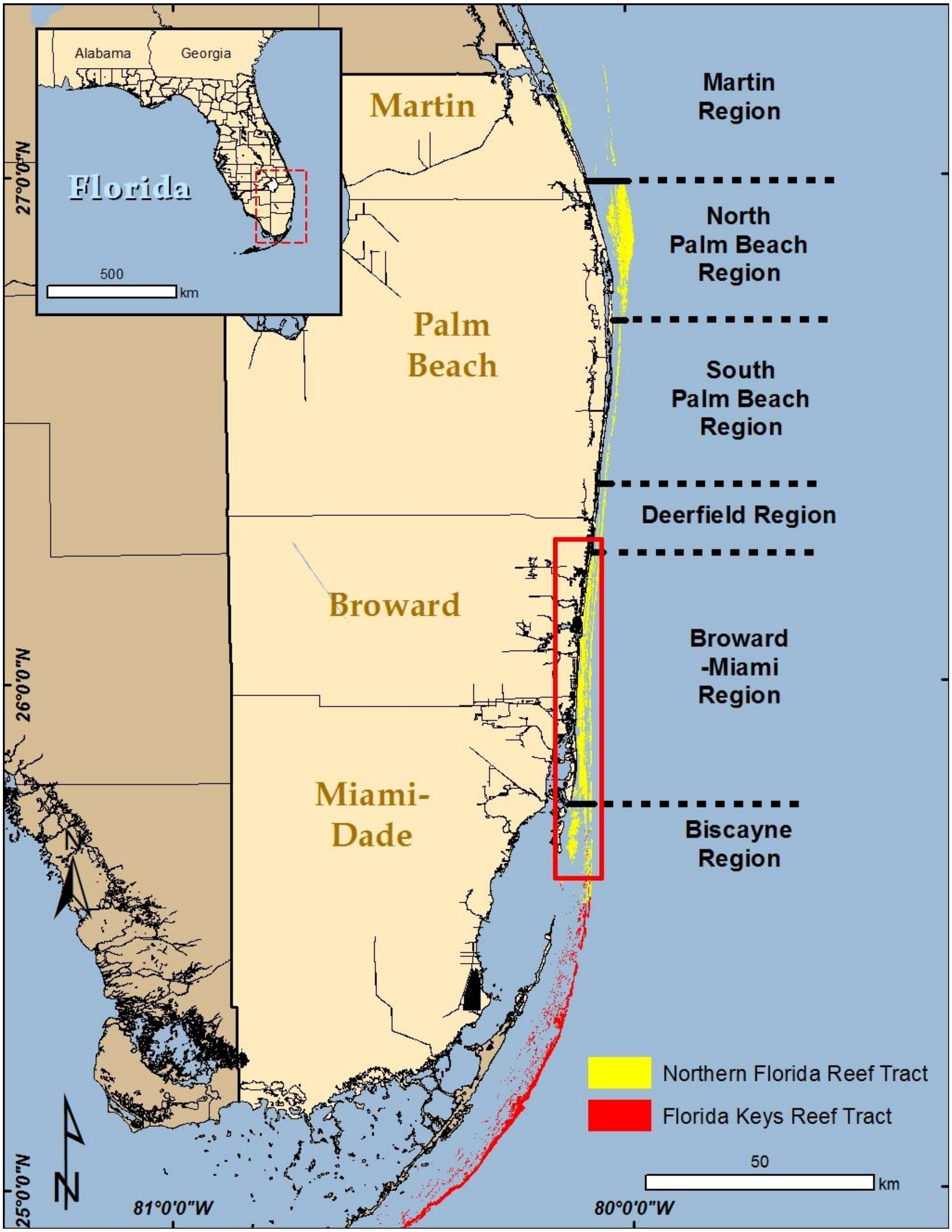


Figure 1. *Nearshore benthic habitat mapping extent (red box). Area includes all marine benthos in 0m - ~10m depth from Key Biscayne to Hillsboro Inlet.*

2. METHODOLOGY

Several data products were integrated for the production of benthic habitat maps. A comprehensive dataset from previous work at the local, state, and federal level was assembled in ArcGIS to aid in the seafloor feature identification including all of the previous data used to create and assess the accuracy of the Broward and Miami-Dade county maps (Walker, 2009; Walker, et al., 2008). Although many data were at hand, three most-recent primary datasets were used: the 2013 aerial photography collected during this study, the 2009 NOAA Office of Coast Survey (OCS) bathymetry, and the 2008 Broward LADS bathymetry. The 2009 Miami-Dade habitat mapping groundtruthing and accuracy assessment videos were also helpful. Aerial photography was used to depict the edges of hard grounds, patch reefs, and sea grass extents. The high resolution, hill-shaded, raster image of the LADS bathymetry data was used to map feature location and geomorphology of visible features. Conflicts between data types were resolved by expert-driven interpretation based on the agreement of the majority of data types with an emphasis on the most recent data.

2.1. Aerial Photography

Full details on the image acquisition can be found in a separate report by GMR Aerial Surveys, Inc. dba Photo Science (Florence, 2013).

GMR Aerial Surveys, Inc. dba Photo Science was subcontracted to collect the imagery. The image acquisition mission occurred on March 8, 2013. The flight season was from November 1, 2012 through December 15, 2012, if optimum conditions exist during this period. Unfortunately, optimum conditions did not exist till March 8, 2013. All images were obtained on March 8, 2013. Photo Science made every effort to collect data during optimum conditions to allow for best water penetration (Figure 2).

All imagery was collected using a Z/I Digital Mapping Camera airborne imaging sensor at a flight height of 10,000 feet. All imagery had a Ground Sample Distance (GSD) of 1 foot. Horizontal Datum referenced the Florida State Plane Coordinate System, East Zone, Units US Survey Feet, North American Datum of 1983 (2007) including the most recent NSRS adjustment. Vertical datum referenced the North American Vertical Datum of 1988 (NAVD 88), Units US Survey Feet, using the most recent geoid model (GEOIDO3 or GEOID06) to compute orthometric heights based on GPS derived ellipsoid heights. All work was under the direct supervision of a Florida licensed Professional Surveyor and Mapper (PSM) and in accordance with the Minimum Technical Standards defined in Rule 61G17, Florida Administrative Code.

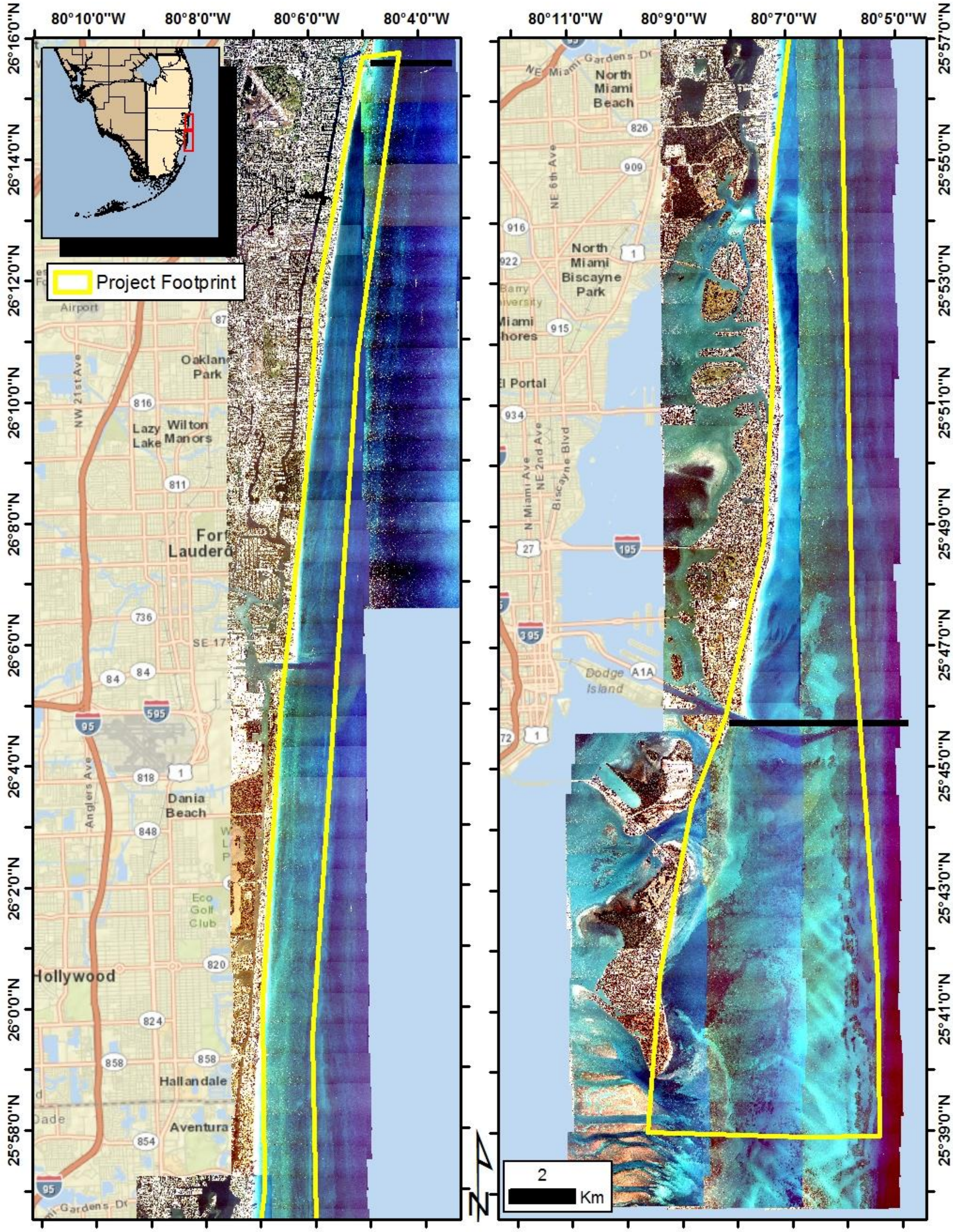


__Figure 2.__ Map of the 2013 aerial photographs taken for this project overlaying the ESRI street map layer.

If an image frame had adequate land cover and subsequently adequate control points, the derived orthophotography met or exceeded a verified horizontal accuracy of 7.6ft at the 95% confidence interval (4.4 ft RMSE) as specified in the FGDC Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy (NSSDA). For optimal performance, Photo Science's Z/I DMC Sensor was configured with an ABGPS and IMU. The natural color, ONE-foot orthophotos mapped consist of 135 cells for the near shore Ridge Complex (NRC) and Inner Reef key from Key Biscayne to Hillsboro Inlet, 68.5km of coastline. Areas were flown with a Z/I Intergraph DMC airborne digital sensor.

The aircraft used for this mission was equipped with Trimble Navigational GPS, including the Trimble 2000 Approach Series, and used the Zeiss T-Flight Navigational Flight Management System. The surface files used for this project were USGS Government 30m DEM

The creation of Digital Orthophotos requires an Exterior Orientation (EO) solution for all frames of photography used in the orthophoto production. The EO solution is a combination of the three dimensional position of each image and the three-dimensional rotation of that same image. The three dimensional position is normally expressed in terms of the easting, northing, and elevation (X, Y, and Z) at the center point of the image, in state plane coordinates. The three-dimensional rotation is expressed in terms of the angular measurement of the roll, pitch, and heading (omega, phi, and kappa) of the image sensor. There are two primary methods of determining the EO solution for all frames captured in a mapping project. The first is the analytical triangulation (AT) process whereby targeted ground control points geographically dispersed throughout the area to be mapped are used in a mathematical process to determine the EO parameters for all image frames. The second requires specialized airborne sensors in the form of airborne GPS (ABGPS) to provide the three-dimensional position and an Inertial Measurement Unit (IMU) sensor to provide the three-dimensional rotation for all frames of photography. This second method was used for the control solution for this project.

An Applanix AV DG 510 inertial measurement system was used for the EO solution. The 510 sensor is a state-of-the-art IMU that is mounted rigidly to the body of the image sensor and calibrated during a boresight procedure to ensure an accurate solution. ABGPS data is captured at a 2Hz (0.5 second) epoch while inertial data is captured at 200Hz during the entire image acquisition process. The raw data captured onboard the aircraft is post-processed against GPS base station data that is captured simultaneously during the flight. Both the ABGPS and IMU data are included in this process and filtered to produce the final EO solution that is subsequently used in the digital orthophoto production.

The digital orthophotography is comprised of 3 bands (RGB) with a 1ft pixel spatial resolution. Once the Z/I Intergraph DMC data were integrated into the Intergraph Software system, the initial radiometric adjustments were performed on the imagery for each flight line attempting to reach the best possible histogram. The rectification process was run using a U.S. Government 30m DEM surface and the radiometrically balanced imagery on each flight line. Automatic seamlines were placed on open water and are noticeable in the imagery. DEM surfaces were provided by the USGS. Quality assurance and quality control was performed looking for smears and other indications of problems within the digital orthophoto creation process. The created tiles are reviewed again for anomalies and interactive radiometric adjustment applied where needed. The final product was GeoTIFF format digital orthos.

Orthophotogrammetric mapping must exceed a verified horizontal accuracy of 7.6ft at the 95 percent confidence interval (4.4ft Root Mean Square Error) as specified in the Federal Geographic Data Committee (FGDC) Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy (NSSDA). The distribution of 20 image check points were located and represented only along the minimum strip of land adjacent to the water body. Based on the 20 image checkpoints, the ortho photogrammetric mapping achieved a verified horizontal accuracy of 2.773 feet at the 95 percent confidence interval (1.602 ft RMSE) as specified in the FGDC Geospatial Positioning Accuracy Standards, Part 3: NSSDA. This is well within the allowable tolerance required for this project.

Upon delivery, the images were evaluated for sun glint, water clarity, and seafloor visibility in ArcGIS to determine their utility for habitat mapping. Polygons were created covering areas of the project footprint where the image quality was deemed Good, Moderate, Poor, Very Poor, and Obscured (Figure 3). A summary of the percentages of area of each category are presented in Table 1. It was determined that the images were sufficient to proceed with the mapping.

Table 1. *A summary of the 2013 aerial photography ratings by percent of the project area.*

Rating	Percent
Good	76.16%
Moderate	21.05%
Poor	2.66%
Very poor	0.13%
Obscured	0.24%

2.2. LIDAR Bathymetry

Bathymetric LIDAR surveys were conducted in 2008 and 2009 using the LADS system with a sounding rate of 900Hz (3.24 million soundings per hour), a position accuracy of 95% at 5m circular error probable, a horizontal sounding density of 4m x 4m, a swath width of 240m, area coverage of $64km^2h^{-1}$, and a depth range of 70m, depending on water clarity. The 2008 survey encompassed all of Broward County and was conducted by Broward County Natural Resources Planning and Management Division (Figure 4). Full details can be found in a separate survey report (Ramsay & Sinclair, 2008). The 2009 survey was conducted by the NOAA OCS and encompassed a large area around Government Cut in Miami-Dade County (Figure 5). The processed x,y,z data were obtained from each agency and split into smaller files. The x.y.z data were gridded by triangulation with linear interpolation into a digital elevation model (DEM) and masked to the data extent. The DEM was then converted to a hillshade image with the sun shaded at a 45° angle and azimuth. The DEM provided depth information while the hillshaded image showed the 3 dimensionality of the seafloor features.

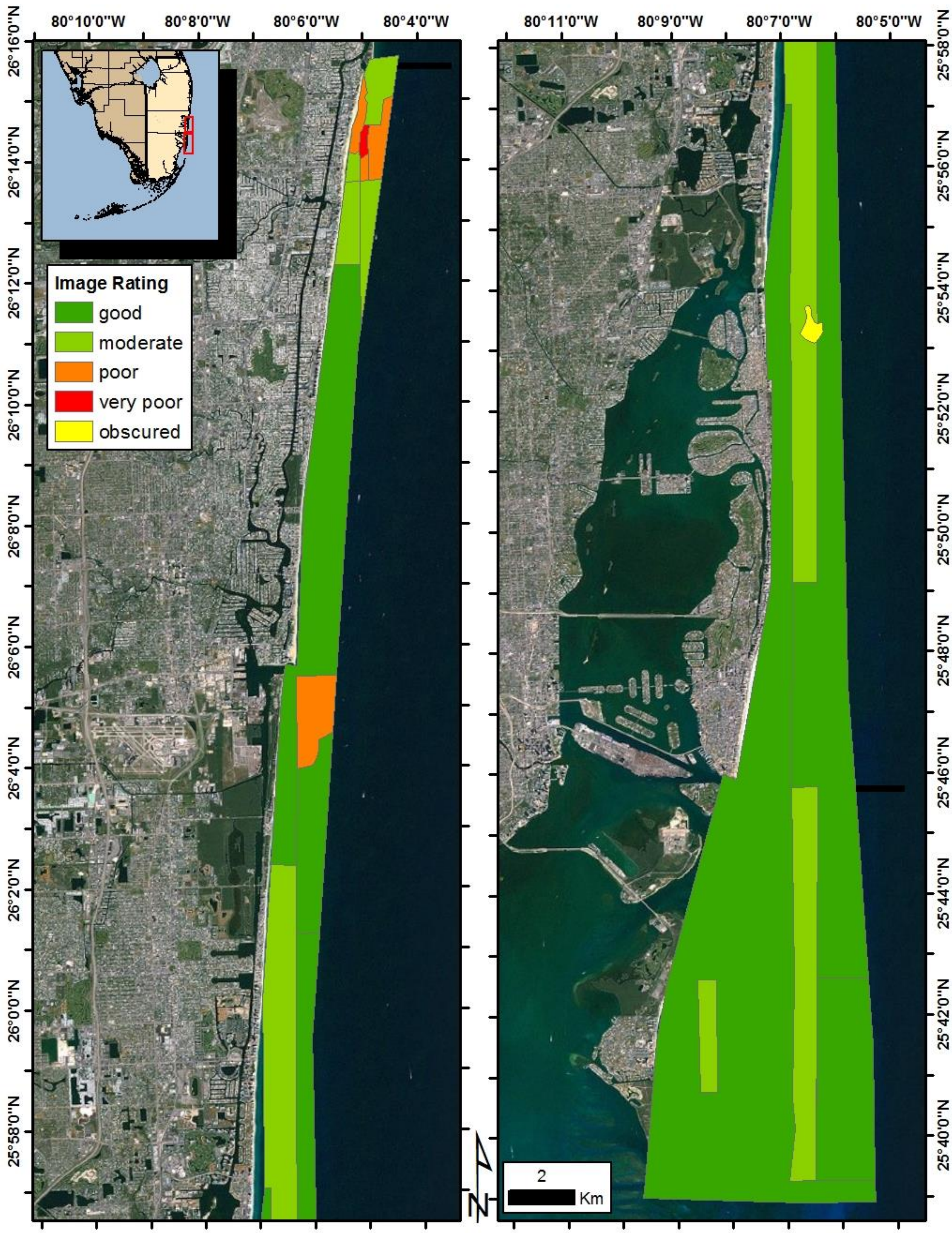


Figure 3. *Map of the 2013 aerial photography usability ratings. Only 3% of the area was rated Poor, Very poor, and Obscured.*

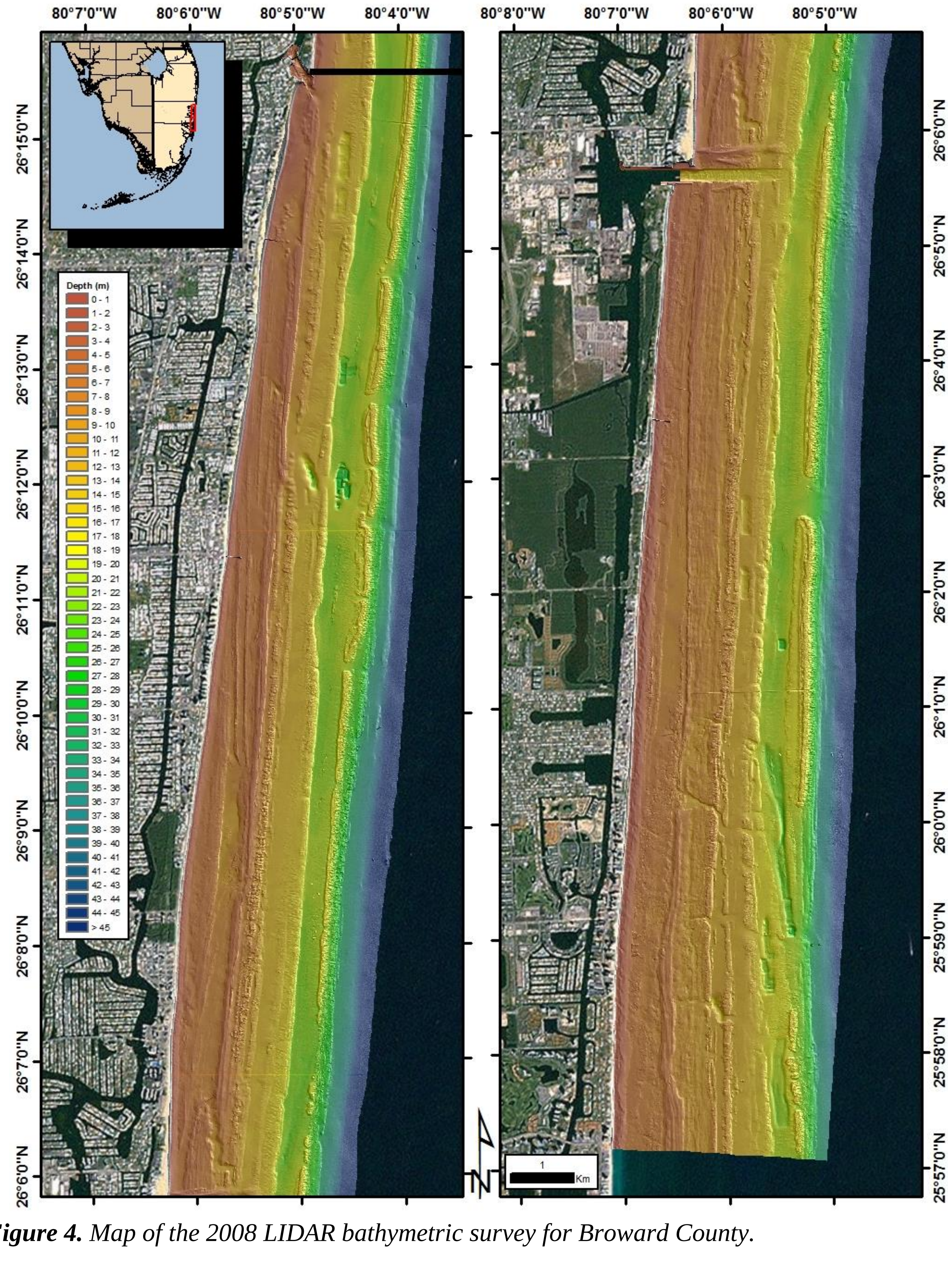


Figure 4. *Map of the 2008 LIDAR bathymetric survey for Broward County.*

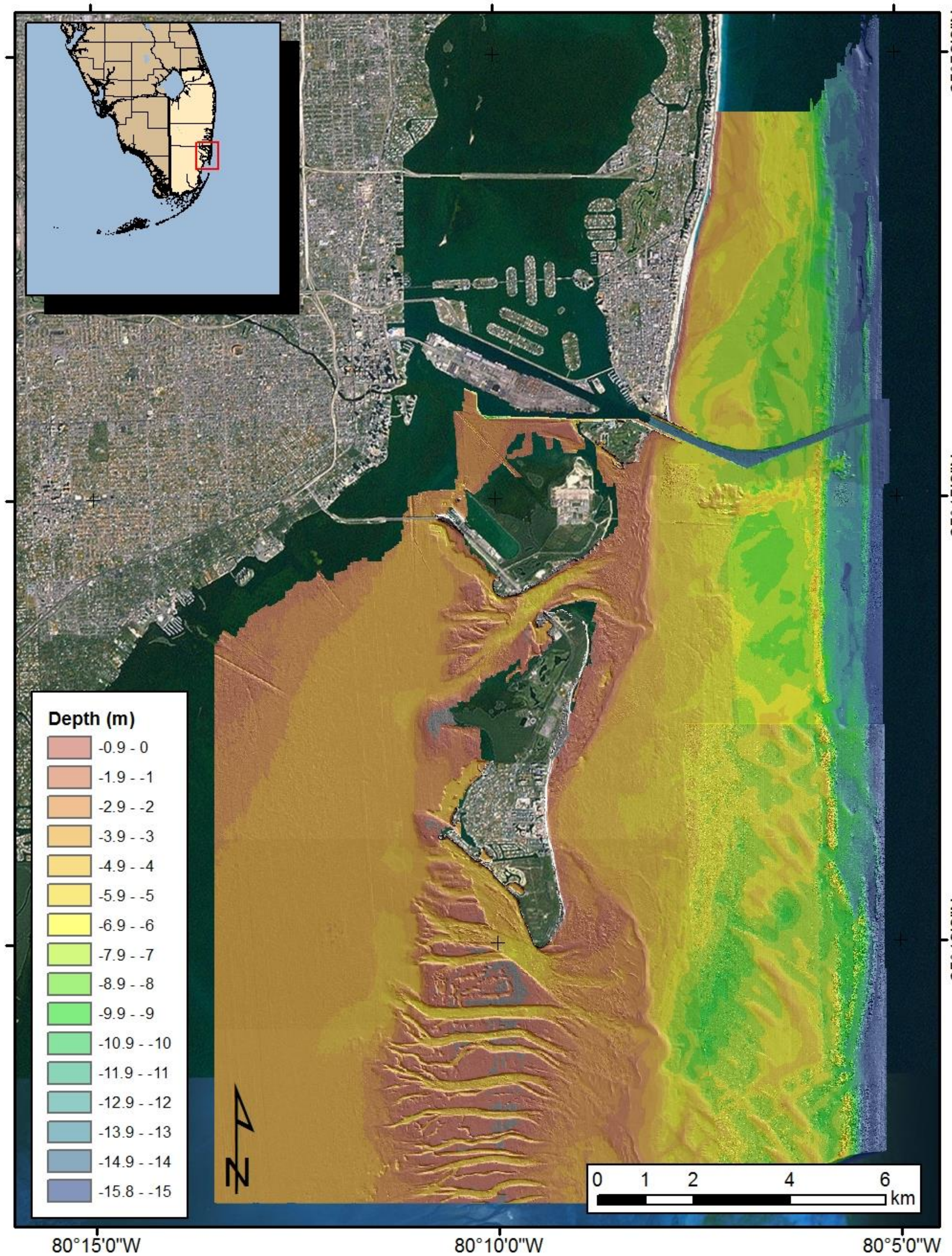


Figure 5. *Map of the 2009 NOAA OCS bathymetric survey for Miami-Dade County. Black and white area is side scan sonar data.*

2.3. Benthic Classification

In ArcGIS using the remote data (aerial photographs, LIDAR, etc.), habitat polygons were drawn at a 1:1000 scale and a minimum mapping unit of 0.1 hectare. The final map polygons conformed to the previous southeast Florida mapping scheme which were based on the NOAA hierarchical classification scheme used in Puerto Rico and the U.S. Virgin Islands NOAA Technical Memorandum National Ocean Service (NOS) National Centers for Coastal Ocean Science (NCCOS) Center for Coastal Monitoring & Assessment (CCMA) 152 (Kendall et al., 2002) with some modification. The criteria for habitat classification were defined by their location, geomorphologic characteristics, and biologic communities.

The NOAA hierarchical classification scheme for structure described in NOAA Coral Reef Conservation Program's (NOAA CRCP) "classification scheme for mapping the shallow-water coral ecosystems of southern Florida" (Rohmann, 2008) served as a basis upon which to characterize the specific benthic habitats. NOAA's classification contains nine reef zones according to the feature's relationship along the shore (i.e. lagoon, back reef, fore reef, bank/shelf, etc.); however, many of these mapped zones did not apply in the mapped area. The absence of an emergent reef in Southeast Florida precluded mapping zones such as lagoon, back reef, and reef crest. Also our effort was confined to depths between 0m and 10m mean lower low water, which excluded the land. The intertidal zone was not distinguished in this project. Thus, all features mapped in this project reside within the Bank/Shelf zone.

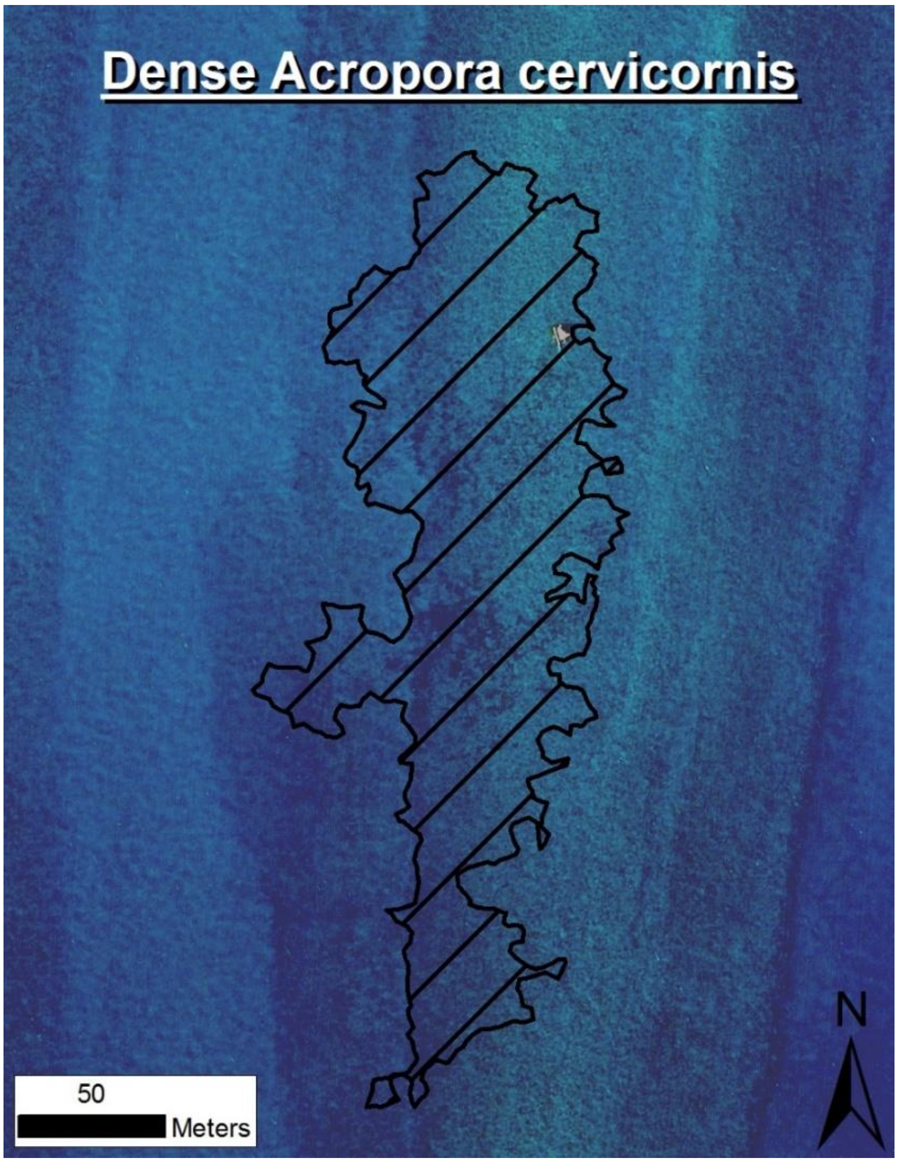
Changes to the NOAA scheme included the addition of ridge and sand borrow area categories, the inclusion of "Linear Reef "category in lieu of "Aggregate Reef", the inclusion and modification of two seagrass categories, and the inclusion of a depth component for many classes. "Linear Reef" was a previous NOAA classifier that was adopted in previous southeast Florida mapping. Its definition fits well with the reef system in southeast Florida and was therefore retained instead of using the more recent NOAA descriptor "Aggregate Reef". The Biscayne ecosystem region contained significant areas of seagrasses, therefore two categories of seagrasses were used: Continuous and Discontinuous. Acoustic ground discrimination results from previous mapping substantiated including a depth component to the colonized pavement, ridge, aggregated patch reef, and sand classes to indicate that habitat on these features varied with water depth. Although all mapping for this project was shallow, these modifiers were retained for future integration into the larger-scale regional map.

The definition of patch reef was problematic. The term is generally not well defined and depend on scale. At what size does a patch reef become something else (e.g. Linear Reef)? What is the difference between a small patch of colonized pavement and a patch reef? Brock et al. (2008) reported a GIS analysis of 1,034 patch reefs east of southern Biscayne Bay. They reported that the planar area of these patch reefs was a mean of 1,111.33m^2 ranging from 92.65m^2 to 13,678.65m^2 and the mean relative relief was 3.48m ranging from 1.00m to 11.17m. These criteria were used to guide mapping decisions on whether a feature was a patch reef or colonized pavement. In general, if it had some relief and was small, it was considered an Individual Patch Reef. If there were many patch features smaller than the minimum mapping unit in close proximity of one another, they were considered Aggregated Patch Reefs.

Coral Reef and Hardbottom: Hardened substrate of unspecified relief formed by the deposition of calcium carbonate by reef building corals and other organisms (relict or ongoing) or existing as exposed bedrock.

Coral Reef and Colonized Hardbottom: Substrates formed by the deposition of calcium carbonate by reef building corals and other organisms or existing as exposed bedrock. Habitats within this category have some colonization by live coral.

Dense *Acropora cervicornis*: areas of semi-continuous *A. cervicornis* coverage, containing large thickets (>100m²), small thickets (<100m²), individual colonies, and small fragments, within close proximity to one another (<4m).

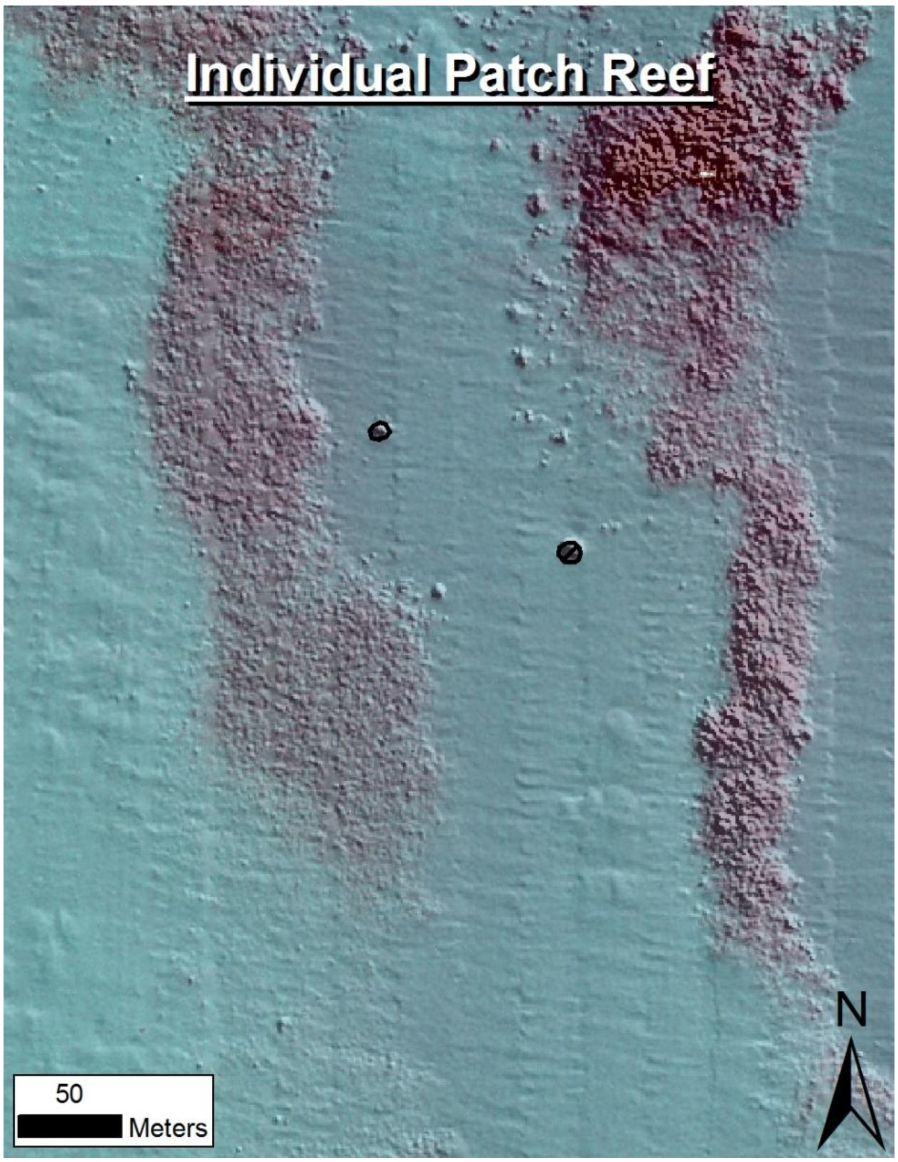


Linear Reef: Linear coral formations that are oriented parallel to shore or the shelf edge. These features follow the contours of the shore/shelf edge. This category is used for such commonly used terms as fore reef, fringing reef, and shelf edge reef.

Linear Reef-Inner: A distinct, relatively continuous, shore-parallel reef that consists of a rich coral reef community which crests in approximately 8 m depth. The inner reef has an immature reef formation growing atop antecedent shallow colonized pavement. Previous acoustic and biological data indicates a distinct benthic community.

Patch Reef: Coral formations that are isolated from other coral reef formations by sand, seagrass, or other habitats and that have no organized structural axis relative to the contours of the shore or shelf edge. A surrounding halo of sand is often a distinguishing feature of this habitat type when it occurs adjacent to submerged vegetation.

Individual Patch Reef: Distinctive single patch reefs that are equal to or larger than the minimum mapping unit (MMU).



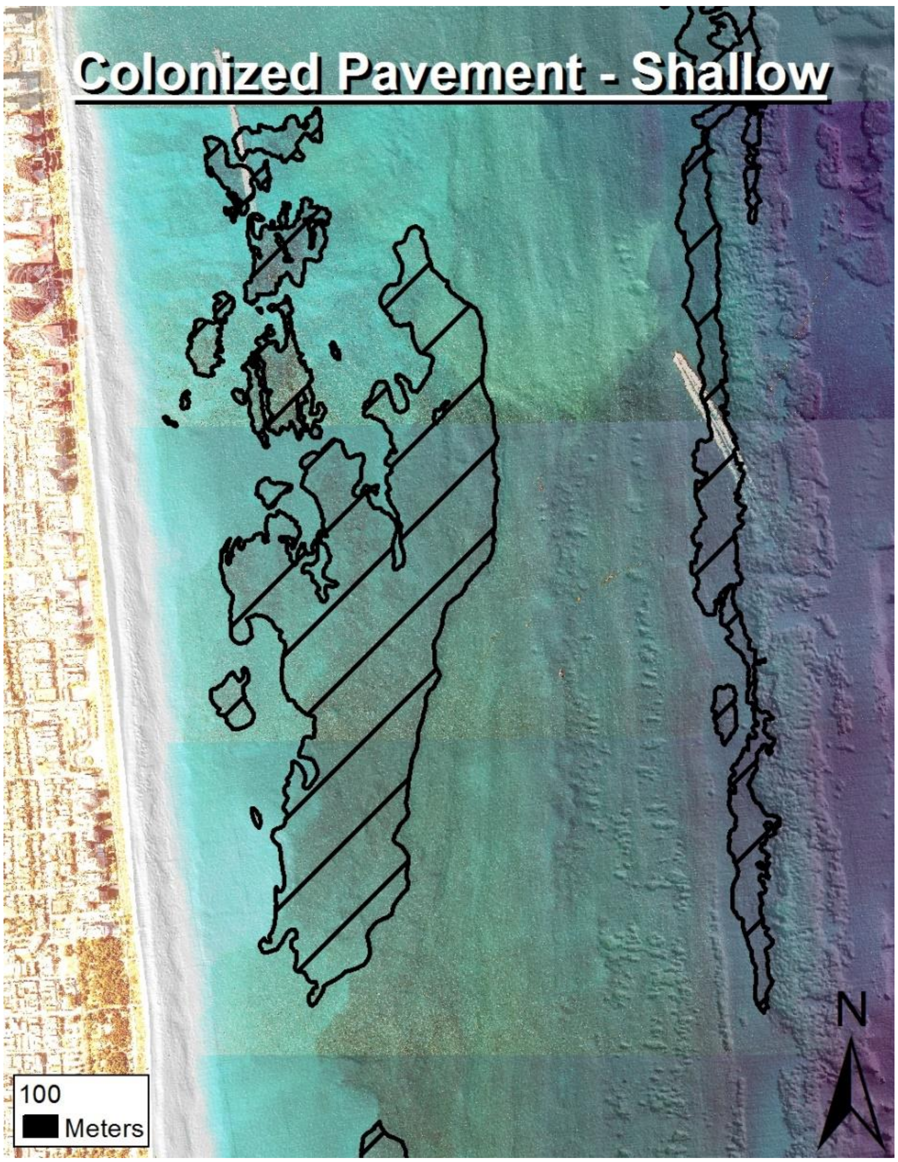
Aggregated Patch Reef: Clustered patch reefs that individually are too small (smaller than the MMU) or are too close together to map separately.

Aggregated Patch Reef-Shallow: Clustered patch reefs that individually are too small (less than the MMU) or are too close together to map separately that occur in water depths less than 20 m.

Scattered Coral/Rock in Unconsolidated Sediment: Primarily sand bottom with scattered rocks that are too small to be delineated individually in water shallower than 20 m.

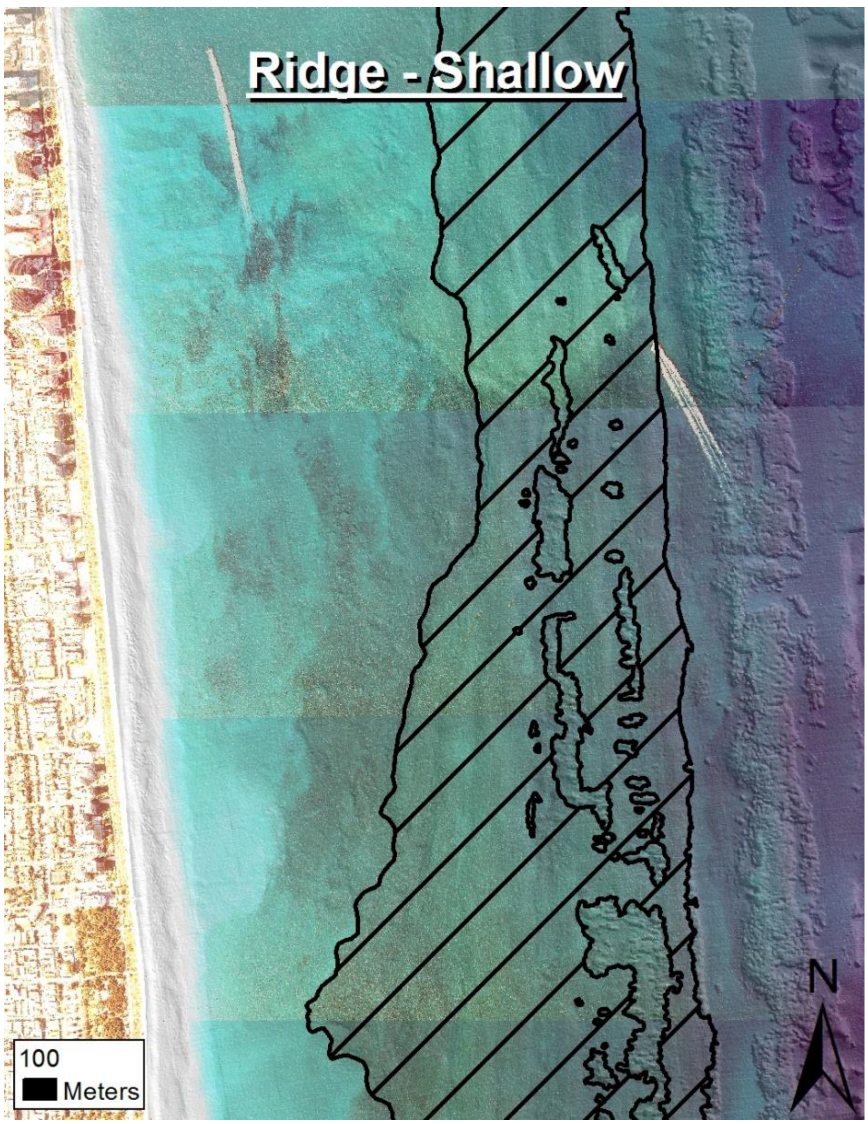
Colonized Pavement: Flat, low-relief, solid carbonate rock with coverage of macroalgae, hard coral, gorgonians, and other sessile invertebrates that are dense enough to partially obscure the underlying carbonate rock.

Colonized Pavement-Shallow: Colonized pavement in water shallower than 10m. This category includes rubble in many areas; however, consolidated rubble fields are a less frequent feature in shallow water. Especially inshore of the ridge complexes, limited rubble is found and a wide, contiguous area of pavement is encountered. This area can have variable sand cover, which shifts according to wave energy in response to weather. Thus, some of the colonized pavement will always be covered by shifting sand and the density of colonization will be highly variable.



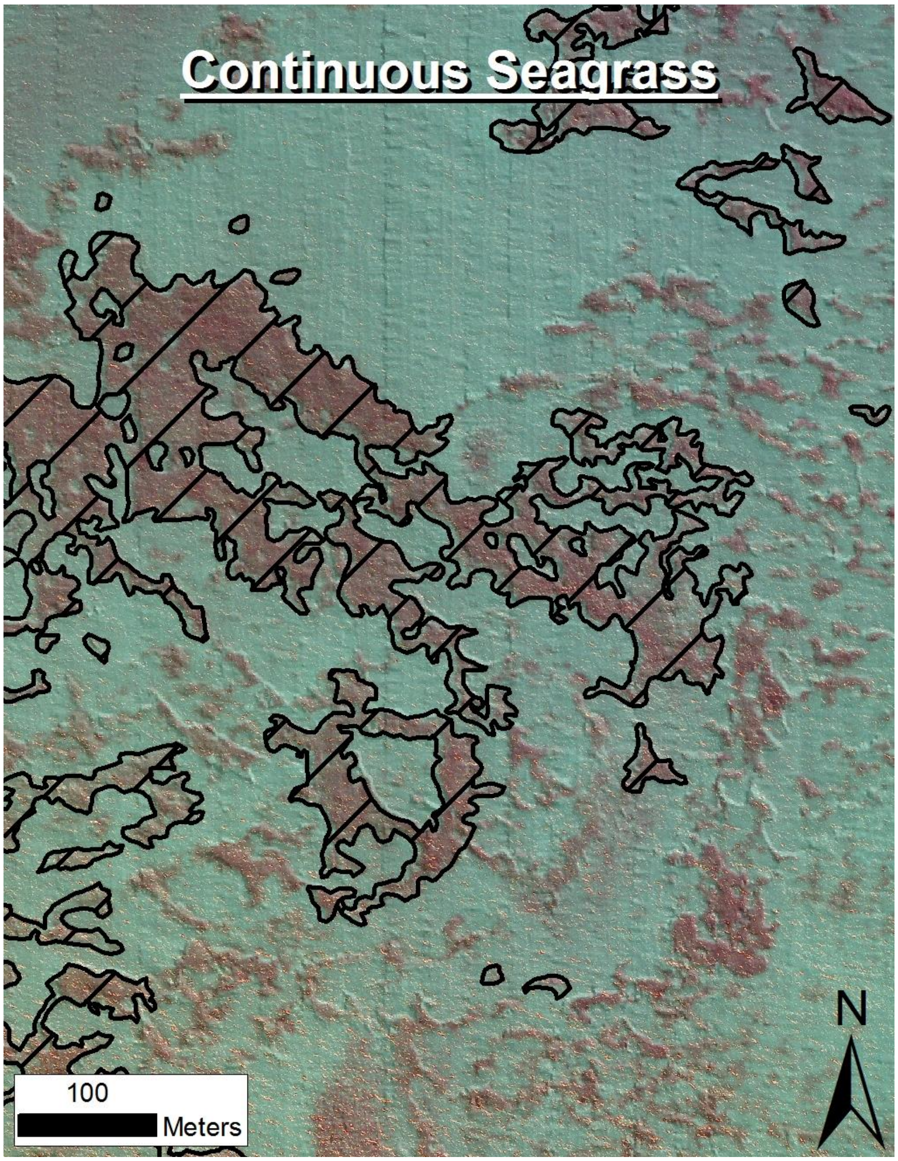
Ridge: Linear, shore-parallel, low-relief features that appear to be submerged cemented ancient shoreline deposits. Presumably, they are an extension of the foundation upon which the linear reefs grew further south and consist of early Holocene shoreline deposits; however, verification is needed. The biological cover is similar to that of colonized pavement with macroalgae, scleractinians, gorgonians, and other sessile invertebrates that are dense enough to partially obscure the underlying carbonate rock.

Ridge-Shallow: Linear, often shore-parallel, low-relief features found in shallow water near shore that are geomorphologically distinct, yet their benthic cover remains similar to the shallow colonized pavement communities on the surrounding hard grounds. They presumably consist of early Holocene shoreline deposits with possibly some *Acropora* framestones. However, verification is needed.

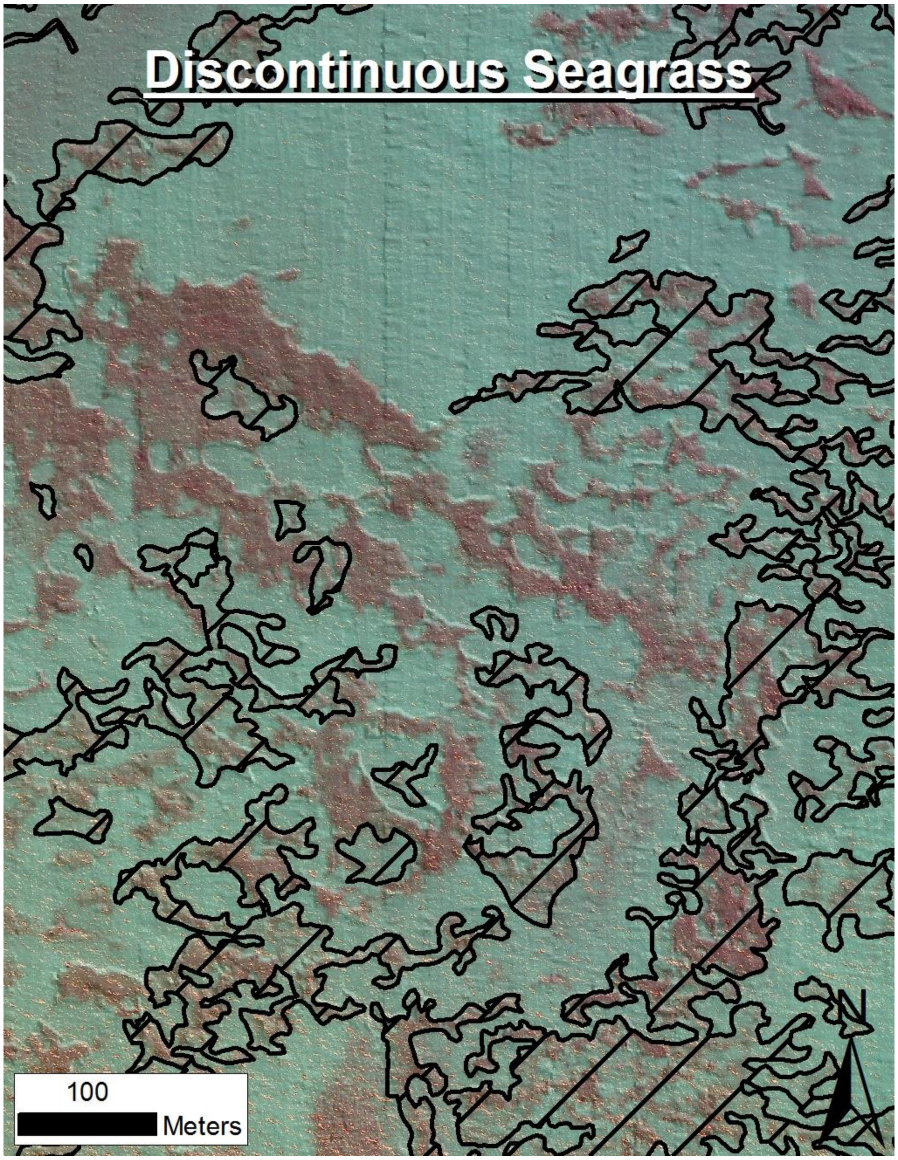


Seagrass: Habitat with 10 percent or more cover of *Thalassia testudinum* and/or *Syringodium filiforme*.

Continuous Seagrass: Seagrass community covering 90 percent or greater of the substrate. May include blowouts of less than 10 percent of the total area that are too small to be mapped independently (less than the MMU).



Discontinuous Seagrass: Seagrass community with breaks in coverage that are too diffuse, irregular, or result in isolated patches that are too small (smaller than the MMU) to be mapped as continuous seagrass.



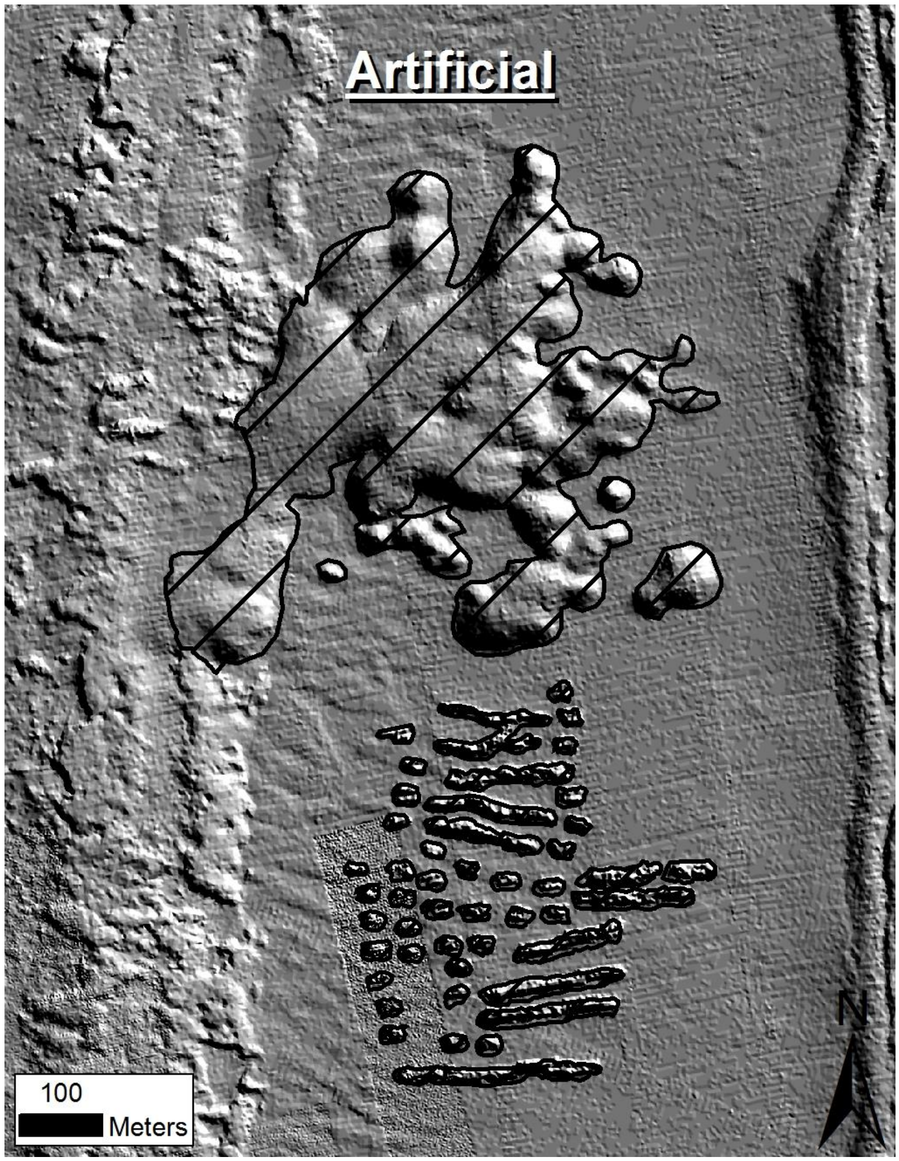
Unconsolidated Sediments: Unconsolidated sediment with less than 10 percent cover of submerged vegetation.

Sand: Coarse sediment typically found in areas exposed to currents or wave energy.

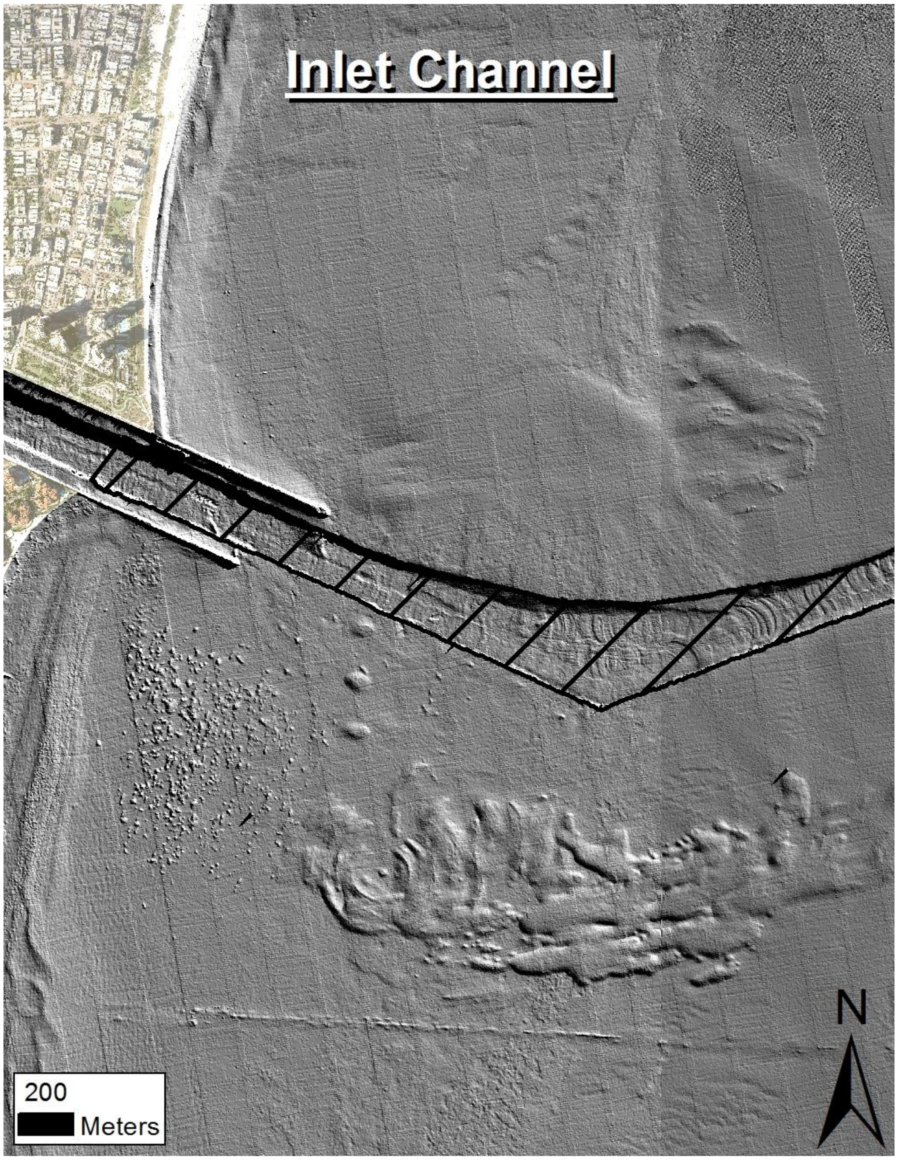
Sand–Shallow: Shallow water (< 25m) sediment exposed to a higher energy environment. Large, mobile sand pockets are found on the areas of consolidated hardgrounds. It is believed that the sand movement is a deciding factor in the generation of benthic patterns.

Other Delineations:

Artificial: Manmade habitats such as submerged wrecks, large piers, submerged portions of rip-rap jetties, and the shoreline of islands created from dredge spoil.



Inlet Channel: All inlet channels in the survey area are maintained artificially and are characterized by dredged bottom and spoil ridges on the flanks.



Sand Borrow Areas: Several borrow pits from previous dredging projects are found throughout the survey area. While they are all found in sandy areas, there may be exposed limestone present that can harbor a strongly localized and patchy, but sometimes dense, benthic fauna.

2.4. Groundtruthing

2.4.1. Qualitative

In total, 265 groundtruthing locations were visited to aid in feature identification (Figure 6). Groundtruthing was conducted by visiting locations identified in the remote data that needed field confirmation. This occurred in one of two ways. Researchers visited sites and either snorkeled the area around the point to identify the habitat at that location collecting photos and short videos, or they used an underwater camera dropped from a boat.

The drop camera system was a Sea Viewer 950 underwater color video drop camera with a Sea-trak global positioning system (GPS) video overlay connected to a Garmin Wide Area Augmentation System (WAAS) GPS (~3m accuracy). During draft map creation, color video was taken at each target location by dropping the camera over the side of a stationary/slowly drifting vessel approximately 0.5m-2m from the bottom. Fifteen second to two minute video clips were recording directly to a digital video recorder in MPEG4 video format at 720x480 resolution and 30fps. Video length depended on the habitat type and vessel drift. Videos of large expansive sand habitats were generally short while reef habitats, especially edges, were longer.

The GPS location at the start and end of each video were entered into a database and plotted in GIS. These data were also categorized according to major habitat type at each location. The target coordinate was used for the snorkel sites. These data were then used to correct any false categorizations in the polygonal habitat layer and to determine how to map the nearshore habitats.

Following the groundtruthing, the draft map was corrected where necessary and used the train the remaining visual interpretation until the project area was fully characterized. Polygons that were adjacent to one another of the same type were merged into one seamless polygon with the exception of several features that were purposely left unmerged to indicate a distinction from one another. The draft benthic habitat polygon layer was then rigorously checked for drawing errors (e.g. overlaps and gaps) and finalized (Figure 7). Finally, the area for each benthic habitat type in the polygon layer was summarized.

The area around Government Cut was problematic due to a wide area of mobile rubble and sand near the channel on both sides that was very difficult to define the boundaries. This substrate was also difficult to fit into the classification scheme because it is likely artificial substrate (dredge spoil) that partially or fully covers the surrounding natural areas.

2.4.2. Quantitative

Quantitative groundtruthing was conducted to provide a rigorous determination of habitat types beyond qualitative efforts, valuable information about the composition of the benthic communities for resource management, and data to statistically test cross-shelf and latitudinal community differences. This effort was accomplished between April and June 2014. Five 1km wide cross-shelf corridors were placed as evenly as possible across the mapped space while maintaining consistent habitat types and amounts between corridors and avoiding any major anthropogenic influences like shipping channels and proximity to inlets and outfalls (Figure 8).

Survey site locations were stratified across three main habitats within each corridor: Colonized Pavement-Shallow, Ridge-Shallow, and Linear Reef-Inner. Five sites were randomly placed in each habitat at a minimum of 40m apart giving a total of 70 sites (Corridor 1 did not contain any Ridge-Shallow habitat).

Methodology for benthic assessments was adopted from proven local methods for species' densities and sizes (D.S. Gilliam, Dodge, Spieler, Jordan, & Goergen, 2010; D.S. Gilliam & Walker, 2011) and those used in the Mesoamerican Barrier Reef System Project (Almada-Villela et al., 2003) and the widely used Atlantic and Gulf Rapid Reef Assessment for percent cover (AGRRA, 2000). Data at each site was collected on four 20 meter point-intercept transects at an intercept density of 0.2m for a total of 400 (100 x 4) points per site. At each point, divers identified the organism under the transect tape by major functional groups (hard coral species, turf algae, macroalgae, sponge, zoanthid, etc.) or bare substrate type. In a 0.75m belt ($15m^2$ per transect) on one side of the four point intercept transects, divers recorded data on corals and gorgonians >0.4cm. Species, colony size (length, width, height), percent mortality, condition (pale or bleached), and presence of disease was recorded for stony corals. Gorgonians were categorized by morphology (rod, plume, fan) and counted in four size classes (4-10, 11-25, 26-50, and >50cm). *Xestospongia muta* and *Cliona spp*. were also counted.

A cluster analysis and corresponding non-metric multi-dimensional scaling (MDS) plot was constructed using Bray-Curtis similarity indices (PRIMER v6) of the benthic cover data (square-root transformed) to evaluate benthic cover sites. A one-way analysis of similarity (ANOSIM) was performed to statistically determine the strength of the site categorization by habitat. ANOSIM is a permutation-based hypothesis test analogous to univariate analyses of variance (ANOVAs) that tests for differences between groups of (multivariate) samples from different experimental treatments. The closer the R statistic is to 1, the stronger the categorical groups. Its strength is dependent on the number of samples per category which defines the number of possible permutations.

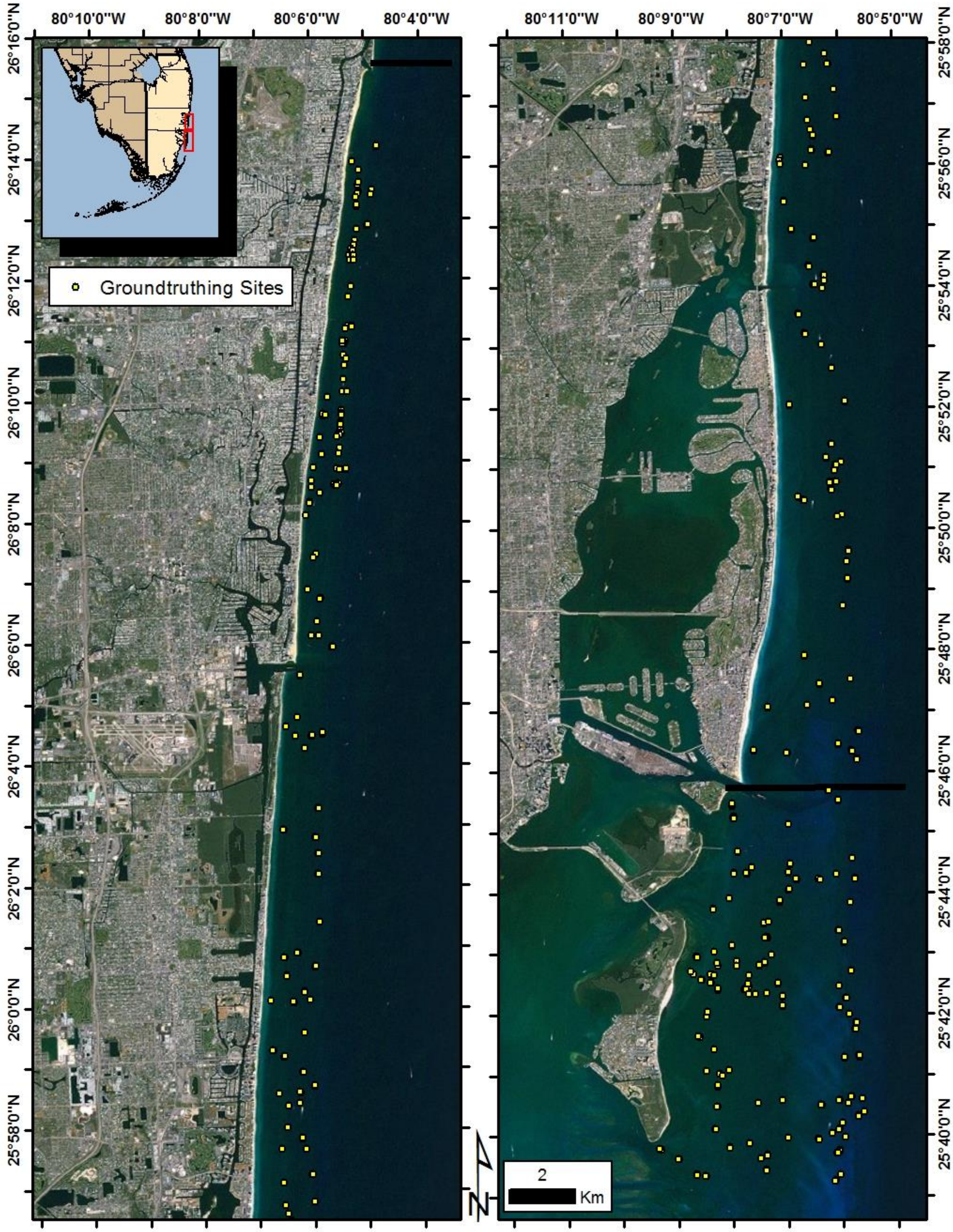


Figure 6. *Map of the 265 groundtruthing locations visited throughout the project area.*

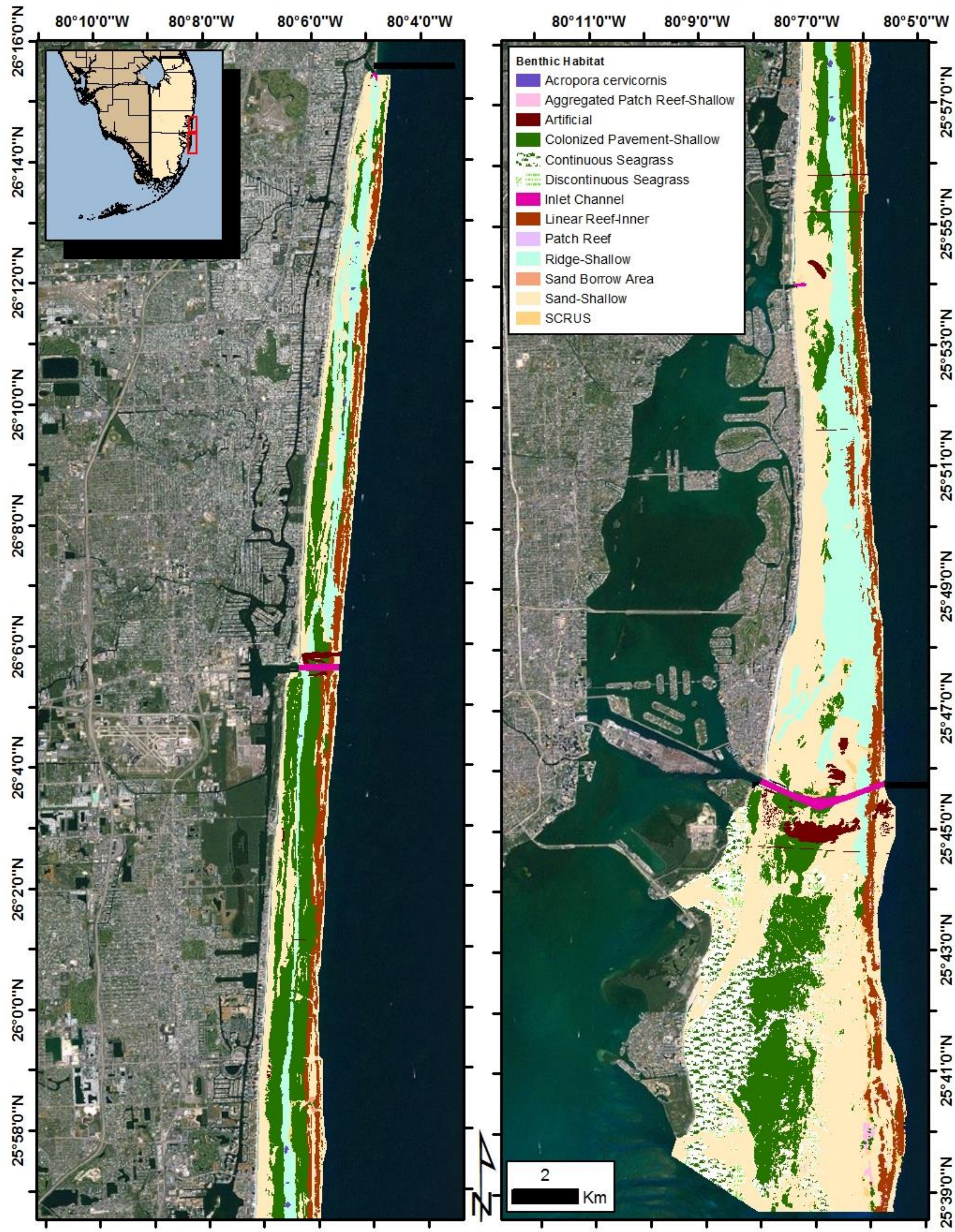


Figure 7. *Map of the final benthic habitat map overlain the ESRI Imagery base layer.*

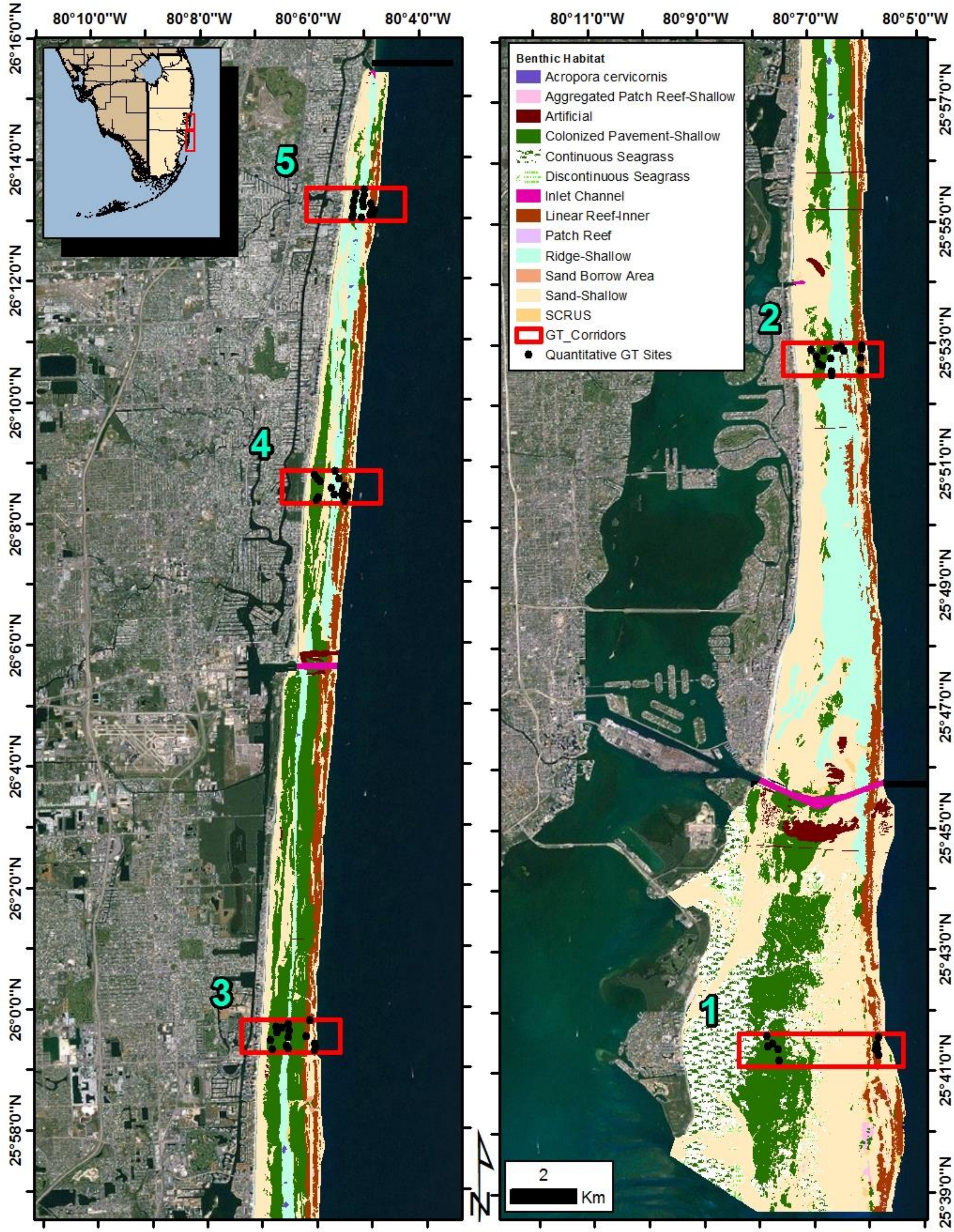


Figure 8. *Map of the 70 quantitative groundtruthing survey locations within the five cross-shelf corridors overlaying the benthic map and the ESRI Imagery base layer.*

2.5. Accuracy Assessment

2.5.1. Data Collection

Accuracy assessment (AA) target locations were determined in ArcGIS after the entire draft habitat map was complete. Target locations for the accuracy assessment procedure were determined by a GIS-based, stratified random sampling technique used in other regional mapping efforts (Walker & Foster, 2010; Walker & Gilliam, 2013; Walker, Rodericks, & Costaregni, 2013). The map proportions of all Coral Reef and Colonized Hardbottom and Artificial habitats were used to guide the percentage of assessment sites per habitat. A minimum of 20 sites were allocated per habitat. Sand-Shallow received 40 sites which is comparable to other efforts. This yielded 501 stratified random accuracy assessment target locations to be visited by drop camera and analyzed by confusion matrix approach (Figure 9).

Underwater video from a drop camera was taken at each AA target location. This procedure involved the boat positioning itself within 5m of the target. A Sea Viewer 950 underwater color video drop camera with a Sea-trak GPS video overlay connected to a Garmin 76CSx GPS with WAAS correction (<3m accuracy) was then lowered to the bottom. Color video was recorded over the side of the stationary/drifting vessel approximately 0.5-2m from the seafloor. Fifteen second to two minute video clips were recorded directly to an 80 GB digital video recorder in MPEG4 video format at 720x480 resolution and 30fps. Video length depended on the habitat type and vessel drift. Videos of large expansive sand habitats were generally short while reef habitats, especially edges, were longer. While the video was being recorded, an observer categorized each site according to the video and surrounding area into a database.

2.5.2. Data Evaluation

The GPS location at the start and end of each video was entered into a database along with the field notes and plotted in GIS resulting in a point layer of 988 locations. These data were then spatially joined to the benthic habitat layer to identify the map classification for each point. Sites that differed between field notes and map classification were evaluated both in GIS and from video to determine possible sources of disagreement. Statistical analyses to determine the thematic accuracy were derived from Congalton (1991), Hudson and Ramm (1987), and Ma and Redmond (1995). Matrices of user and producer map accuracy error, overall map accuracy error, and the Tau coefficient were generated. The producer's error matrix indicates how well the map producer can classify a given habitat type; the user's error matrix indicates how often map polygons of a certain type are classified correctly; and the Tau Statistic is a measure of the probability that a feature is correctly mapped compared to chance alone. A sampling station was considered correctly classified if the habitat type identified in the field matched the habitat type mapped by the map producer. Overall map accuracy was determined by dividing the total of the correctly classified sampling locations in the error matrix by the total number of sampling locations.

Two benthic habitat classes found in the draft benthic habitat map were excluded from the accuracy analysis; the Inlet Jetty and Sand Borrow Area. These were excluded because they are unnatural habitats, although artificial was included because of their ecologic value.

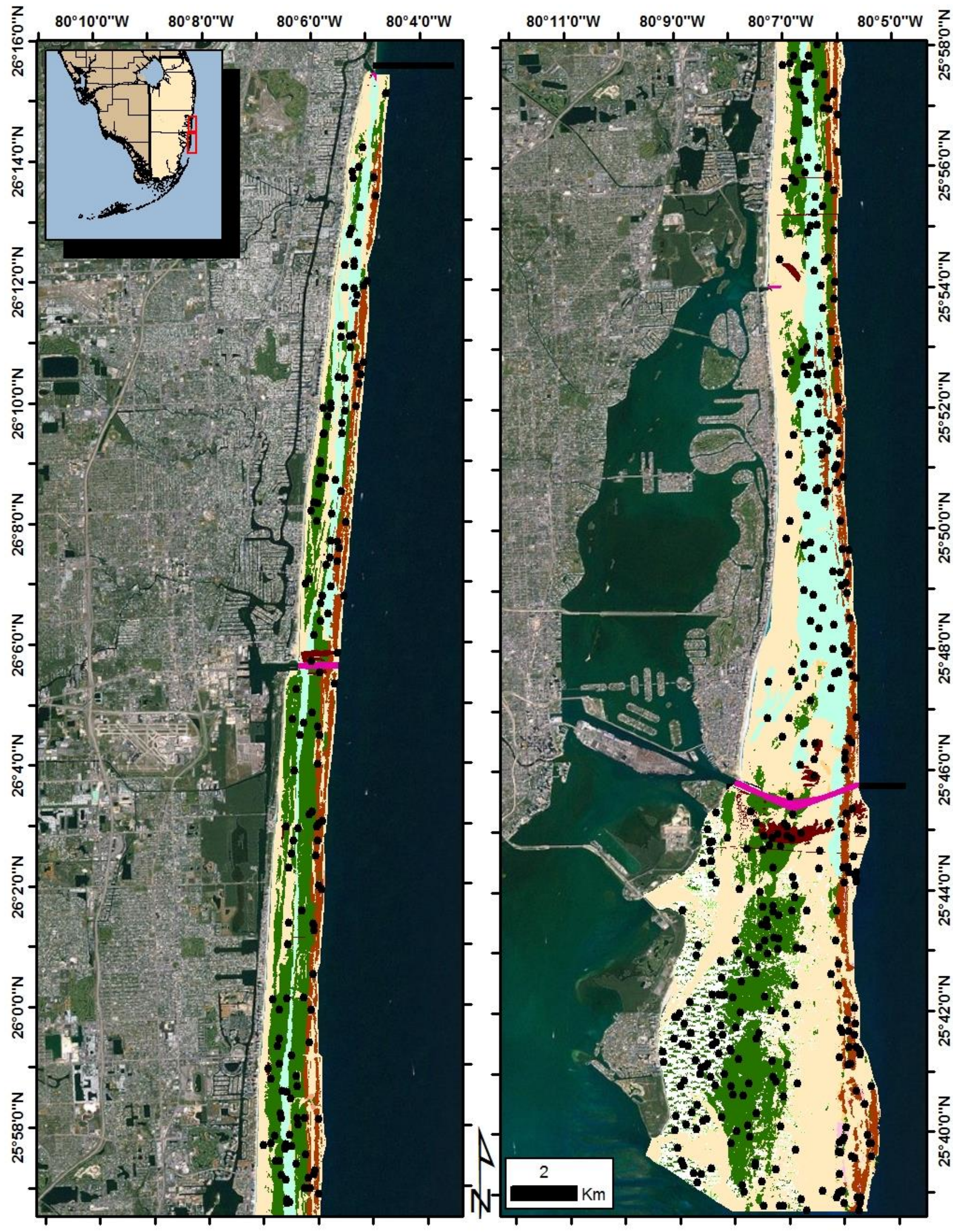


Figure 9. *Stratified random accuracy assessment locations (black dots) overlain on the draft benthic habitat map and the ESRI world imagery.*

2.5.3. Data Analyses

A number of statistical analyses were used to characterize the thematic accuracy of the benthic habitat map. A total of four error matrices were prepared for the attributes of Major and Detailed Habitat levels of classification. Overall accuracy, producer's accuracy, and user's accuracy were computed directly from the error matrices (Story & Congalton, 1986). Direct interpretation of these producer's and overall accuracies can be problematic, as the stratified random sampling protocol can potentially introduce bias (Hay, 1979; J. van Genderen & Lock, 1977; J. L. Van Genderen, Lock, & Vass, 1978). Stratification ensures adequate representation of all map categories, by assigning an equal number of accuracy assessment to each map category, using the draft benthic habitat map as a guide. This caused rare map categories to be sampled at a greater rate (observations per unit area) than common map categories. The bias introduced by differential sampling rates was removed using the method of Card (1982), which uses the known map marginal proportions, i.e. the relative areas of map categories. The map marginal proportions were calculated as the area of each map category divided by the total area calculated from the habitat map polygons. The map marginal proportions were also used in the computation of confidence intervals for the overall, producer's, and user's accuracies (Card 1982). The efficacy of the habitat map was further examined by computation of the Tau coefficient, which adjusted the overall accuracies based on the number of map categories, allowing for statistical comparison of error matrices of different sizes (Ma and Redmond 1995). As a classification metric, Tau is a measure of the improvement of the classification scheme over a random assignment of polygons to categories, bounded between -1 (0% overall accuracy for 2 map categories) and 1 (100% accuracy for any number of categories).

The error matrices were constructed as a square array of numbers arranged in rows (map classification) and columns (true, or ground truthed classification). The overall accuracy (P_o) was calculated as the sum of the major diagonal, i.e. correct classifications, divided by the total number of accuracy assessment samples. The producer's and user's accuracies are both category-specific. Each diagonal element was divided by the column total to yield a producer's accuracy and by the row total to yield a user's accuracy. The producer's and user's accuracies provide different perspectives on the classification accuracy of a map. The producer's accuracy (omission/exclusion error) indicates how well the mapper classified a particular habitat, e.g. the percentage of times that substrate known to be sand was correctly mapped as sand. The user's accuracy (commission/inclusion error) indicates how often map polygons of a certain habitat type were classified correctly, eg. the percentage of times that a polygon classified as sand was actually sand. The distinction between these two types of error is subtle. For example, the user's accuracy for the map category of sand is calculated as the number of accuracy assessment points that were mapped as sand and later verified to be sand, divided by the total number accuracy assessment points that were mapped as sand. But this measure of user's accuracy for mapping sand totally ignores points that were verified to be sand, but mapped as something else, i.e. producer's error.

Considering the uneven distribution of map category area in the map, a simple random assignment of accuracy assessment points would have required an unrealistically large number of points to adequately cover all map categories. The stratified random sampling protocol was used to ensure that each habitat class would be adequately sampled, assigning an equal number of accuracy assessment points to each map category of Detailed Habitat (modifier) within the mapped area. As previously mentioned, this non-random sampling method introduced bias in the producer's and overall accuracies, as map categories with very large areal extents were sampled at the same rate as categories with very small extents.

To remove the bias introduced by the stratified random sampling procedure, the overall and producer's accuracies were adjusted to the known areal proportions of map categories (Card, 1982). The known map marginal proportions (π_i) were computed from the GIS layer of the draft benthic habitat map for each of the four error matrices, by dividing the area of each category by the total map area. Then the individual cell probabilities, i.e. the product of the original error matrix cell values and π_i, divided by the row marginal (total map classifications per category), were computed for the off-diagonal elements using the following equation:

$$\hat{P}_{ij} = \pi_i n_{ij} / n_{i-}$$

The relative proportions of the cell values within a row of the error matrix were unaffected by this operation, but the row marginals were forced to the known map marginal proportions, i.e. the row total of a particular habitat now equaled the fraction of map area occupied by that habitat, instead of the total number of accuracy assessment points. The estimated true marginal proportions were computed as the sum of individual cell probabilities down each column of the error matrix. The π_i-adjusted overall, producer's, and user's accuracies were then computed from the new error matrix, now populated by individual cell probabilities. The values of the π_i-adjusted overall and producer's accuracies differ by design from those of the original error matrix, as they have been corrected for the areal bias introduced by the stratified random sampling protocol. The variances and confidence intervals of the overall, producer's, and user's accuracies were then computed from the following set of equations:

Overall Variance = $V(\hat{P}_c) = \sum_{i=1}^{r} p_{ii}(\pi_i - p_{ii}) / n_{i-})$

Overall Confidence Interval = $\hat{P}_c \pm 2[V(\hat{P}_c)]^{1/2}$

Producer's Variance = $V(\hat{\theta}_{ii}) = p_{ii} p_i^{-4} [p_{ii} \sum_{j \neq 1}^{r} p_{ij}(\pi_i - p_{ij}) / n_{i-} + (\pi_i - p_{ii})(p_i - p_{ii})^2 / n_{i-j}]$

Producer's Confidence Interval = $\hat{\theta}_{ii} \pm 2[V(\hat{\theta}_{ii})]^{1/2}$

User's Variance = $V(\hat{\lambda}_{ii}) = p_{ii}(\pi_j - p_{ii}) / n_{i-}$

User's Confidence Interval = $\hat{\lambda}_{ii} \pm 2[V(\hat{\lambda}_{ii})]^{1/2}$

The Tau coefficient is a measure of the improvement of classification accuracy over a random assignment of map units to map categories (Ma & Redmond, 1995). For a supervised classification scheme there are two possible forms of the Tau coefficient, differing only by the estimation of the probability of random agreement (P_r). In one case it is known *a priori* that the probability of class membership differs among map categories, e.g. a previous map that quantified the disproportionate areal extents of habitat classes. In this case, Tau (T_p) is an adjustment of overall accuracy (P_o) by the number of groups (r) and the *a priori* probabilities informing the classification. In the other case it is not possible to quantify the *a priori* disparities of group membership. In the case of the SE Florida nearshore benthic habitat map there was no *a priori* information available, and thus a Tau based on equal probability of group membership (T_e) was used to evaluate classification accuracy. In this case, the probability of random agreement simplifies to the reciprocal of the number of map categories ($1/r$), and T_e is simply an adjustment of P_o by the number of map categories. As the number of categories increases, the probability of random agreement diminishes, and T_e approaches P_o. Values of T_e were calculated as follows:

Tau coefficient for equal probability of group membership = $T_e = (P_o - 1/r) / (1 - 1/r)$

Because there are only two possible outcomes for each accuracy assessment point, i.e. correct or incorrect, the probability distribution of P_o follows a binomial distribution. However, when the total number of accuracy assessment samples within the error matrix is large, i.e. $n > 100$, the probability distribution of P_o approximates a normal distribution (Steel & Torrie, 1960). Given that the distribution of P_o approximates normality, it can then be assumed that the distribution of T_e will also approximate normality (Kohen, 1960). Because the individual row values of P_r are fixed before the map is classified, i.e. equal to $1/r$, they can be treated as constants and a variance can be calculated for Tau (Ma and Redmond 1995):

Variance of Tau coefficient = $\sigma_r^2 = P_o(1 - P_o) / n(1 - P_r)^2$

Confidence intervals were then calculated for each Tau coefficient at the 95% confidence level ($1-\alpha$), using the following generalized form:

95% CI = $T_e \pm Z_{\alpha/2}(\sigma_r^2)^{0.5}$

3. RESULTS & DISCUSSION

3.1. Benthic Habitat Mapping

Of the 172.73km² seafloor mapped, the polygon totals indicated 41.34% was Sand, 47.07% was Coral Reef and Colonized Pavement, 9.35% was Seagrass, and 2.25% was Other Delineations (Table 2). These totals are estimates due to some habitats having a large mix of sand within. For example, the Scattered Coral/Rock in Sand (SCRUS) category contained varying unknown ratios of sand to hardbottom. This habitat comprised 1.62km² of habitat, 0.94% of the total area, so the impact of this issue is minimal. This aspect inflates the area summaries of hardbottom habitats. Therefore the areas in Table 2 for Aggregated Patch Reef-Shallow, Scattered Coral Rock in Sand-Shallow, and Discontinuous Seagrass are over estimates.

Three habitat types dominated the mapped hardbottom area. The largest was Colonized Pavement (38.36km²), followed by Ridge-Shallow (25.52km²), and Linear Reef-Inner (14.99km²). These comprised 97% of the hardbottom habitats. SCRUS comprised 2% and Aggregated Patch Reef, Patch Reef, and dense *Acropora cervicornis* made up 1% of the mapped hardbottom habitats.

Seagrass accounted for 9.35% of the map and was solely contained south of Government Cut. Continuous Seagrass comprised 73.7% of the mapped seagrasses and Discontinuous comprised 26.3%. Sand comprised 41.34% of the map and Other Delineations accounted for 2.25%. Artificial habitats accounted for 66.7% of the Other Delineations, the largest of which were focused near Government Cut and Port Everglades.

Aside from the updated habitat areas reported herein, the previous literature on the habitat morphologies and histories are still relevant for this mapped spaced. See Walker (2012), Walker (2009), and Walker et al. (2008) for more details.

The increased resolution from 0.4 hectare minimum mapping unit to 0.1 hectare resulted in differences in habitat areas between the previous map and the new one (Table 3). As expected, the area of Continuous Seagrass increased by 39% whereas the area of Discontinuous Seagrass dropped by 55%. This was mostly due to the increased resolution. Areas of Continuous Seagrass that were previously smaller than the minimum mapping unit (0.4ha) were previously included in the Discontinuous Seagrass category. Increasing resolution gave a finer depiction of the Continuous Seagrass habitat and leading to a reduction in Discontinuous Seagrass. Other causes for differences in seagrass area were not investigated. Another notable affect from resolution was the decrease in area of Aggregated Patch Reef habitat because delineating features at a higher resolution incorporated less sediment into the polygon. The high resolution images and LIDAR enabled a better depiction of Scattered Coral/Rock in Sand (SCRUS) habitats (Figure 10). The finer details in the newer remote data facilitated the visualization of this habitat by distinguishing slight differences in seafloor color and smaller features visible in the bathymetry that were not previously possible.

Table 2. *SE Florida nearshore benthic habitat polygon areas. Hierarchical habitats are nested within broader categories to the left. The total area in km² and the percent of the total mapped area are given for each category in all three hierarchical levels.*

SE FL Nearshore Benthic Habitat Areas (km²) v3

Habitat	Type	Modifier	Modifier Area (km²)	Habitat Area (km²)
Coral Reef and Colonized Hardbottom	Acropora cervicornis		0.16 ; 0.09%	81.30 ; 47.07%
	Colonized Pavement	Shallow	38.36 ; 22.21%	
	Ridge	Shallow	25.52 ; 14.77%	
	Linear Reef	Inner	14.99 ; 8.68%	
	Aggregated Patch Reef	Shallow	0.64 ; 0.37%	
	Patch Reef	Shallow	0.013 ; 0.008%	
	Scattered Coral/Rock in Sand	Shallow	1.62 ; 0.94%	
Unconsolidated Sediment	Sand	Shallow	71.40 ; 41.34%	71.40 ; 41.34%
Seagrass	Seagrass	Continuous	11.89 ; 6.88%	16.14 ; 9.35%
		Discontinuous	4.25 ; 2.46%	
Other Delineations	Artificial		2.59 ; 1.50%	3.88 ; 2.25%
	Inlet Channel		1.17 ; 0.67%	
	Sand Borrow Area		0.13 ; 0.07%	
Total Mapped Area (km²)			172.73 100.00%	172.73 ; 100.00%

Table 3. *Comparison between the SE Florida nearshore benthic habitat polygon areas (km^2) in the previous 0.4 hectare minimum mapping unit map and the new 0.1 hectare map.*

Habitat	Previous map 0.4 ha mmu	New map 0.1 ha mmu	Percent Difference
Acropora cervicornis	0	0.156	156%
Aggregated Patch Reef-Shallow	0.866	0.639	-26%
Artificial	2.845	2.594	-9%
Colonized Pavement-Deep	0.002	0	-100%
Colonized Pavement-Shallow	41.281	38.365	-7%
Continuous Seagrass	8.576	11.888	39%
Discontinuous Seagrass	9.513	4.255	-55%
Inlet Channel	1.177	0.000	-100%
Linear Reef-Inner	15.859	14.988	-5%
Patch Reef	0.120	0.013	-89%
Ridge-Shallow	25.581	25.516	0%
Sand-Shallow	65.906	71.403	8%
Sand Borrow Area	0.231	0.125	-46%
SCRUS-Shallow	0.630	1.623	158%
Wormrock	0.004	0	-100%

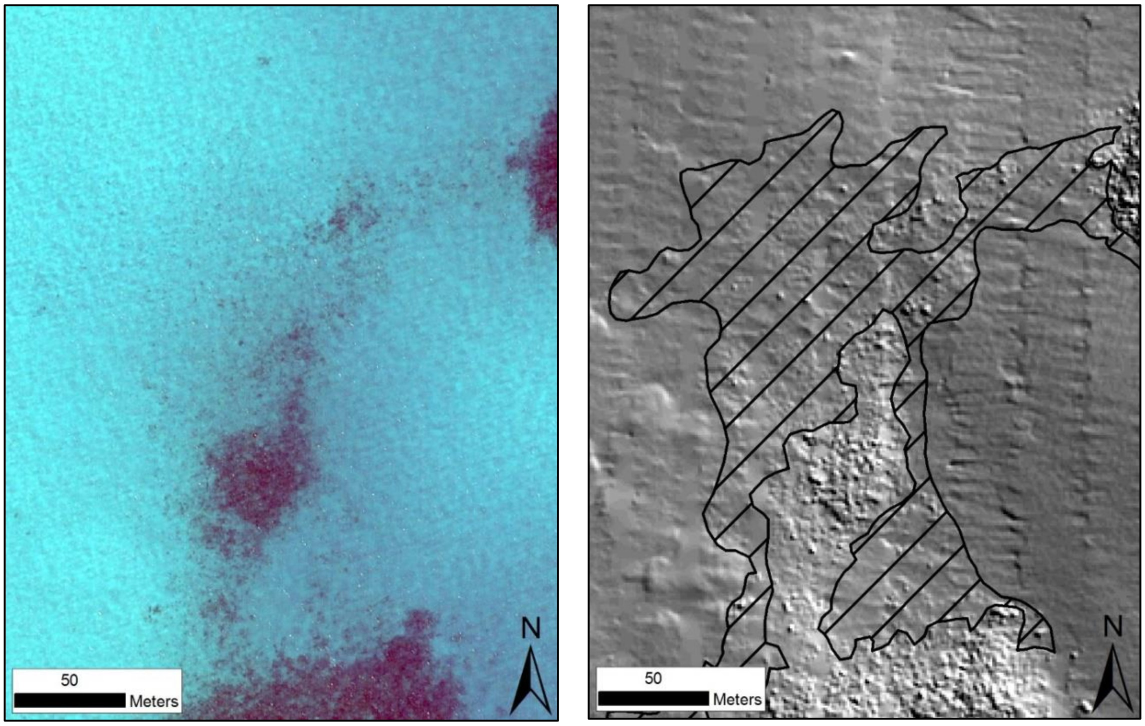


Figure 10. *An example of how the bathymetry (right) aided in the determination of Scattered Coral/Rock in Sand. This likely increased the map accuracy versus solely using the aerial imagery.*

The nearshore mapping yielded some surprising results. Relatively large areas along the Ridge-Shallow had a unique spectral signature. Some of these corresponded to known locations of dense *Acropora cervicornis*. Thus the Ridge-Shallow was visually scanned in the aerial photographs to identify all areas with a similar signature. Seventy locations were identified for groundtruthing. Thirty-five of these locations were found to be dense *A cervicornis*, only seven of which were previously reported. Dense patches of *A. cervicornis* have been known to exist along the Florida coast off Broward County for over 15 years; however, their sizes, distributions, and persistence have not been sufficiently elucidated (Vargas-Ángel, Thomas, & Hoke, 2003; Walker, Larson, Moulding, & Gilliam, 2012). These are the largest dense patches in the continental United States. Using aerial photography delineations area estimates, the seven patches near the known existing locations totaled approximately 46,000m² whereas the 28 newly confirmed areas exceed 110,000m² (Figure 11).

The identification of these new, large dense patches highlights a critical data gap in our knowledge of *A. cervicornis* distributions and population distribution, demographics, and status. The polygons depicted in the habitat map are likely under representative of the shape and sizes of these patches.

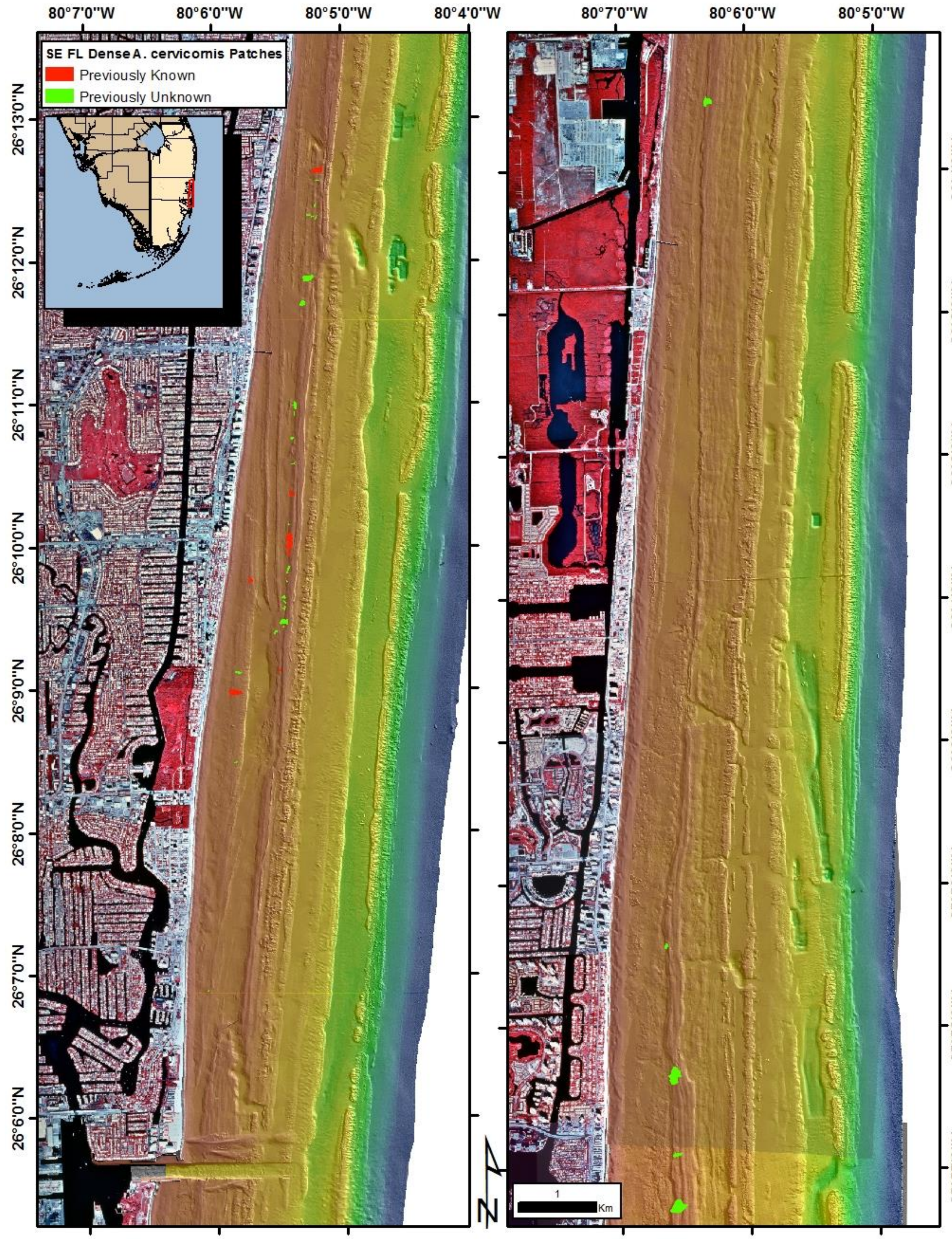


Figure 11. *The distribution of known and potential dense A. cervicornis patches along the northern FRT.*

The aerial photographs are not ideal for obtaining the size and condition of the patches because only the densest portions are visible in the imagery and there is no way to determine if it's alive. These patches usually have "fuzzy" boundaries that may extend beyond what is visible remotely, therefore, detailed patch mapping, characterization, and long-term monitoring is needed to fully inventory this resource. Walker et al. (2012) employed an in situ means of mapping these dense patches and have done so repeatedly to monitor two patches movement through time. A similar method applied to all of these new areas would provide a more realistic understanding of the area these dense patches cover. It would also provide a baseline for future reference.

Although evidence is lacking, some studies have speculated that the existence of these patches is relatively new and may be the result of climate change (Precht & Aronson, 2004). Evaluating the effect of climate change on population distribution is a challenging task, but evaluating condition of currently monitored patches and mapping, characterizing and monitoring new patches could provide critical information on the persistence and condition of patches over time. In the last ten years, some large patches have disappeared (Coral Ridge in Vargas-Ángel et al. 2003), whereas previous imagery showed that at least one new site did not exist in 2000 (Figure 12). Walker et al. (2012) suggested that the lack of framework may give the appearance the patch is recent, however asexual fragmentation caused two of the patches to spread out considerably over a three-year period leading them to the question: Are we losing coral or is it just moving outside of our monitoring areas? These new dense patches have never been mapped in detail and there is currently no information on their extent, condition, or distributions. Without a regional mapping approach, including *in situ* work and aerial photography, there is no way of knowing when new dense patches form, if they are increasing in number, and if they are moving or dissipating through time.

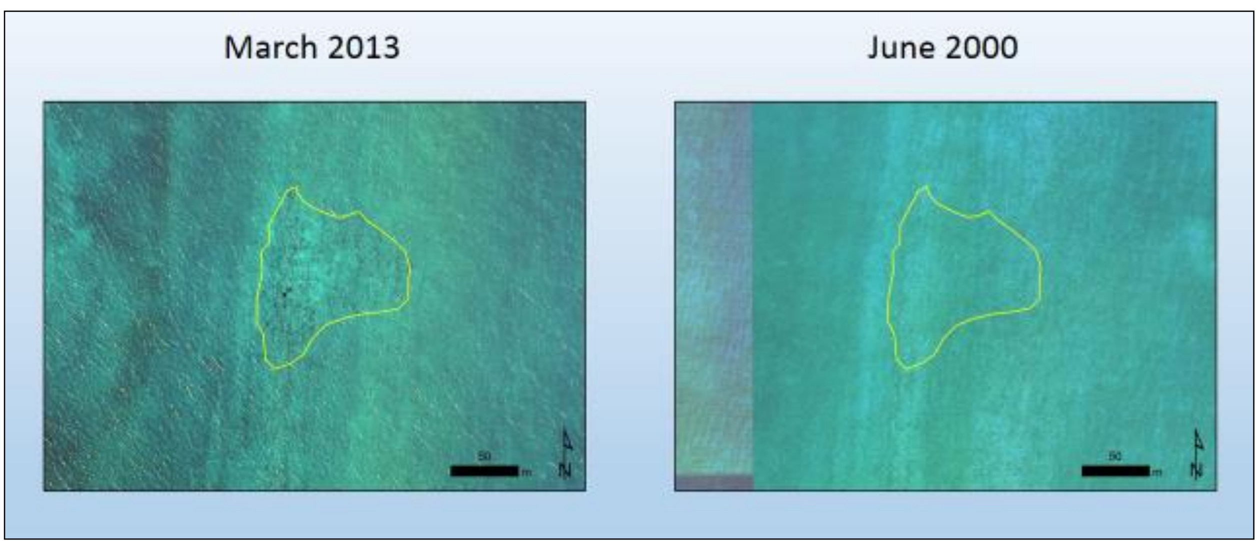
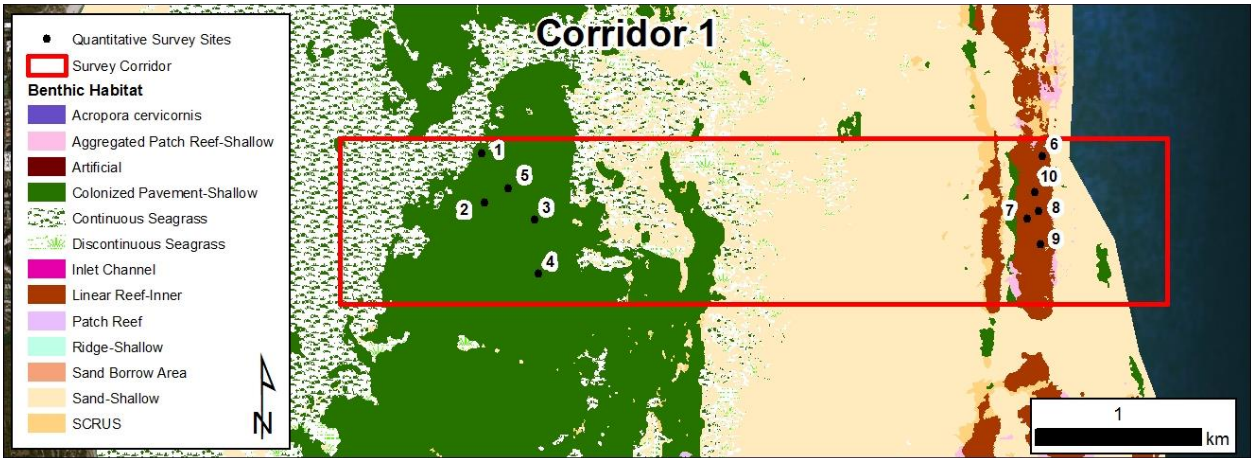


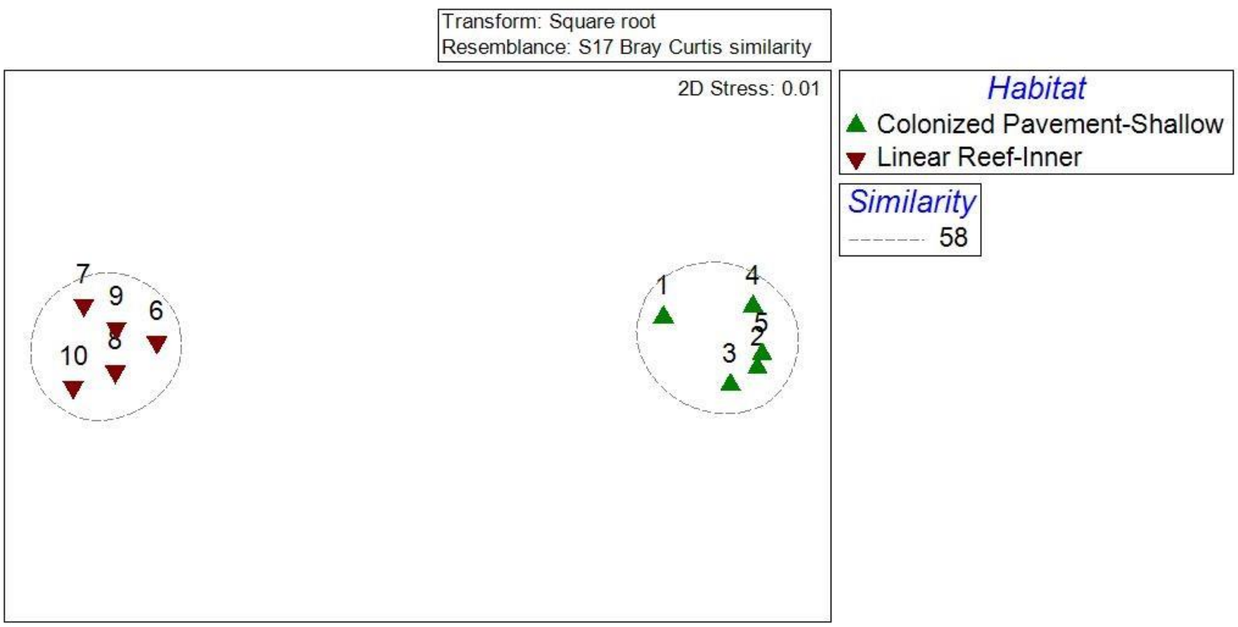
Figure 12. *A newly discovered A. cervicornis site in the March 2013 aerials that was not evident in June 2000. The yellow polygon is a rough areal estimate of the site totaling 9,284m².*

3.2. Quantitative Groundtruthing

A cluster analysis and corresponding non-metric, multi-dimensional scaling (MDS) plot was constructed using Bray-Curtis similarity indices (PRIMER v6) of the percent benthic cover transect data (square-root transformed) to evaluate similarities between sites where shape represents a site. The sites were categorized by corridor and map habitat types *a priori* and entered in PRIMER as factors. The MDS plot was then configured to display the factors to illustrate the analyses' results (Figure 13). The MDS plot is designed to statistically show similarities and differences in multivariate data by plotting them in two dimensions where the relative distance apart is indicative of their similarity. Thus, sites very close together are more similar than those further apart and the sites furthest apart are the least similar. These analyses were run between all sites within each corridor to evaluate local cross-shelf habitat differences and between all sites in a given habitat type to look at latitudinal community differences.

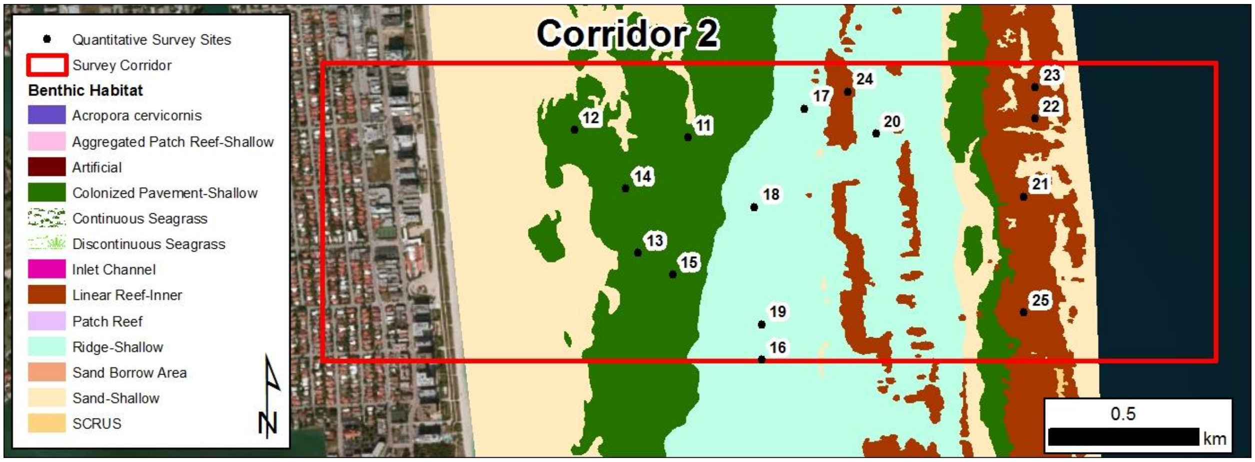
Significant differences in percent benthic cover between habitats occurred in all corridors, however some comparisons were stronger than others. Corridor 1 exhibited clear differences between the colonized pavement and inner reef sites as indicated in the MDS plot and the ANOSIM table (Figure 13). A similarity percentages (SIMPER) analysis indicated that the main distinction was due to the high percentages of seagrass ($\bar{x}$ = 19.4% ± 12.3 σ) on the colonized pavement that did not occur on the Inner Reef sites (nor any other habitat in the region). The tight clustering of sites between habitats indicates they are much more similar to each than sites in the other habitat. Corridor 2 showed much weaker differences between habitat types, however the colonized pavement sites were significantly distinct from the inner reef and ridge sites (Figure 14). This was mainly due to the comparatively high percentage of sand on the colonized pavement ($\bar{x}$ = 20.5% ± 16 σ) versus the inner reef ($\bar{x}$ = 4.3% ± 2.2 σ) and ridge ($\bar{x}$ = 3.1% ± 0.9 σ). The comingling of ridge and inner reef sites indicates there was no measurable differences in benthic cover between sites in these habitats. Corridor 3 ridge was significantly distinct from the colonized pavement and inner reef sites (Figure 15). SIMPER analysis indicated this difference was mostly due to lower percentage of *Palythoa spp*. on the ridge ($\bar{x}$ = 1.7% ± 1.2 σ) compared to colonized pavement ($\bar{x}$ = 4.2% ± 2.3 σ) and the inner reef ($\bar{x}$ = 5.5% ± 1.5 σ). The ridge sites had much less variability between each other as indicated by their relatively tight clustering in the MDS plot. In Corridor 4, inner reef sites were significantly different from the others (Figure 16). This was driven by two benthic cover types. Inner reef sites had much higher percentage of macroalgae ($\bar{x}$ = 33.3% ± 6.8 σ) than the ridge ($\bar{x}$ = 9.5% ± 5.3 σ) and colonized pavement ($\bar{x}$ = 10.9% ± 1.9 σ). *Palythoa spp*. was also higher on the inner reef ($\bar{x}$ = 12.9% ± 5.1 σ) than the ridge ($\bar{x}$ = 2.1% ± 2.1 σ) and colonized pavement ($\bar{x}$ = 2.7% ± 2.9 σ). The significance is evident in the clear separation of inner reef sites from the comingled ridge and colonized pavement sites in the MDS plot. Corridor 5 exhibited significant differences between all habitat types (Figure17). Sites from all three habitats grouped separately in the MDS plot. Inner reef sites had higher percentages of *Palythoa* spp., gorgonians, and sponges than any other habitat. Colonized pavement sites had the lowest percentages of gorgonians and *Palythoa* spp. while having the highest percentages of sand.





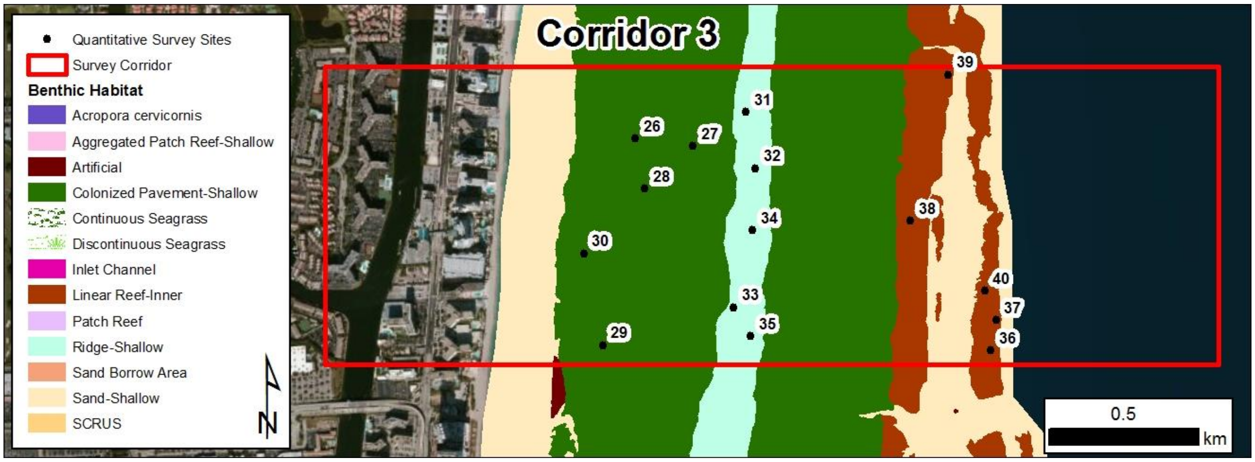
ANOSIM Pairwise Test	**R**	**Significance**
Habitat comparison	**Statistic**	**Level %**
Linear Reef-Inner, Colonized Pavement-Shallow	**1**	**0.8**

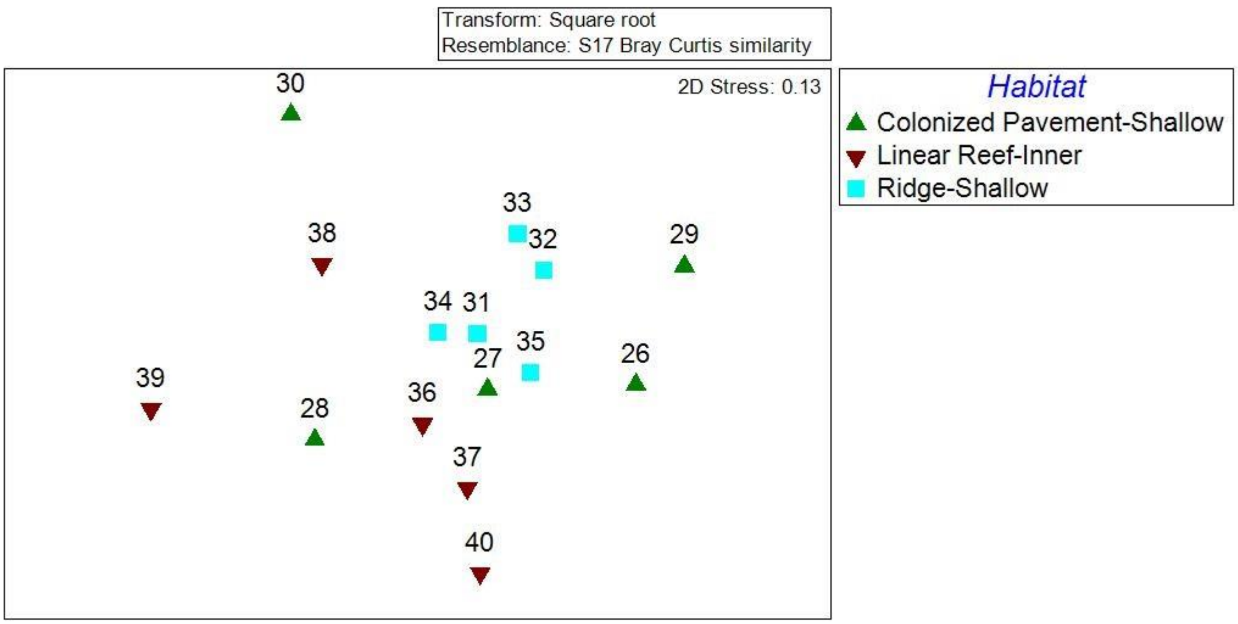
Figure 13. *Corridor 1 multivariate analyses results. Top image shows the corridor and the randomly stratified survey locations. The middle figure is the multidimensional scaling (MDS) plot of the Bray-Curtis similarity matrix of the percent benthic cover data at the Corridor 1 sites. The outlines represent 58% similarity from the cluster analysis. Table shows the summary of the analysis of similarity (ANOSIM) pairwise test between habitat types. The closer the R statistic is to 1, the stronger the dissimilarity between groups. Bold indicates a significant result.*



ANOSIM Pairwise Tests	**R**	**Significance**
Habitat comparison	**Statistic**	**Level %**
Colonized Pavement-Shallow, Linear Reef-Inner	**0.332**	**2.4**
Colonized Pavement-Shallow, Ridge-Shallow	**0.408**	**0.8**
Linear Reef-Inner, Ridge-Shallow	0.216	6.3

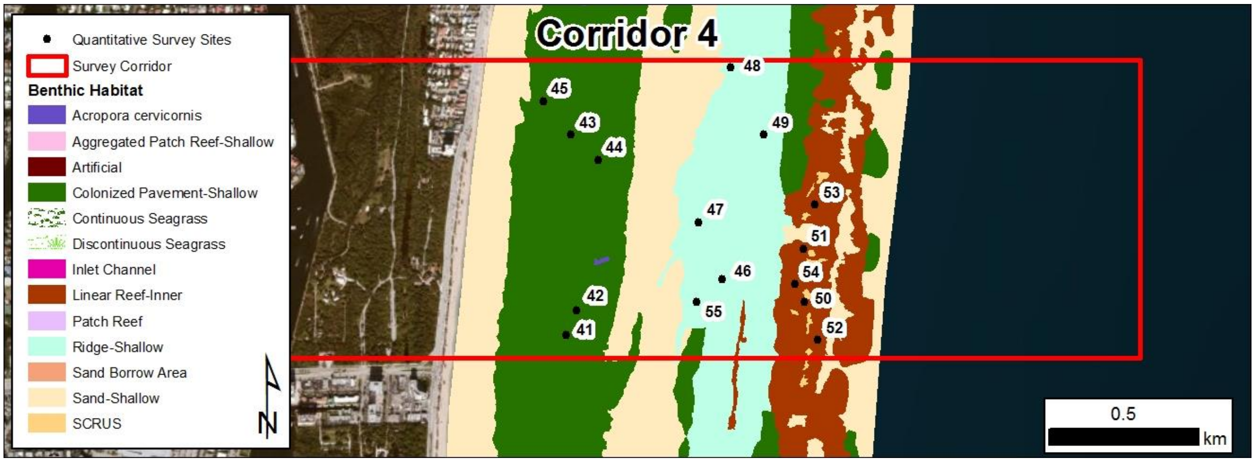
***Figure 14**. Corridor 2 multivariate analyses results. Top image shows the corridor and the randomly stratified survey locations. The middle figure is the multidimensional scaling (MDS) plot of the Bray-Curtis similarity matrix of the percent benthic cover data at the Corridor 2 sites. Table shows the summary of the analysis of similarity (ANOSIM) pairwise test between habitat types. The closer the R statistic is to 1, the stronger the dissimilarity between groups. Bold indicates a significant result.*

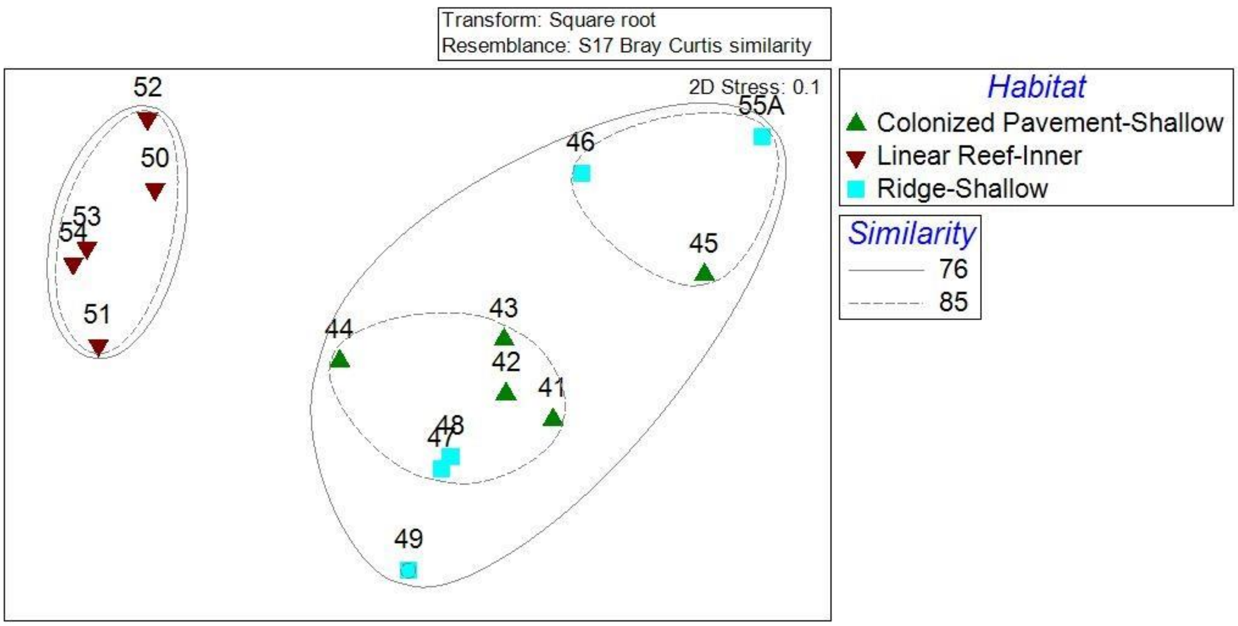




ANOSIM Pairwise Tests	**R**	**Significance**
Habitat comparison	**Statistic**	**Level %**
Colonized Pavement-Shallow, Linear Reef-Inner	0.18	9.5
Colonized Pavement-Shallow, Ridge-Shallow	**0.184**	**2.4**
Linear Reef-Inner, Ridge-Shallow	**0.436**	**0.8**

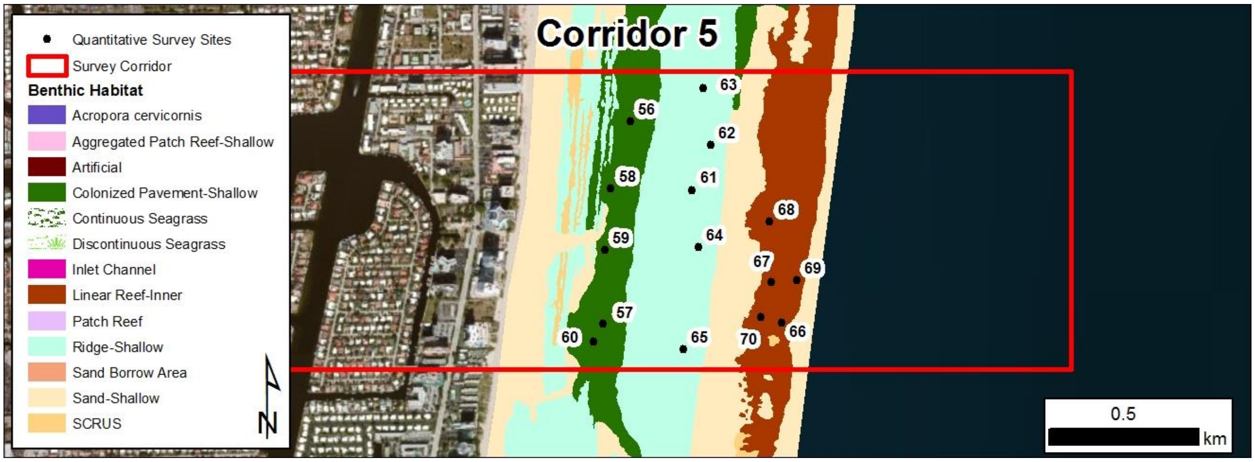
Figure 15. *Corridor 3 multivariate analyses results. Top image shows the corridor and the randomly stratified survey locations. The middle figure is the multidimensional scaling (MDS) plot of the Bray-Curtis similarity matrix of the percent benthic cover data at the Corridor 3 sites. Table shows the summary of the analysis of similarity (ANOSIM) pairwise test between habitat types. The closer the R statistic is to 1, the stronger the dissimilarity between groups. Bold indicates a significant result.*

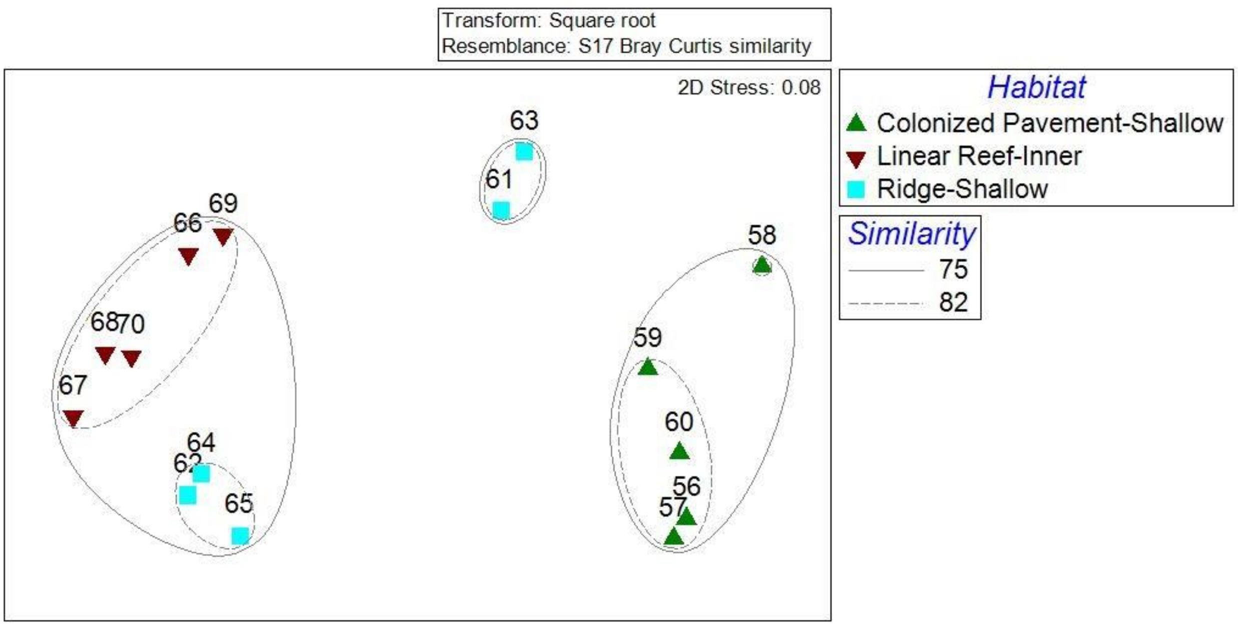




ANOSIM Pairwise Tests	**R**	**Significance**
Habitat comparison	**Statistic**	**Level %**
Colonized Pavement-Shallow, Linear Reef-Inner	**0.539**	**1.1**
Colonized Pavement-Shallow, Ridge-Shallow	0.094	28.6
Linear Reef-Inner, Ridge-Shallow	**0.48**	**2.9**

Figure 16. *Corridor 4 multivariate analyses results. Top image shows the corridor and the randomly stratified survey locations. The middle figure is the multidimensional scaling (MDS) plot of the Bray-Curtis similarity matrix of the percent benthic cover data at the Corridor 4 sites. The outlines represent 76% and 85% similarity from the cluster analysis. Table shows the summary of the analysis of similarity (ANOSIM) pairwise test between habitat types. The closer the R statistic is to 1, the stronger the dissimilarity between groups. Bold indicates a significant result.*



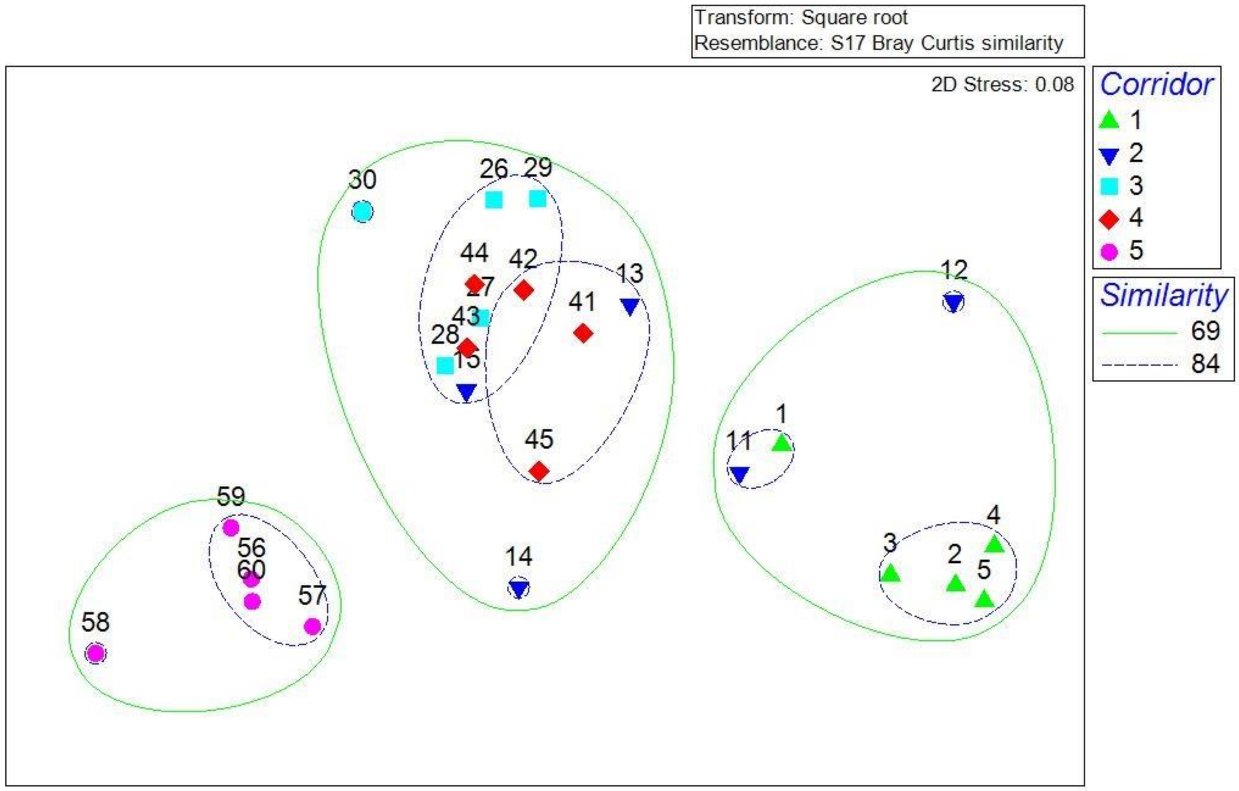


ANOSIM Pairwise Tests	**R**	**Significance**
Habitat comparison	**Statistic**	**Level %**
Colonized Pavement-Shallow, Linear Reef-Inner	**1**	**0.8**
Colonized Pavement-Shallow, Ridge-Shallow	**0.82**	**0.8**
Linear Reef-Inner, Ridge-Shallow	**0.452**	**0.8**

Figure 17. *Corridor 5 multivariate analyses results. Top image shows the corridor and the randomly stratified survey locations. The middle figure is the multidimensional scaling (MDS) plot of the Bray-Curtis similarity matrix of the percent benthic cover data at the Corridor 5 sites. The outlines represent 75% and 82% similarity from the cluster analysis. Table shows the summary of the analysis of similarity (ANOSIM) pairwise test between habitat types. The closer the R statistic is to 1, the stronger the dissimilarity between groups. Bold indicates a significant result.*

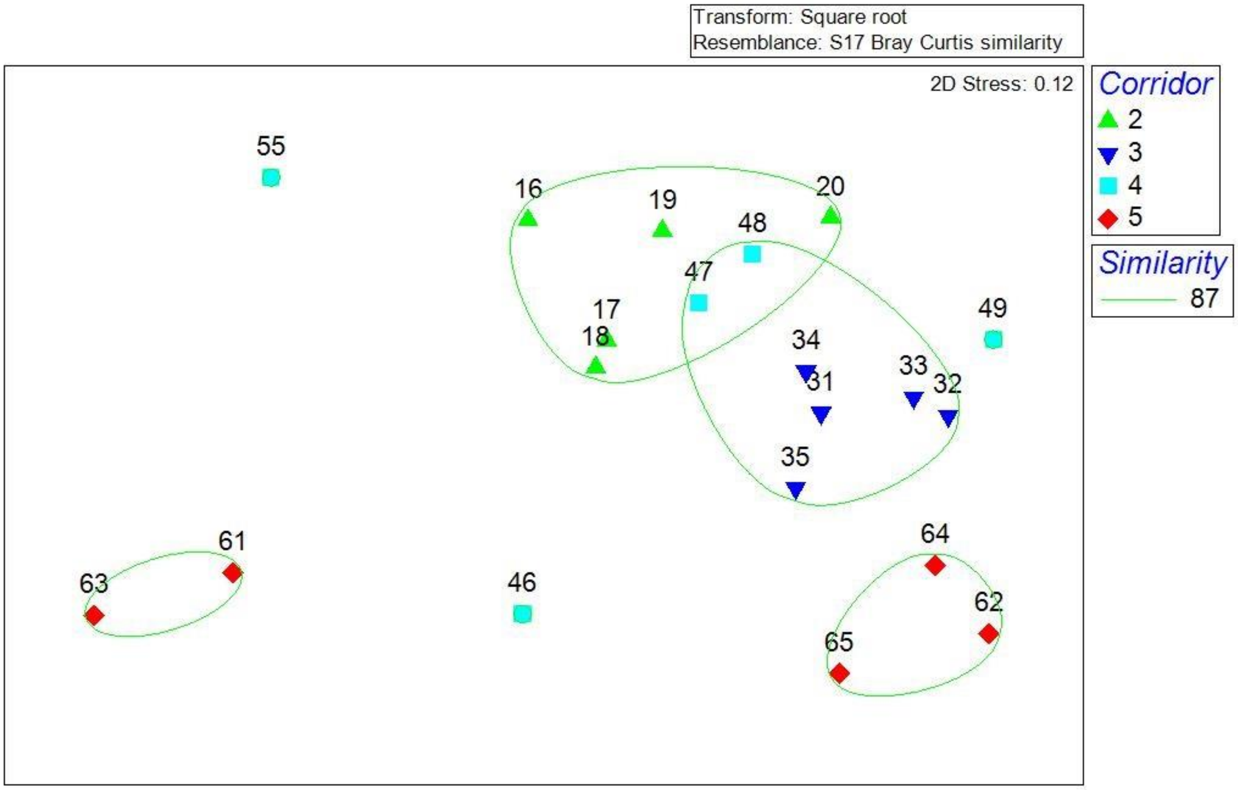
Comparisons of benthic cover percentages between all sites in a given habitat type were conducted to evaluate latitudinal community differences. Among all colonized pavement sites, Corridor 1 was significantly different from sites in all other corridors due to the presence of seagrass which only occurred in Corridor 1 colonized pavement (Figure 18). This was evident in the MDS by the tight clustering of almost all of corridor 1 sites away from all others. Corridor 5 was also significantly distinct from all other corridors as also indicated by tight distinct clustering in the MDS. The major benthic cover category contributing to these differences varied, but in general, SIMPER analysis determined it was due to a low percentage of gorgonians, stony corals, and *Palythoa spp*. with a high percentage of turf algae. Colonized pavement sites in corridors 2, 3, and 4 were mostly comingled in the MDS plot indicating that the variability within these corridors was as much as between them. The ridge sites comparisons showed distinct clustering of corridors 2, 3, and 5 in the MDS (Figure 19). Corridor 4 sites were extremely variable and spread out throughout the plot indicating a high level of variability among ridge sites in that corridor. These results indicate that there are latitudinal differences in benthic cover in the ridge habitat. SIMPER analyses indicated that the main dissimilarity contributors in corridor 2 were lower percentages of palythoa spp. and macroalgae than corridors 3 and 5 and higher percentages of gorgonians and stony corals than corridor 5. Corridor 3 had higher percentages of macroalgae, stony corals, and gorgonians than corridor 5. The inner reef sites also exhibited latitudinal differences in benthic cover (Figure 20). Corridors 1 and 5 separated out from the other corridors and each other. Corridor 5 also had three of the five sites separate in a distinct cluster. Corridors 2, 3 and part of 5 were comingled. SIMPER analysis indicated the main cover classes driving the clustering of corridor 1 sites were high percentages of gorgonians and *Palythoa spp*, while the main contributor to the corridor 4 cluster was high macroalgae percentages in that corridor.

Stony corals, gorgonians, *Xestospongia muta*, and *Cliona spp*. were assessed along benthic quadrat transects to gain a better understanding of their distributions and condition between habitats and corridors. A total of 4,568 stony coral colonies were identified, counted, and measured (Table 4). Twenty-two species were found, but *Porites astreoides* (29.7%), *Siderastrea siderea* (17.5%), and *Acropora cervicornis* (10.3%) comprised 57.5% of the total number of stony corals measured in this study. Stony coral density pooled for the entire surveyed area of 4,200m² was 1.09 corals/m², equating to a coral colony about every square meter. This was not equal among all sites, habitats, or corridors. Mean coral density was lowest in the colonized pavement sites ($\bar{x} = 0.56 \pm 0.15$ SEM) and highest in the inner reef sites ($\bar{x} = 1.8 \pm 0.15$), however this also varied by corridor (Figure 21). The colonized pavement coral density in Corridors 1 ($\bar{x} = 0.11 \pm 0.17$) and 5 ($\bar{x} = 0.27 \pm 0.17$) was lowest and highest in Corridors 3 ($\bar{x} = 0.92 \pm 0.17$) and 4 ($\bar{x} = 0.99 \pm 0.17$ SEM) (Figure 21). Coral density on ridge habitat had a similar pattern to colonized pavement with corridor 3 having the highest density ($\bar{x} = 1.6 \pm 0.2$). Conversely coral density on the inner reef was highest in corridor 1 ($\bar{x} = 3.34 \pm 0.21$) and corridor 4 ($\bar{x} = 2.06 \pm 0.21$). The top three densest coral species had differing patterns between corridors and habitats (Figure 22). *Porites astreoides* mirrored this pattern which may indicate that it was driving the pattern since it was the most dominant species. *Siderastrea siderea* was consistently low in all corridors on colonized pavement and ridge habitats, but was denser in general on the inner reef and was densest in corridor 1 and least dense in corridor 5. *Acropora cervicornis* was found in higher densities than *S. siderea* on the colonized pavement but it only occurred in corridors 3 and 4. It was also found in higher density on ridge habitat but was not found in corridor 5. Of the 471



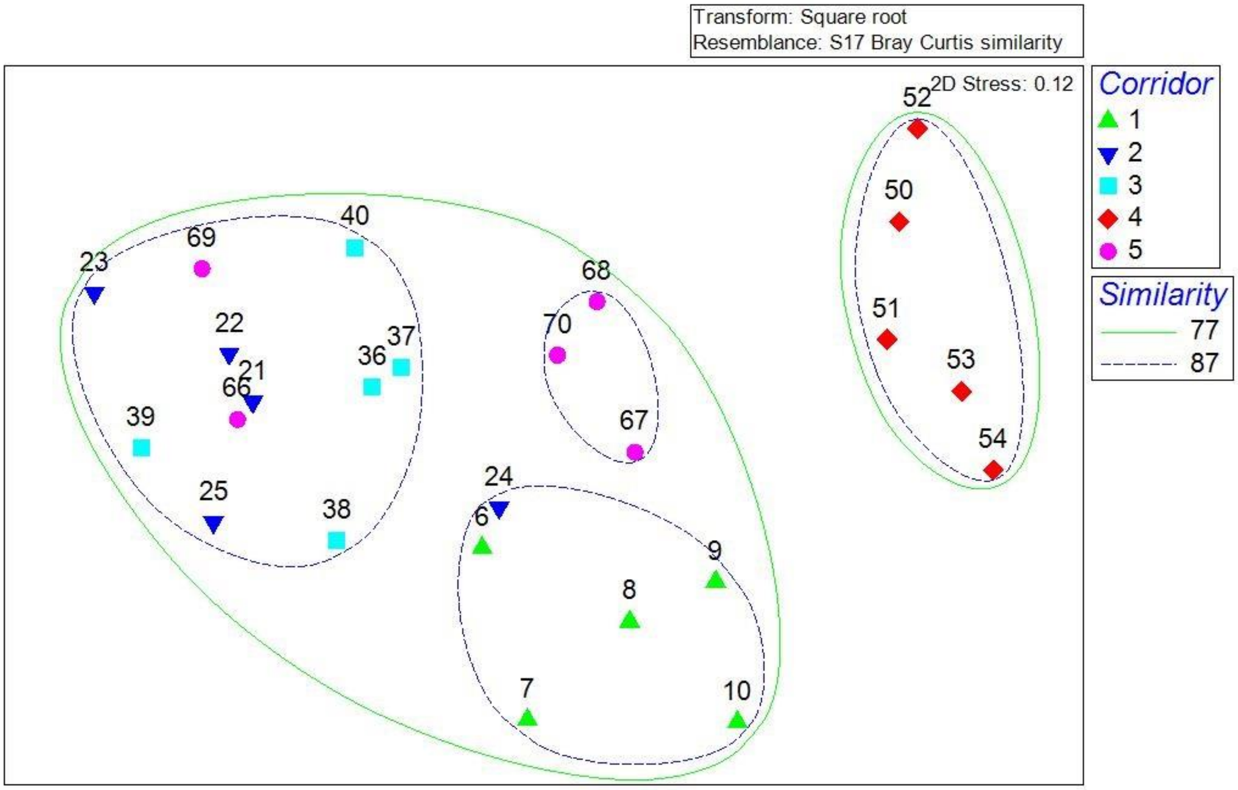
ANOSIM Pairwise Tests	**R**	**Significance**
Corridor comparison	**Statistic**	**Level %**
1, 2	**0.684**	**0.8**
1, 3	**1**	**0.8**
1, 4	**1**	**0.8**
1, 5	**1**	**0.8**
2, 3	**0.44**	**0.8**
2, 4	0.136	12.7
2, 5	**0.88**	**0.8**
3, 4	**0.288**	**4.8**
3, 5	**1**	**0.8**
4, 5	**1**	**0.8**

Figure 18. *Results of multivariate analyses comparing benthic cover percentages between all Colonized pavement-shallow sites. Top image shows the multidimensional scaling (MDS) plot of the Bray-Curtis similarity matrix of the percent benthic cover data of all colonized pavement sites. The outlines represent 69% and 84% similarity from the cluster analysis. Table shows the summary of the analysis of similarity (ANOSIM) pairwise test between corridors. The closer the R statistic is to 1, the stronger the dissimilarity between groups. Bold indicates a significant result.*



ANOSIM Pairwise Tests	**R**	**Significance**
Corridor comparison	**Statistic**	**Level %**
2, 3	**0.896**	**0.8**
2, 4	0.168	11.9
2, 5	**0.436**	**0.8**
3, 4	**0.308**	**1.6**
3, 5	**0.452**	**0.8**
4, 5	0.18	13.5

Figure 19. *Results of multivariate analyses comparing benthic cover percentages between all Ridge-shallow sites. Top image shows the multidimensional scaling (MDS) plot of the Bray-Curtis similarity matrix of the percent benthic cover data of all ridge sites. The outline represents 87% similarity from the cluster analysis. Table shows the summary of the analysis of similarity (ANOSIM) pairwise test between corridors. The closer the R statistic is to 1, the stronger the dissimilarity between groups. Bold indicates a significant result.*



ANOSIM Pairwise Tests	**R**	**Significance**
Corridor comparison	**Statistic**	**Level %**
1, 2	**0.784**	**0.8**
1, 3	**0.82**	**0.8**
1, 4	**0.964**	**0.8**
1, 5	**0.648**	**0.8**
2, 3	-0.036	52.4
2, 4	**0.992**	**0.8**
2, 5	0.168	11.9
3, 4	**1**	**0.8**
3, 5	0.204	13.5
4, 5	**0.8**	**0.8**

Figure 20. *Results of multivariate analyses comparing benthic cover percentages between all Inner reef sites. Top image shows the multidimensional scaling (MDS) plot of the Bray-Curtis similarity matrix of the percent benthic cover data of all ridge sites. The outlines represent 77% and 87% similarity from the cluster analysis. Table shows the summary of the analysis of similarity (ANOSIM) pairwise test between corridors. The closer the R statistic is to 1, the stronger the dissimilarity between groups. Bold indicates a significant result.*

Table 4. *List of stony coral species, abundance, and their percentage of the total corals observed in the benthic quadrat surveys sorted by the most abundant.*

Species	Abundance	Percent
Porites astreoides	1356	29.68%
Siderastrea siderea	801	17.54%
Acropora cervicornis	471	10.31%
Porites porites	411	9.00%
Stephanocoenia intersepta	352	7.71%
Montastraea cavernosa	282	6.17%
Agaricia agaricites	233	5.10%
Dichocoenia stokesii	209	4.58%
Solenastrea bournoni	191	4.18%
Meandrina meandrites	101	2.21%
Pseudodiploria strigosa	39	0.85%
Orbicella faveolata	33	0.72%
Pseudodiploria clivosa	28	0.61%
Agaricia fragilis	26	0.57%
Colpophyllia natans	12	0.26%
Orbicella annularis	6	0.13%
Pseudodiploria labyrinthiformis	5	0.11%
Eusmilia fastigiata	4	0.09%
Mycetophyllia aliciae	3	0.07%
Madracis decactis	3	0.07%
Solenastrea Hyades	1	0.02%
Agaricia lamarcki	1	0.02%
Total	**4568**	**100.00%**

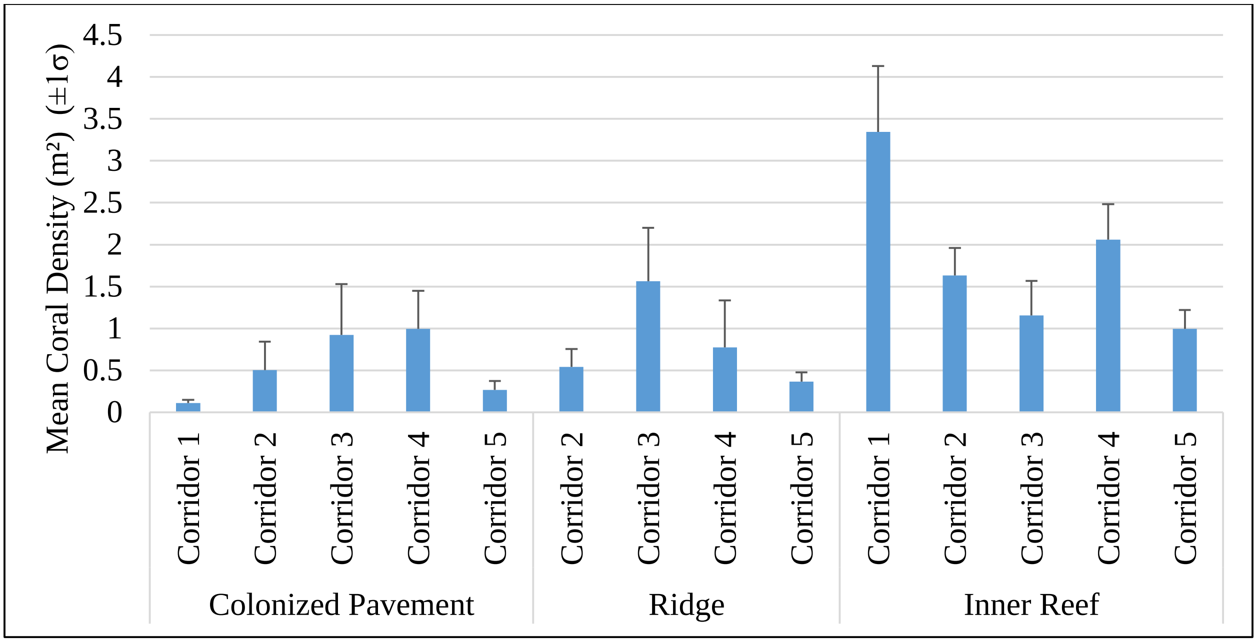


Figure 21. *Mean coral density by corridor and habitat. Corridors were organized from south to north where Corridor 1 is the southernmost and Corridor 5 the northernmost. Error bars equal 1 standard deviation (σ).*

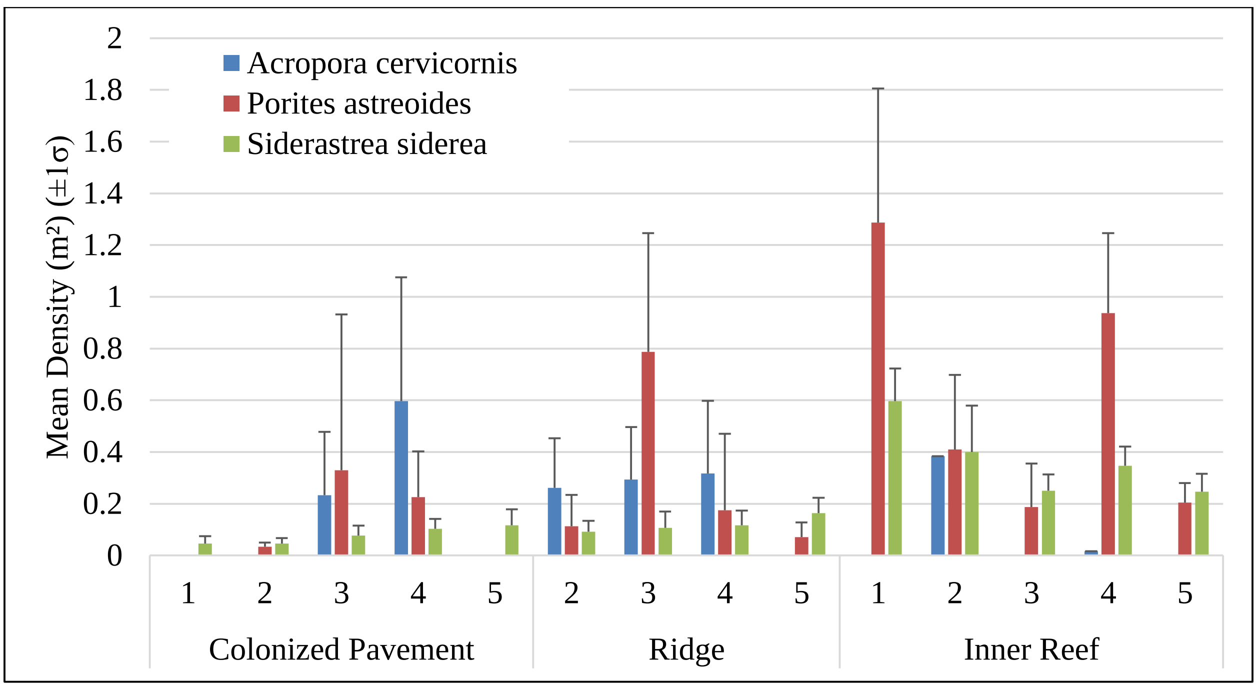


Figure 22. *Mean density of the three densest species in the study by corridor and habitat. Corridors were organized from south to north where Corridor 1 is the southernmost and Corridor 5 the northernmost. Error bars equal 1 standard deviation (σ).*

A. cervicornis colonies counted, only 25 (5.3%) occurred on the inner reef. Two hundred and thirty-five (49.9%) were found in the colonized pavement and 211 (44.8%) at the ridge sites.

The mean number of coral species (richness) varied by corridor and habitat (Figure 23). Colonized pavement sites had the lowest richness ($\bar{x}$ = 4.96 ± 0.4 SEM). Mean richness at ridge sites was higher ($\bar{x}$ = 7.6 ± 0.44 SEM) and highest on inner reef ($\bar{x}$ = 10.9 ± 0.4 SEM). As with density, mean richness varied by corridor within habitats as well. Among the colonized pavement sites, corridor 3 ($\bar{x}$ = 7.4 ± 0.76 SEM) and corridor 4 ($\bar{x}$ = 6.4 ± 0.76 SEM) had the highest mean richness and corridor 5 the lowest ($\bar{x}$ = 2.2 ± 0.76 SEM). Similarly, among the ridge site, mean coral richness was highest in corridor 3 ($\bar{x}$ = 9.6 ± 0.42 SEM) and lowest in corridor 5 ($\bar{x}$ = 5.6 ± 0.42 SEM). Conversely, mean richness among inner reef sites were not very different however corridor 1 ($\bar{x}$ = 12.2 ± 0.67 SEM) was significantly higher than corridor 3 ($\bar{x}$ = 9.6 ± 0.67 SEM).

The longest, widest, and tallest coral measured was a *Siderastrea siderea* located in corridor 4 which measured 225 cm long, 200 cm wide, 140 cm tall and an estimated 4.1 m² of live tissue. Table 5 provides a summary of the lengths, widths, heights, colony areas, and estimated live tissues areas for all species measured in the benthic quadrat transects.

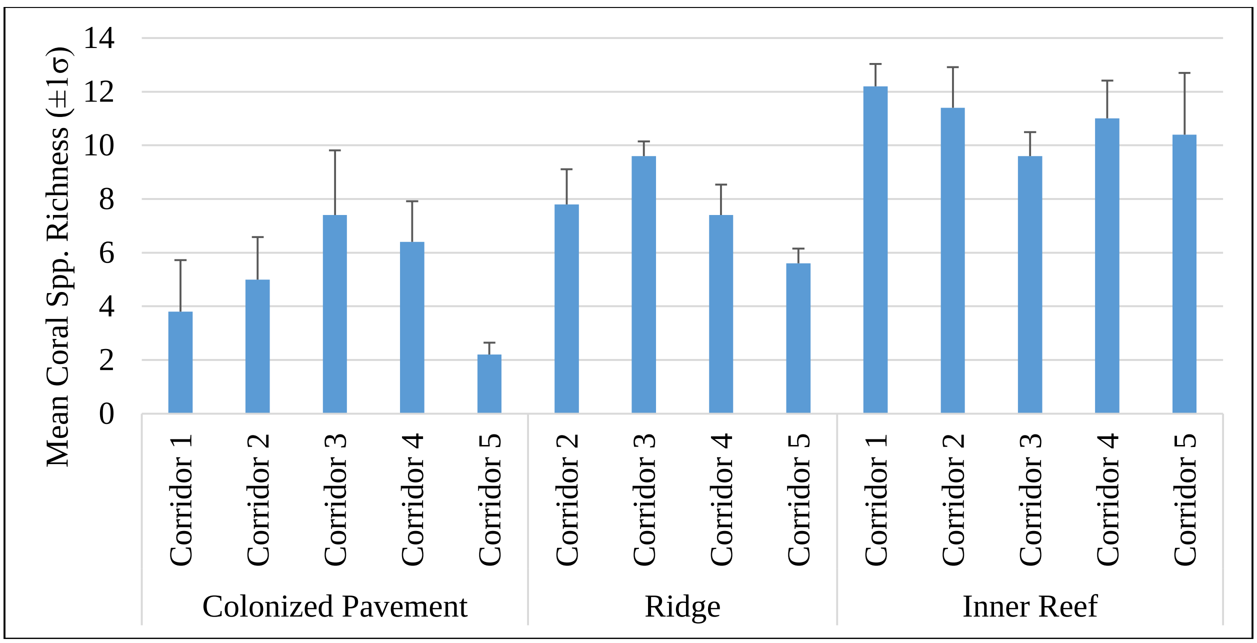


Figure 23. *Mean number of coral species by corridor and habitat. Corridors were organized from south to north where Corridor 1 is the southernmost and Corridor 5 the northernmost. Error bars equal 1 standard deviation (σ).*

Table 5. *Summary of size metrics for the coral species measured in the quadrat surveys. Min = minimum size measured; Max = maximum size measured; $\bar{x}$ = mean; and σ = standard deviation. Colony area = L x W. Live tissue area = (L x W) – (L x W (percent dead)).*

	Length (cm)				Width (cm)				Height (cm)				Colony Area (cm²)				Live Tissue Area (cm²)			
Coral Species	**Min**	**Max**	**x̄**	**σ**	**Min**	**Max**	**x̄**	**σ**	**Min**	**Max**	**x̄**	**σ**	**Min**	**Max**	**x̄**	**σ**	**Min**	**Max**	**x̄**	**σ**
Acropora cervicornis	1	180	29	21	1	170	21	16	1	55	15	10	1	30600	916	1845	1	22950	697	1407
Agaricia agaricites	4	35	11	5	2	22	8	4	1	22	5	4	8	528	108	94	8	336	85	69
Agaricia fragilis	4	25	8	4	3	11	6	2	1	15	3	3	15	250	51	52	15	132	45	36
Agaricia lamarcki	10	10	10	N/A	7	7	7	N/A	2	2	2	N/A	70	70	70	N/A	35	35	35	N/A
Colpophyllia natans	5	70	32	23	4	60	24	18	2	45	18	15	20	4200	1146	1399	20	4200	963	1285
Dichocoenia stokesii	4	50	11	7	2	45	9	6	1	27	7	5	8	2250	141	224	7.6	1800	113	174
Diploria labyrinthiformis	5	30	17	11	5	22	14	9	2	15	8	6	25	660	313	293	25	660	313	293
Eusmilia fastigiata	4	11	7	3	2	10	5	4	2	10	5	4	8	110	43	47	6.4	110	41	47
Madracis decactis	6	25	14	10	5	15	10	5	2	6	4	2	30	375	168	183	19.8	318.75	123	170
Meandrina meandrites	4	100	31	24	3	97	26	21	1	50	10	9	12	9506	1320	1967	12	8555.4	1090	1697
Mycetophyllia aliciae	8	10	9	1	7	8	7	1	2	3	2	1	56	80	64	14	39.2	80	58	21
Orbicella annularis	20	54	30	13	18	53	27	14	5	38	19	13	360	2862	977	995	180	2146.5	783	757
Montastraea cavernosa	4	185	30	25	2	150	25	21	1	80	16	14	8	27750	1269	2311	6	10721.7	882	1415
Orbicella faveolata	12	170	50	36	9	150	42	32	6	100	31	22	108	25500	3250	5087	75	22950	2315	4406
Porites astreoides	3	50	12	6	2	37	10	5	1	25	5	4	8	1480	141	162	4.4	1332	112	126
Porites porites	2	20	7	3	2	18	5	3	1	23	4	2	4	360	44	48	3.2	225	32	32
Pseudodiploria clivosa	5	91	35	29	4	100	29	25	1	22	7	5	20	8000	1630	2370	15	6400	1002	1519
Pseudodiploria strigosa	5	75	27	20	3	73	22	17	1	35	13	9	18	5475	940	1398	17.1	4927.5	759	1200
Siderastrea sidereal	4	225	10	11	1	200	8	9	1	140	4	7	4	45000	175	1611	2.1	40500	134	1442
Solenastrea bournoni	4	62	23	13	2	60	19	11	1	40	15	9	12	3600	585	630	9.6	3060	485	579
Solenastrea hyades	5	5	5	N/A	4	4	4	N/A	2	2	2	N/A	20	20	20	N/A	16	16	16	N/A
Stephanocoenia intersepta	4	40	10	6	2	33	8	4	1	23	4	3	8	1188	96	133	5	675	70	86
Total	**1**	**225**	**15**	**15**	**1**	**200**	**12**	**13**	**1**	**140**	**8**	**8**	**1**	**45000**	**369**	**1306**	**1**	**40500**	**279**	**1029**

Gorgonians were also assessed in the benthic quadrat surveys. A total of 30,076 gorgonians were counted, classified by morpho-type (Fan, Plume, Rod), and binned into size classes (Table 6). Rods were the most abundant comprising almost 72% (21,624) of the total number counted. Plumes were second-most dominant comprising 24% (7,205) of the total. The total number of gorgonians varied by corridor and habitat. With all size classes combined, fans were lowest on the colonized pavement ($\bar{x}$ = 3.6 ± 3.2 SEM) and highest on the ridge ($\bar{x}$ = 33.1 ± 3.5 SEM) with the inner reef in between ($\bar{x}$ = 19.8 ± 3.2 SEM). Plumes were higher on the inner reef ($\bar{x}$ = 158.9 ± 14.5 SEM) than the colonized pavement ($\bar{x}$ = 75 ± 14.5 SEM) and ridge ($\bar{x}$ = 67.9 ± 16.2 SEM). Conversely rods were lower on the inner reef ($\bar{x}$ = 181.7 ± 43.4 SEM) than the colonized pavement ($\bar{x}$ = 366.4 ± 43.4 SEM) and ridge ($\bar{x}$ = 396.2 ± 48.5 SEM). Gorgonians also varied within habitat types by corridor. In colonized pavement, fans were highest in corridors 3 and 4 whereas plumes were more abundant in the southern corridors (Figure 24). Rods were dominantly abundant throughout the colonized pavement except for corridor 5 where they were conspicuously absent. In the ridge habitat, fans varied among corridors without a clear latitudinal pattern. Plumes were more abundant in the southern corridors, while rods were dominantly abundant throughout. The inner reef habitats generally had a higher abundance of plumes and a more even ratio of rod and plume abundance throughout all corridors. Plumes were the most abundant type in corridor 1, but were also high in corridors 3 and 5.

Table 6. *Total gorgonian abundance pooled for all sites by habitat and corridor.*

Total Gorgonian Abundance (Pooled)	**Corridor 1**	**Corridor 2**	**Corridor 3**	**Corridor 4**	**Corridor 5**	**Total**
Fan	**86**	**140**	**345**	**311**	**365**	**1247**
Colonized Pavement	0	7	48	33	3	91
Ridge	N/A	104	255	82	220	661
Inner Reef	86	29	42	196	142	495
Plume	**1898**	**1606**	**2028**	**692**	**981**	**7205**
Colonized Pavement	472	749	544	95	16	1876
Ridge	N/A	461	529	182	185	1357
Inner Reef	1426	396	955	415	780	3972
Rod	**2634**	**5135**	**5720**	**4564**	**3571**	**21624**
Colonized Pavement	1783	2512	2779	2043	42	9159
Ridge	N/A	2138	1896	1588	2301	7923
Inner Reef	851	485	1045	933	1228	4542
Grand Total	**4618**	**6881**	**8093**	**5567**	**4917**	**30076**

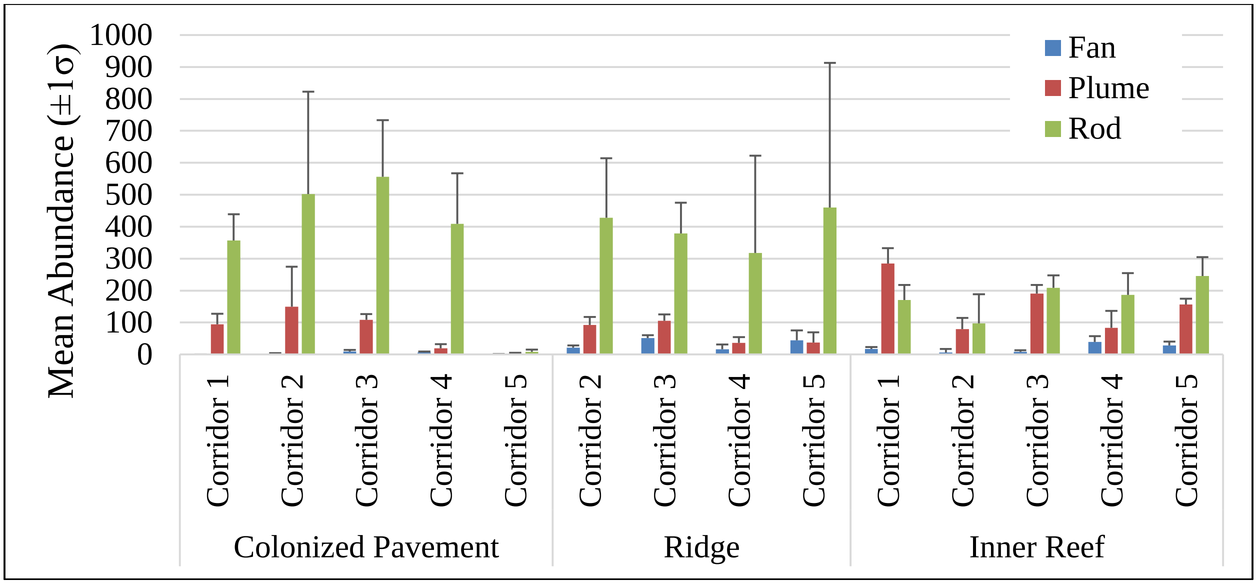


Figure 24. *Mean gorgonian-type abundance by corridor and habitat.Corridors were organized from south to north where Corridor 1 is the southernmost and Corridor 5 the northernmost. Error bars equal 1 standard deviation (σ).*

Two ecologically important sponges were counted in the benthic quadrat transects, *Xestospongia muta* and *Cliona spp*. *X. muta* colonies were predominantly found at the inner reef sites ($\bar{x}$ = 9.2 ± 0.95 SEM) versus colonized pavement ($\bar{x}$ = 0.24 ± 0.95 SEM) and ridge ($\bar{x}$ = 1.3 ± 1.06 SEM) (Table 6). Of the 262 total colonies counted, 230 (87.7%) were at inner reef sites. Densities were lower than gorgonians and stony corals throughout the study (Table 7). Mean *X. muta* abundance varied between corridors (Figure 25). In colonized pavement and ridge habitats, *X. muta* predominantly occurred on corridor 4 however mean abundance was very low (colonized pavement $\bar{x}$ = 1.2 ± 0.26 SEM, ridge $\bar{x}$ = 4.4 ± 0.87 SEM). At the inner reef sites, *X. muta* was much lower in corridor 1 ($\bar{x}$ = 1.8 ± 3.02 SEM) than all other corridors, which did not significantly vary.

Cliona spp. was also found in low abundance in this study (Table 9). Of the 144 total colonies counted, 97 (67.4%) were found at inner reef sites. *Cliona spp*. were predominantly found at inner reef sites ($\bar{x}$ = 3.9 ± 0.56 SEM) versus colonized pavement ($\bar{x}$ = 1.1 ± 0.56 SEM) and ridge ($\bar{x}$ = 0.95 ± 0.62 SEM). *Cliona spp*. densities were the lowest of the biologic taxa assessed in this study (Table 10). Mean *Cliona spp.* abundance varied between corridors (Figure 25). In colonized pavement habitats, it predominantly occurred on corridor 4 ($\bar{x}$ = 4.6 ± 1.18 SEM). At ridge sites *Cliona spp*. was found in low abundance in corridors 2 ($\bar{x}$ = 2.0 ± 0.61 SEM), 3 ($\bar{x}$ = 0.6 ± 0.61 SEM), and 4 ($\bar{x}$ = 1.2 ± 0.61 SEM). Although in higher abundance, *Cliona spp*. did not significantly vary between corridors at the inner reef sites.

Table 7. *Total Xestospongia muta abundance for all sites by habitat and corridor.*

Total Xestospongia Abundance	**Corridor 1**	**2**	**3**	**4**	**5**	**Habitat Total**
Colonized Pavement	0	0	0	6	0	6
Ridge	N/A	1	3	22	0	26
Inner Reef	9	69	51	39	62	230
Corridor Total	**9**	**70**	**54**	**67**	**62**	**262**

Table 8. *Mean Xestospongia muta density for all sites by habitat and corridor. Parentheses equals 1 standard deviation (σ).*

Mean Xestospongia Density (m²) (±1σ)	**Corridor 1**	**2**	**3**	**4**	**5**	**Habitat Mean**
Colonized Pavement	0	0	0	0.020 (0.022)	0	0.004 (0.012)
Ridge	N/A	0.003 (0.007)	0.010 (0.022)	0.073 (0.061)	0	0.022 (0.043)
Inner Reef	0.030 (0.014)	0.230 (0.091)	0.170 (0.081)	0.130 (0.144)	0.207 (0.166)	0.153 (0.125)
Corridor Mean	0.015 (0.018)	0.078 (0.122)	0.060 (0.092)	0.074 (0.096)	0.069 (0.134)	0.062 (0.104)

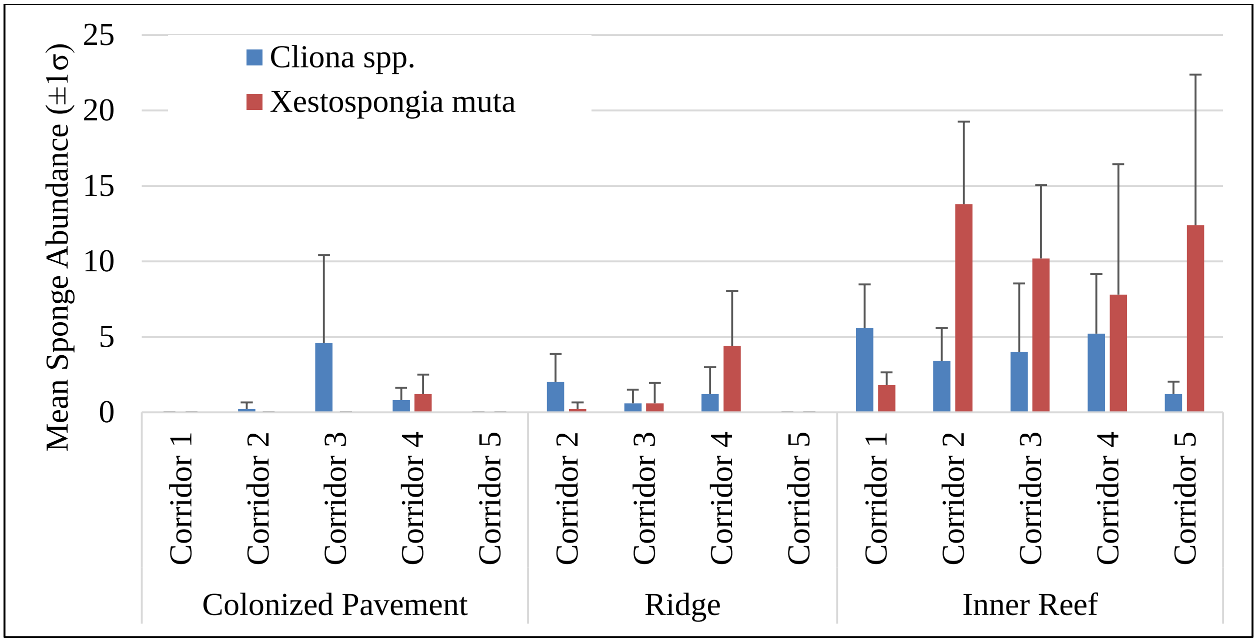


Figure 25. *Mean sponge abundance by corridor and habitat. Corridors were organized from south to north where Corridor 1 is the southernmost and Corridor 5 the northernmost. Error bars equal 1 standard deviation (σ).*

Table 9. *Total* Cliona spp. *abundance for all sites by habitat and corridor.*

Total Cliona Spp. Abundance	**Corridor**					**Habitat Total**
	1	**2**	**3**	**4**	**5**	
Colonized Pavement	0	1	23	4	0	28
Ridge	N/A	10	3	6	0	19
Inner Reef	28	17	20	26	6	97
Corridor Total	**28**	**28**	**46**	**36**	**6**	**144**

Table 10. *Mean* Cliona spp. *density for all sites by habitat and corridor. Parentheses equals 1 standard deviation (σ).*

Mean Cliona spp. Density (m²) (±1σ)	**Corridor**					**Habitat Mean**
	1	**2**	**3**	**4**	**5**	
Colonized Pavement	0	0.003 (0.007)	0.077 (0.097)	0.013 (0.014)	0	0.019 (0.050)
Ridge	N/A	0.033 (0.031)	0.010 (0.015)	0.020 (0.030)	0	0.016 (0.024)
Inner Reef	0.093 (0.048)	0.057 (0.037)	0.067 (0.075)	0.087 (0.066)	0.020 (0.014)	0.065 (0.055)
Corridor Mean	**0.047 (0.059)**	**0.031 (0.034)**	**0.051 (0.073)**	**0.040 (0.052)**	**0.007 (0.012)**	**0.034 (0.051)**

3.3. Accuracy Assessment

Of the total 500 accuracy assessment ground validation targets, 494 sites were visited and used in this assessment. The identity and number of planned targets differed from that of the final targets as a result of targets being omitted due to field logistical concerns.

Error matrices for Major Habitat are presented in Tables 11 and 12. The overall accuracy (P_o) was 97.9% at the Major Habitat level (Table 11). The Tau coefficient for equal probability of group membership (T_e) was 0.968 ± 0.019 (α=0.05), i.e. the rate of misclassifications at the Major Structure level was 96.8% less than would be expected from random assignment of polygons to categories. Table 12 is populated by the individual cell probabilities ($\hat{P}_{ij}$), which are the product of the original error matrix cell values and the known map marginal proportions, divided by the row marginal of the original error matrix. The overall accuracy (P_o), corrected for bias using the known map marginal proportions, was 97.2% ± 2.2 (α=0.05). The producer's accuracies, adjusted for known map marginal proportions, are shown for individual map categories. A 95% confidence interval was calculated for each value of producer's and user's accuracy.

Adjusting the producer's accuracy to the known map marginal proportions had little effect on the Major Habitat accuracy. This was mostly due to the infrequent confusion amount Major Habitats. In the original error matrix (Table 11), the largest confusion was 3 sites mapped as hardbottom that were sand and vice versa. Although there was a disproportionately high sampling of hardbottom habitats, the producer's confusion between these two habitats was not exaggerated by it.

Error matrices for Detailed Habitat are presented in Tables 13 and 14. The overall accuracy (P_o) was 96.0% at the Detailed Habitat level (Table 13). The Tau coefficient for equal probability of group membership (T_e) was 0.955 ± 0.019 (α=0.05), i.e. the rate of misclassifications at the Detailed Habitat level was 95.5% less than would be expected from random assignment of polygons to categories. T_e more closely approached P_o at the Detailed level (r = 11) than at the Major level (r = 3), reflecting the diminishing probability of random agreement with increasing map categories. Table 14 is populated by the individual cell probabilities ($\hat{P}_{ij}$), which are the product of the original error matrix cell values and the known map marginal proportions, divided by the row marginal of the original error matrix. The overall accuracy (P_o), corrected for bias using the known map marginal proportions, was 95.9% ± 2.4 (α=0.05). The producer's accuracies, adjusted for known map marginal proportions, are shown for individual map categories. A 95% confidence interval was calculated for each value of producer's and user's accuracy.

The overall accuracy for major habitat was better than all other regional mapping efforts. Overall map accuracy was 8.3% less in the original Broward map (89.6%) (Walker et al. 2008), 8.7% less in Palm Beach (89.2%) (Riegl et al. 2005), and 4.9% in Miami-Dade (93.0%) (Walker 2009). The other mapping efforts did not adjust for map marginal proportions, but it did not contribute to a meaningful difference in Major Habitat accuracy. This was unlike Martin County where the Soft bottoms comprised 95.2% of the entire mapped area and hard bottoms only 4.13% making the map marginal proportion correction necessary to reflect a better estimation.

Although changes to the NOAA classification scheme precluded a direct comparison, results were higher than other regional accuracy assessments. Kendall et al. (2001) reported an overall accuracy of 93.6% for the NOAA Puerto Rico and Virgin Island maps. Walker et al. (2013) reported an accuracy of 92.6% after map proportion correction for four combined areas in the Florida Keys. The NOAA St. John effort reported 96% total map accuracy for Major Geomorphologic Structure (Zitello et al., 2009). They adopted the methods reported in Walker and Foster (2010) to adjust for map marginal proportions, which increased the overall accuracy to 96.7%.

The Detailed Habitats were mapped at a similar level of accuracy, albeit slightly lower than Major Habitat, as indicated by the overall accuracy (96.0%), the overall adjusted accuracy (95.9%), and the Tau coefficient (0.955) (Tables 13 and 14). The overall accuracy was 5.5% greater than that reported for Miami-Dade (Walker 2009). Sixteen of the twenty-two adjusted user's and producer's accuracies were greater than 90% and six of those were 100%.

Aggregated Patch Reef had the lowest user's accuracy (85.7%) of all classes. Of the 14 sites mapped as Aggregated Patch Reef, one was found to be Sand and one Colonized Pavement. Patch Reef had the lowest adjusted producer's accuracy of the natural habitats (1.2%), however this was only due to one error where the patch was not found in the video. Misclassified points in proportionally small areas can dramatically reduce the accuracy of those habitats. Because only eight sites were designated as Patch Reef and the habitat was 0.008% of the mapped space, one error brought the Producer's accuracy from 87.5% to 1.2%. Because seven out of eight Patch Reef sites were mapped correctly, it is likely the adjustment is not warranted here.

Inner Reef, Discontinuous Seagrass, and Artificial had a 100% Producer's accuracy. Colonized Pavement had the most frequent and variable producer's errors in the map. Six sites groundtruthed as Colonized Pavement were mapped as one of five other classes; Inner Reef (2), Aggregated Patch Reef (1), Sand (1), Continuous Seagrass (1), and Discontinuous Seagrass (1).

The high accuracy of the maps can likely be attributed to the short timeframe between image acquisition, mapping, and assessment. The longer the time lag between data collection and map creation, the more probability there is for errors to be introduced into the map based on temporal changes in habitat through time. For example, the Martin map was created in 2011 and assessed for accuracy in 2012, but the data upon which the maps are based are from 2008 and 2009 (Walker & Gilliam, 2013). Thus the maps released in 2012 were based on three to four-year-old data. This time lag can have significant impact on the accuracy of the maps. Low relief habitats can often be covered and uncovered by sand movement during large storm events (D.S. Gilliam, 2007; Walker, 2009; Walker & Foster, 2009; Walker & Foster, 2010; Walker, et al., 2008) and the ephemeral nature of the system, especially in low relief pavement, likely contributes to some map errors. This has been reported in southern Miami-Dade where mapping showed large changes over a three year period (Walker 2009). Large areas on the order of several thousand square meters that used to be dense seagrass in previous imagery were sand. Furthermore, Walker and Foster (2009) found large changes in satellite images between 2005 and 2006. Some large-scale changes were noted in the 2006 imagery that were not reflected in the map nor the AA, presumably due to extreme storm conditions during hurricanes Katrina and Wilma indicating that large-scale changes have occurred in the recent past within the mapped area. These types of changes throughout the region affect the benthic habitat map accuracy and may degrade it over time. There was little time lag in this study. The images were collected in March 2013, the map was created shortly thereafter and the accuracy was assessed in March 2014. Also there were no major tropical storms or hurricanes during that period.

The combination of the bathymetry and aerial photography likely added to the accuracy. In many areas the bathymetry was high enough resolution to pick out very small objects (<1m). This enabled a better interpretation of many of the hardbottom habitats, but especially Scattered Coral/Rock in Sand where the boundaries were difficult to discern solely with the imagery (Figure 12).

There are no strict rules as to which ground validation sampling methodology works best. Assessments at point locations and areal assessments are equally valid (Stehman & Czaplewski, 1998), but ideally the reference data should be collected at the MMU's scale (Stadelmann et al., 1994). The minimum mapping unit was 0.1ha. It was neither practical nor economically feasible to assess the seafloor at this scale. However, assessment at a localized point wasn't ideal because it would not give a good representation of the area surrounding the sample point at the map scale. Localized point ground validation would have been problematic in mixed habitats like Scattered Coral Rock in Unconsolidated Sediment where patches may be spread out and might not be visible at all discrete locations in the polygon. For example, a random point may be placed in the polygon such that the video would contain only Unconsolidated Sediments. This would be considered an error in the map, yet the error was caused by the difference in scale between the map and the assessment method rather than a true map error. This could also cause problems in the assessment of Biological Cover which can vary significantly on small spatial scales. In order to address this issue, AA samples in this effort were taken near the random sample location while drifting. The drift allowed for more of the surrounding area to be visited and recorded, thus giving more insight and confidence in the Geomorphological Structure and Biological Cover at a scale closer to the map MMU. This also helped reduced the spatial errors associated with a precise GPS location.

The drifting assessment helped assess the transitions between habitats (i.e. the polygon borders) as well. A certain level of error is inherent in habitat transitions due to the scale of mapping (1:6000) and spatial errors in the imagery and GPS precision (Foody, 2002). Constraining sampling away from polygon boundaries to minimize spatial errors between the imagery and GPS is common practice, however, this strategy, may optimistically bias the results by not assessing the habitat transitions. Employing transect sampling and not constraining the samples from polygon edges allowed some component of the habitat transition errors to be captured. Although habitat transitions were not specifically targeted, assessed, or quantified, several occasions were encountered where the boat drifted from one habitat into another and the change was evident in the video. In these instances, the site location was considered the GPS coordinate from the point in the video where the targeted habitat was encountered.

The true error of non-sampled portions of the map is ultimately unknown and further sampling in these areas of the map would allow for a better understanding of the entire map accuracy, however, the accuracy assessments ensured that a well-distributed, representative set of monitoring locations were surveyed that closely represented the entire mapped region. For this reason it is thought to be a good measure of the map accuracies for the broader area. Many of the Biological Cover habitats were very small relative to the overall percentage of the entire mapped area; therefore the total map accuracy adjusted for marginal map proportions was likely a better gauge of the overall map accuracy than P_0. This, however, should not diminish the use of Tau as a metric to gauge map accuracy. Adjusting for marginal map proportions does not account for the probabilities of error due to increased number of classes, thus both metrics should be used as a gauge of the overall accuracy of the map products.

Table 11. *Error matrix for Major Habitat. The overall accuracy (P_o) was 97.9%. The Tau coefficient for equal probability of group membership (T_e) was 0.968, with a 95% Confidence Interval of 0.949– 0.988.*

	MAJOR HABITAT	**TRUE (GROUND-TRUTHED) (j)** hard	soft	seagrass	n_{i-}	**USERS Accuracy (%)**
MAP (i)	**hard**	**332**	3	1	336	**98.8**
	soft	3	**65**	**0**	68	**95.6**
	seagrass	2	**1**	**67**	70	**95.7**
	n_{-j}	337	69	68	**474** <= n	
	PRODUCERS Accuracy (%)	**98.5**	**94.2**	**98.5**	P_o **97.9%**	

T_e = **0.968 ± 0.019**

Table 12. *Error matrix for Major Habitat using individual cell probabilities (P_{ij}). The overall accuracy, corrected for bias using the known map marginal proportions (π_i), was 97.2% with a 95% Confidence Interval of 95.0% – 99.4%.*

	TRUE (GROUND-TRUTHED) (j)					
MAJOR HABITAT	**hard**	**soft**	**seagrass**	π_i	**USERS Accuracy (%)**	**USERS CI (± %)**
MAP (i) hard	**0.4758**	0.0043	0.0014	0.482	**98.8**	**1.2**
MAP (i) soft	0.0187	**0.4042**	**0.0000**	0.423	**95.6**	**5.0**
MAP (i) seagrass	0.0027	**0.0014**	**0.0915**	0.096	**95.7**	**2.8**
$n_{\cdot j}$	0.497	0.410	0.093	**1.000**	**<= *n***	
PRODUCERS Accuracy (%)	**95.7**	**98.6**	**98.5**	P_o	**97.2%**	
PRODUCERS CI (± %)	**4.3**	**5.2**	**45.8**	**CI (±)**	**2.2%**	

Table 13. *Error matrix for Detailed Habitat. The overall accuracy (P_o) was 96.0%. The Tau coefficient for equal probability of group membership (T_e) was 0.955, with a 95% Confidence Interval of 0.936 – 0.975. Blank cells indicate 0 occurrences.*

TRUE (GROUND-TRUTHED) (j)

MAP DATA (i) — ***DETAILED HABITAT***	**A cerv**	**Pav**	**Ridge**	**Inner Rf**	**APR**	**Patch**	**SCRUS**	**Sand**	**ContSG**	**DisSG**	**Art**	**n_{i-}**	**USERS Accuracy (%)**
A cerv	**18**											18	**100.0**
Pav	1	**117**			1		2	1	1			123	**95.1**
Ridge	1		**80**									81	**98.8**
Inner Rf		2	1	**71**	1							75	**94.7**
APR		1			**12**			1				14	**85.7**
Patch						**7**						7	**100.0**
SCRUS							**17**	1				18	**94.4**
Sand		1			1	1		**65**				68	**95.6**
ContSG		1							**53**			54	**98.1**
DisSG		1						1		**14**		16	**87.5**
Art											**20**	20	**100.0**
n_{-j}	20	123	81	71	15	8	19	69	54	14	20	**494**	**<= *n***
PRODUCERS Accuracy (%)	**90.0**	**95.1**	**98.8**	**100.0**	**80.0**	**87.5**	**89.5**	**94.2**	**98.1**	**100.0**	**100.0**	**P_o**	**96.0%**

T_e = 0.955 ± 0.019

Table 14. *Error matrix for Detailed Habitat using individual cell probabilities (P_{ij}). The overall accuracy, corrected for bias using the known map marginal proportions (π_i), was 95.9% with a 95% Confidence Interval of 93.5% – 98.3%. Blank cells indicate 0 occurrences.*

TRUE (GROUND-TRUTHED) (j)

MAP DATA (i)

DETAILED HABITAT	**A cerv**	**Pav**	**Ridge**	**Inner Rf**	**APR**	**Patch**	**SCRUS**	**Sand**	**ContSG**	**DisSG**	**Art**	π_i	**USERS Accuracy (%)**	**USERS CI (± %)**
A cerv	**0.0009**											0.001	**100.0**	**0.0**
Pav	0.0018	**0.2129**			0.0018		0.0036	0.0018	0.0018			0.224	**95.1**	**3.9**
Ridge	0.0018		**0.1470**									0.149	**98.8**	**2.5**
Inner Rf		0.0023	0.0012	**0.0828**	0.0012							0.087	**94.7**	**5.2**
APR		0.0003			**0.0032**			0.0003				0.004	**85.7**	**0.0**
Patch						**0.0001**						0.000	**100.0**	**0.0**
SCRUS							**0.0089**	0.0005				0.009	**94.4**	**10.8**
Sand		0.0061			0.0061	0.0061		**0.3981**				0.416	**95.6**	**5.0**
ContSG		0.0013							**0.0681**			0.069	**98.1**	**3.7**
DisSG		0.0016						0.0016		**0.0217**	0.0000	0.025	**87.5**	**0.0**
Art										0.0000	**0.0151**	0.015	**100.0**	**0.0**
$n_{\cdot j}$	0.005	0.224	0.148	0.083	0.012	0.006	0.013	0.402	0.070	0.022	0.015	**1.000 <= *n***		
PRODUCERS Accuracy (%)	**19.9**	**94.9**	**99.2**	**100.0**	**26.0**	**1.2**	**71.1**	**99.0**	**97.4**	**100.0**	**100.0**	**P_o**	**95.9%**	
PRODUCERS CI (± %)	**22.4**	**6.7**	**2.9**	**5.5**	**27.6**	**2.4**	**29.5**	**5.2**	**6.2**	**52.2**	**0.0**	**CI (±)**	**2.4%**	

4. ADDITIONAL DISCOVERIES

In addition to the discovered increased amount of *Acropora cervicornis* dense patches in the region, this study also led to the discovery of the existence of many large (>2m), resilient corals. Much of the colonized pavement and ridge has a smooth texture in the LIDAR enabling the detection of singular large objects if the laser bounces off the feature and returns a shallower depth than the surrounding area. This occurs as a blip in the hillshaded surface of an interpolated seafloor model. Although smaller than the minimum mapping unit for this study (and thus not in this study's scope and funded separately), 187 blips in the LIDAR associated with dark specs in the imagery were identified and a portion investigated. Of the 53 that were visited, 47 were stony corals estimated between 2 and 5 meters in diameter. Twenty-three (43%) were alive in various conditions (Figure 26). These were predominantly *Orbicella faveolata* (20), but 2 were *Siderastrea siderea* and one was a *Montastrea cavernosa*. Considering that 72% of the points remain to be visited, it might be that there are many more very large live corals existing in the southeast Florida region. Previously there was only one coral reported of a comparable size by Drs. Kevin Helmle and Richard Dodge of Nova Southeastern University.

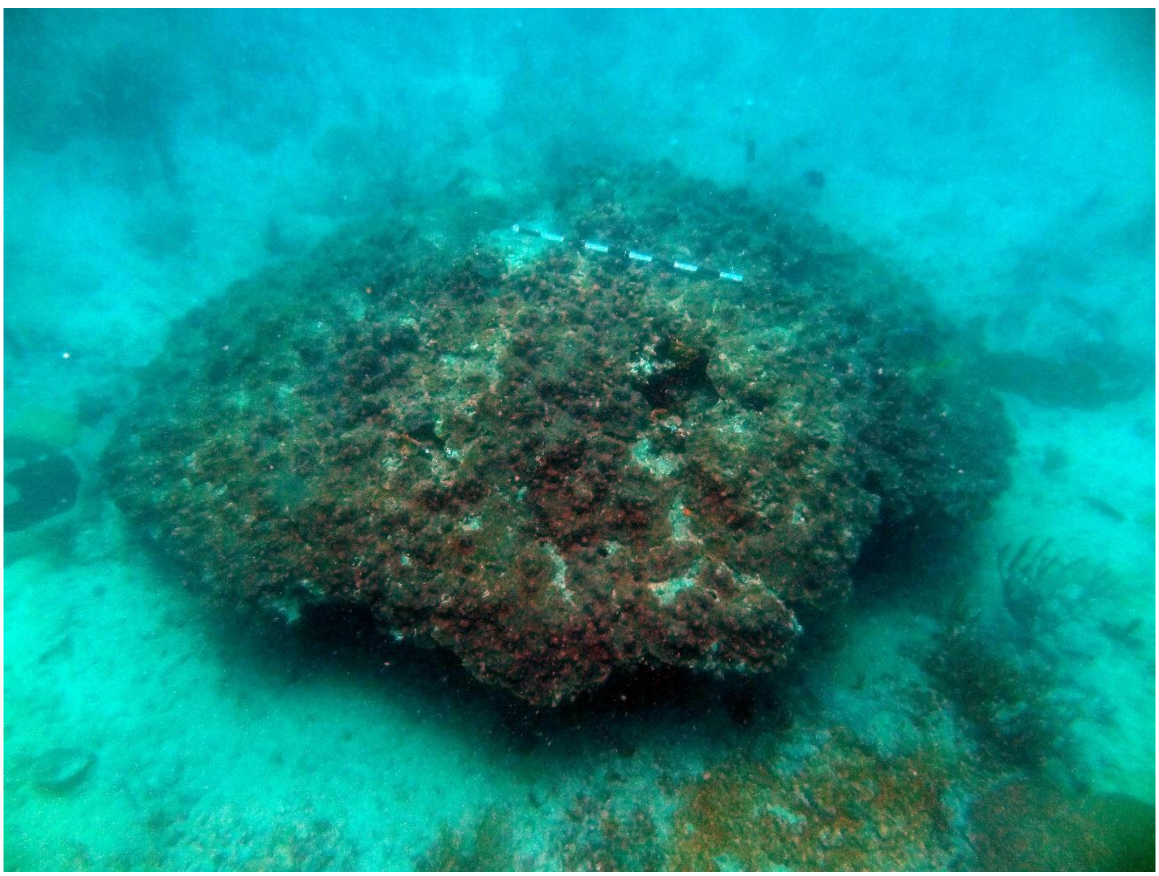


Figure 26. *Example of one large (~4m) Obricella faveolata discovered as a result of this study. The stick in the photo is 1m in length for scale.*

5. CONCLUSIONS & RECOMMENDATIONS

This study achieved its goals to provide a spatially appropriate map of increased resolution and a regional quantitative characterization of nearshore benthic resources to evaluate differences in benthic communities between habitats and with latitude for the southeast Florida region of the northern Florida Reef Tract. Habitats were mapped with high accuracy at a finer resolution. The images provided a clear visualization of the nearshore habitats giving a snapshot of the current extent of shallow-water coral reef community. Differences were measured in stony coral, gorgonian, and sponge densities across habitats and latitudes indicating the habitats were distinct from one another and not homogenous throughout the region. However, these distinctions were not present in all data.

This study elucidated new data on the extent of the Endangered Species Act threatened coral species, *Acropora cervicornis*. Only approximately 30% of the discovered dense patches were identified as previously known and the total regional area of *A. cervicornis* dense patches is now estimated at 156,000 m^2. The identification of these new, large dense patches highlights a critical data gap in our knowledge of *A. cervicornis* distributions and population distribution, demographics, and status. The condition of the coral in these patches cannot be surmised from the images. Additionally, the polygons depicted in the habitat map are likely under-representative of the shape and sizes of these patches due to their fuzzy boundaries.

> *Recommendation 1: A detailed study is needed to map A. cervicornis dense patch boundaries and characterize their condition to properly inventory these patches and their condition.*

It has been speculated that the abundance of this species is increasing in this region due to climate change (Precht & Aronson, 2004), however no evidence has shown this to be the case. These patches are known to boom and bust through time. They are also highly dynamic, moving considerable distance in short periods of time (Walker et al., 2012). The only way to fully understand if the net amount is increasing is to investigate it on a regional level. Unfortunately no consistent data sets have been identified that can be used for this purpose at this time. Some local imagery has been helpful in some cases.

> *Recommendation 2: Identify historic imagery and analyze it to determine the timing of when the dense A. cervicornis patches came into existence.*

> *Recommendation 3: Collect a regional set of imagery repeatedly on a regular timeframe in the future to elucidate the dynamics of dense patches and document the current extent of nearshore resources. This is especially important after large storm events.*

This study has expanded the present knowledge on the amount, location, and species type of resilient, large (>2m) coral colonies. In SE FL, corals increase in size with age by an estimated 1cm per year. Corals of this size are hundreds of years old, meaning they have persisted through the multitude of anthropogenic impacts that have occurred in the region. For example, the previously known large coral was cored and aged to 311 years. Large coral colonies are more fecund, giving an exponentially increased amount of reproductive output making these colonies particularly important in the restoration of the reef system.

> *Recommendation 4: Conducted a full inventory study to understand the extent, size, condition of these large, resilient corals.*
>
> *Recommendation 5: Monitor the large, resilient corals on a regular basis to document condition change through time.*
>
> *Recommendation 6: Investigate the large, resilient corals' reproduction to determine if they are spawning.*
>
> *Recommendation 7: Investigate the genetic diversity of the large, resilient corals and dense A. cervicornis patches to determine if they are genetically similar to each other and other local populations.*
>
> *Recommendation 8: Investigate the use of the large, resilient corals to help propagate naturally resilient corals in local restoration efforts.*

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