Developing a Coral Cover Index from the Florida Reef Resilience Program's Coral Monitoring Data to incorporate into the Coastal Resilience Wave Toolkit's Interactive Map

An Internship Report

Submitted to the Faculty
of the University of Miami,
Rosenstiel School of Marine and Atmospheric Science
in partial fulfillment of the requirements for the
Degree of Master of Professional Science

In cooperation with
The Nature Conservancy

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December, 2014

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Developing a Coral Cover Index from the Florida Reef Resilience Program's Coral Monitoring Data to incorporate into the Coastal Resilience Wave Toolkit's Interactive Map

Abstract of a master's degree internship report at the University of Miami, Rosenstiel School of Marine and Atmospheric Science. Supervised by: *Dr. Andrew Baker, James Byrne, and Dr. Diego Lirman*. Number of pages in text: 32

The biodiverse barrier reef ecosystem of Florida provides many valuable services including shoreline protection, tourism and recreational services, fisheries and employment (Collier et al., 2008; Burke et al., 2011). Unfortunately, 80% of Caribbean coral cover has been lost over the past 30 years due to disease outbreak, bleaching, climate change and anthropogenic stressors (Gardner et al., 2003; Baker et al., 2008; Hughes et al., 2010). The loss of live coral cover also reduces net reef accretion rates, and may lead to net erosion of reefs if cover drops below 10% (Perry et al., 2013). Without continued reef growth, sea-level rise is projected to decrease the ability of reefs to provide services such as reduction of wave energy (Alvarez-Filip et al., 2009; Ferrario et al., 2014). When determining the health of the reef ecosystem, indicators are needed to measure its ability to provide services, differentiate natural versus anthropogenic impacts and evaluate the effectiveness of current management (McField and Kramer, 2007).

Since live coral cover is a widely used indicator across monitoring programs and is a good evaluator of long-term condition and structure, % LCC was extrapolated from the reef-monitoring database collected by the Florida Reef Resilience Program (FRRP, 2005-2013). There have been >1700 surveys completed across the Florida Reef Tract (FRT) since 2005, among all subregions and reef zones. From the results, a report-card response is as follows: (1) <5 %LCC may result in reef erosion; (2) 5-10 %LCC may be able to remain stable; and (3) >10 %LCC may be able to maintain reef accretionary properties (Perry et al., 2013). Throughout all subregions, forereef and mid-channel zones (outermost barrier reefs) were mostly <10 %LCC which should cause some concern for management and conservation agencies. The % LCC index of the FRT can help document the current reef condition and structure that can be integrated into the Coastal Resilience wave toolkit, ultimately providing Florida's policymakers, scientists and public community with a decision-support tool to help reduce ecological and socio-economic risks to coastal hazards, such as sea-level rise. Increased awareness of these hazards will help improve statewide conservation and restoration efforts.

Acknowledgements

I would like to thank my committee members for their help and support in the writing process. Thanks to my committee Co-Chair's Dr. Andrew Baker and Dr. Diego Lirman for the useful editing and overall project advice. Thanks also to my hosting agency, The Nature Conservancy, and my internship supervisor, James Byrne, for working with me many days when I needed help with ArcGIS and data collection. Also a special thanks to Meaghan Johnson and Caitlin Lustic for being supportive office mates, as well as assisting me numerous times along the way. Also, the long commutes would not have been quite the same without carpooling with you, Meaghan.

I'd also like to give a special thanks to Dr. Jill Richardson, Sharon Auguste and Dr. Evan D'Alessandro, as I would not have gotten through the fast-paced, stressful MPS program without their guidance.

Thanks to all my professors at RSMAS for teaching me things that I will keep with me forever. I owe much of that knowledge and guidance to Dr. Chris Langdon and Dr. Keene Haywood. I really appreciate the time and effort you both put into helping me achieve my goals. I learned a lot in my short time with this community, and I won't forget it.

I appreciate my fellow students for studying and working hard in classes, then enjoying time at the Wetlab when it was all said and done. I am sure we will all stay in touch through this very family-oriented field of marine science!

Thanks to the Florida Reef Resilience Program divers that gave their time over the past ten years for this robust dataset, as well as those at CREMP, especially Dr. Mike Collela at FWC. Another special thanks to Dr. Phillip Kramer for giving me great advice on the best way to analyze the large datasets I had to work with, even though he was not a part of my committee.

I want to recognize my family and friends for supporting my academic endeavors and my pursuit to help save the environment! I owe so much to my three siblings, and most to my amazing parents! I love you all and I would not be where I am today without you!

And finally, thank you to my wonderful, sweet and supportive boyfriend, Jake Luce. You have stuck with me through a crazy year and a half of graduate school, through all its ups and downs. I am not sure I would have remained sane without your love and encouragement. I love you.

Table of Contents

List of Tables

List of Figures

Appendix

1.0 Introduction

1.1 The Florida Reef Tract: Ecosystem services, coral status trends, and wave attenuation properties

Coral reefs are often likened to rainforests because the magnitude of their biodiversity is comparable. The key to a healthy reef is having high biodiversity and productivity. The reef must contain healthy numbers of hard and soft corals in order to provide a dynamic habitat in which organisms, such as fish and other invertebrates, reside (Lirman, 2012). A biodiverse reef ecosystem can provide many beneficial services to people including jobs and revenue for the economy, a beautiful destination for tourists, healthy fisheries and shoreline protection (Collier et al. 2008; Burke et al. 2011).

It is estimated that coral reef-related activities worldwide generate approximately $30 billion per year (Cesar et al., 2003), with Florida bringing in more than $6 billion (Johns et al., 2001). These statistics illustrate the sheer importance of healthy, accreting reefs. Unfortunately, a high percentage of coral reefs worldwide are declining, particularly in the Caribbean where coral cover has declined by nearly 80% (Gardner et al., 2003). Caribbean coral reefs have decreased from approximately 35% to 17% cover, losing nearly 50% since the 1970s (Jackson et al., 2014). Most of this loss is due to mortality from disease and coral bleaching (Aronson and Precht, 2006), but overfishing (both historical and contemporary, Jackson et al., 2001; Bellwood et al., 2004), nutrient pollution, and habitat destruction have also contributed significantly to this decline.

Coral bleaching results from thermal stress induced by global climate change. Hoegh-Guldberg et al. (2007) illustrate climate change scenarios that could increase global temperature by two degrees Celsius, along with a atmospheric CO2 reaching 500 parts per million with "business as usual" by 2100. Climate change, without a decrease in local anthropogenic stressors (such as poor water quality, eutrophication and excessive carbon dioxide emissions) exemplifies this "business as usual" scenario. These stressors will result in devastating, irreversible damage to the world's reefs. In the western Atlantic, most reef communities have continued to decline following mass bleaching, as a result of combined anthropogenic stressors and repetitive, milder bleaching episodes, but elsewhere reefs have been able to regenerate, given the right conditions (Baker et al. 2008). Mass bleaching in the Caribbean has also resulted from extremely low temperatures, rather than warmer ones. Lirman et al. (2011) studied the effects of a cold-water bleaching event in January 2010, in which the Florida Reef Tract (FRT) experienced the worst mortality recorded to date. In Southeast Florida and the Keys most past bleaching events have resulted in some permanent loss of coral cover and changes in trophic structure, and have greatly reduced coral diversity at many sites.

Coral bleaching, or other disturbances, can also lead to increased disease frequency because susceptibility is heightened for communities already under stress. White band disease has already had critical impact on Caribbean reefs due to its devastation of elkhorn and staghorn corals, *Acropora palmata* and *Acropora cervicornis,* starting in the 1970s. These two important reef-building branching species made up the framework of shallow Caribbean reefs, and their loss fundamentally changed the nature of Caribbean reefs, with potential impacts on their structural integrity and diversity. In recent years, disease outbreaks have become more common (Burke et al. 2011).

Ultimately, reef health depends on its resilience to these disturbances. McClanahan et al. (2012) defines resilience in two parts: resistance and recovery. The ability of a reef community has to "bounce back" from a disturbance may be dependent on its functional redundancy.

Ecosystems that have high functional redundancy have multiple species with similar roles in the ecosystem that can fill available niches if needed due to the loss of another, functionally similar, species (Bellwood et al., 2004; Hughes et al., 2010). An example of functional redundancy, or lack thereof, is the case of historical overfishing in many Caribbean reefs that led to a decrease in herbivores, followed by disease that wiped out the black long-spined sea urchin, *Diadema antillarum*. The die-off eventually lead to a phase shift in these ecosystems from a coral dominated to an algal dominated state (Hughes et al. 1994). The shift occurred because species richness in the Caribbean is lower than in the Indo-Pacific where there are substantially more species with similar functional roles (Bellwood et al. 2004; McField and Kramer, 2007). Coral reefs must be able to maintain and adapt both their structure and function to survive and provide beneficial ecosystem services.

Coral reef ecosystem-based adaptation is necessary to counteract the negative impacts of global climate change and coastal threats, as well as sustain valuable services (Spalding et al., 2013). Healthy reefs are a first line of defense and a major food source for coastal communities worldwide, protecting over 150,000 kilometers of coastline in at least 100 countries (Burke et al., 2011). Ferrario et al. (2014) conducted a meta-analysis and found that healthy reefs reduce wave energy in 97% of cases, and are much cheaper than artificial structures to maintain. Sadly, sea-level rise is projected to outpace new reef accretion, which will increase water depths and result in increased erosion and sediment suspension, and will decrease its ability to maintain its ecosystem services (Storlazzi et al., 2011). According to Alvarez-Filip et al. (2009), this "flattening" of reefs has been occurring since the 1980s. There is a balance between carbonate accretion and erosion rates on coral reefs. In a Caribbean-wide study, Perry et al. (2013) suggest that there is a "threshold" of at least 10% live coral cover that must be maintained in order to avoid chances of becoming net erosional. They found that ~37% of reefs were net erosional and that overall, the loss in coral cover since the 1980s due to increased human and climatic stressors has decreased accretion rates, which may be further exacerbated by projected sea-level rise.

Due to these reductions in coral cover and projected climate change, coral reef conservation research and management efforts have been increasingly implemented in recent years (Kramer, 2003; Mumby and Steneck, 2008; McClanahan et al., 2012). Factors considered by researchers and agencies when determining the resilience of a reef include coral diversity, nutrient pollution, sedimentation, human impacts, herbivore biomass, temperature variability, macroalgae, disease and fishing pressures (McClanahan et al., 2012). Most of these resilience factors are used as ecosystem indicators to provide condition assessments of coral reefs. McField and Kramer (2007) depict a healthy reef as one that is assessed according to four categories of ecosystem indicators: structure, function, drivers of change and social well-being. Their study reiterates the need to have more than one indicator to assess the overall condition of the ecosystem. These indicators quantify ecosystem services, differentiate natural versus anthropogenic impacts, help evaluate current management effectiveness, and increase public awareness.

A few indicators that are used in various survey programs include of live cover, coral mortality, species diversity, bleaching, disease and physical damage (Kramer, 2003, McField and Kramer, 2007; FRRP, 2011; Formel, 2013). From these indicators, the long-term condition and community structure of a reef can be determined by calculating the percent cover and mortality over time (Kramer, 2003). Other indicators, such as bleaching and percent recent mortality, are better for evaluating reef function and can be used as early warning signals of recent stress events (Kramer, 2003; McField and Kramer, 2007; Baker et al., 2008; Lirman et al., 2013;

Formel, 2013).

The Florida Reef Resilience Program (FRRP: www.frrp.org) is a cooperative effort involving a variety of partners that focuses on monitoring the Florida Reef Tract (FRT). The FRT is the only barrier reef tract in the continental United States and is approximately 358 miles long, from the St. Lucie Inlet in Martin County to 70 miles southwest of Key West, ending at the Dry Tortugas National Park (Department of Environmental Protection [DEP], 2012). The FRRP Disturbance Response Monitoring (DRM) program develops resilience-based adaptive management strategies to stressors such as bleaching, disease and global warming. The goal is to track changes in the FRT over time by using a set of ecosystem indicators that will help evaluate the health of the ecosystem by managers and researchers alike. Since 2005, 1758 coral surveys have been completed (www.frrp.org).

The Coral Reef Evaluation and Monitoring Project (CREMP) is another Florida survey program that has been collecting coral reef data since 1996 (CREMP, 2012). They are one of the longest running coral monitoring programs, and unlike FRRP, they collect coral cover during their surveys, as well as coral demographic data since 2011.

Percent live coral cover was the best ecosystem indicator to use for the purposes of this study. Coral cover is a measure of the structural integrity of the current FRT coral community and its likelihood of attenuating waves and "keeping up" with sea-level rise. It is measured across most monitoring programs and is a standard measure of the overall condition of the coral reef community (McField and Kramer, 2007).

1.2 Objectives

This study has three major objectives. The first involves using CREMP's coral cover and coral demographic dataset to develop a live coral cover index to measure the amount of cover across Florida Reef Resilience Program's DRM coral monitoring dataset. The second is to use the index in ArcGIS to create a spatial interpolation of the average percent live coral cover across the FRT. The final goal is to integrate the interpolations into the Coastal Resilience Wave Tool Kit to produce an interactive map that can be used as a decision support tool for policy makers, scientists and other stakeholders (CREMP, 2012; http://coastalresilience.org). The GIS interpolation maps and the wave tool will both serve as tools for management purposes.

1.3 Significance of Study

Integrating coral cover into the toolkit will allow planners, government officials and other stakeholders to better quantify how the FRT currently protects the coasts. The index will provide a more detailed measure of the current conditions across the reef tract, compared to the current measure of live versus dead coral. Understanding the amount of live coral cover throughout the regions and the attenuating properties it can provide in each region is imperative to improving the assessment of coral reef health. These assessments will provide more detailed information on the ability of the reef structures to buffer the impacts of waves, currents and sea level rise. This will help management agencies better understand the actions they should take to improve the resilience of the reefs and coastlines, as well as measure the benefits of restored reefs with engineered structures. Thus, having an idea of the condition of the coral cover present in each region FRT, and should improve the overall coral and coastal conservation and restoration efforts.

1.4 Limitations

McClanahan et al. (2011) argue that coral cover is robust to changes in ecosystem processes and therefore may be a poor metric for evaluating the health of the reefs. FRRP does not measure percent coral cover, as CREMP does, so therefore it's an estimate of cover, rather than an exact measurement. The accuracy of this measurement may be compromised because of these extrapolations. Also, across different subregions and habitat types, coral cover is extremely variable, so when identifying the cause of reduced coral cover at various sites, may be unlikely from a management prospective (McField and Kramer, 2007).

Other studies suggest that declines in coral cover can decrease coral calcification and increase drivers of bioerosion, ultimately decreasing wave attenuation properties by reducing their three-dimensional structure (Kennedy et al. 2013; Alvarez-Filip et al. 2009). Thus, using live coral cover as an indicator may not limit the parameters of this investigation since the wave tool will use cover to predict a reef's ability to attenuate waves.

2.0 Methods and Materials

2.1 Study Site

The study site for this project runs from the Upper Keys through the Dry Tortugas (See Fig. 1). The study area within the Florida Keys region involves the coral habitat within subregions of the FRT. The Marquesas' subregions do not have an adequate number of surveys observed to be included in the analysis. Sites that did not fall within the study area were excluded from the analysis.

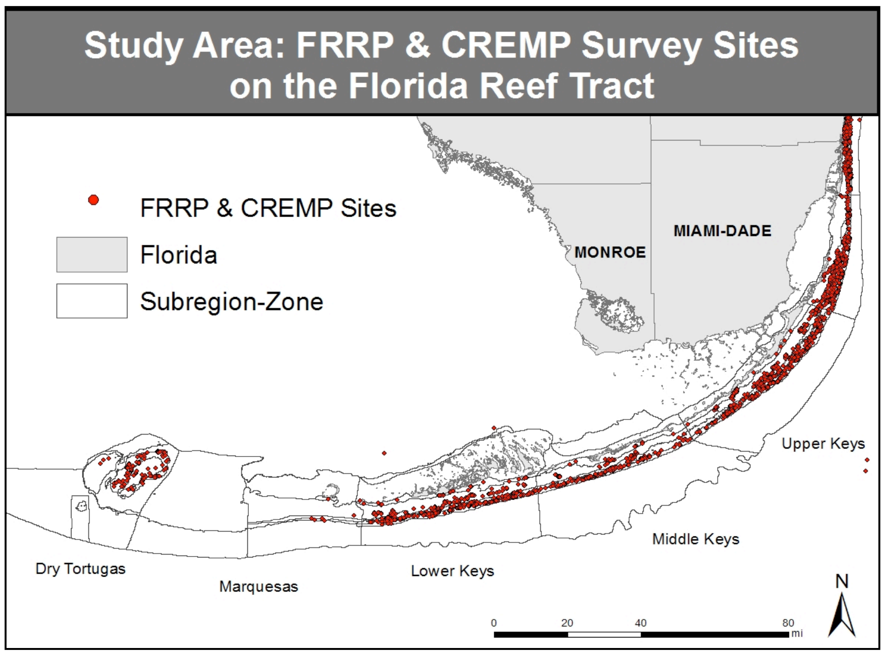

Figure 1: A map displaying FRRP and CREMP site locations used for surveys across the FRT within the separate subregion-zones (The sites outside the subregion-zone boundaries were not included in this study).

2.2 Survey Designs

Coral demographic and percent cover data was obtained from CREMP, as well as coral demographics data from FRRP for this study. Both use stratified random survey techniques, although CREMP's sites are fixed every year, unlike FRRP (CREMP, 2012; FRRP, 2011). For FRRP, predetermined sites and GPS coordinates are randomized annually through a probabilistic survey design that stratifies by subregion and by habitat zone within the FRT (Smith et al., 2011). Within this stratified layer, the sites are 200 m x 200 m cells where two 1x10 m belt transects are haphazardly laid and monitored by divers. At each site, primary and secondary coordinates are made available to FRRP partners in case the first site is not suitable. Only coral colonies greater than four centimeters are measured for size, mortality (old and new), number of tissue isolates, degree of bleaching, and presence of disease. Each coral is identified to the species level and recorded in the FRRP database (FRRP, 2011; www.frrp.org). For each of CREMP's fixed sites, there are four fixed stations. These stations occupy $44m^2$, where three transects are surveyed for coral cover and demographic data (CREMP, 2012).

2.3 Developing a coral cover index

From literature I have reviewed, using percent coral cover, as an ecosystem indicator, best suited this study (Kramer, 2003; McField and Kramer, 2007). FRRP does not measure percent coral cover, but they do measure attributes such as coral size and percent mortality that can be used to calculate density, area and coral cover. CREMP monitoring surveys collect percent coral cover data, using the point count method, and since 2011, they have also collected coral demographic data. By applying the coral area and density formulas used by both AGRRA and FRRP summary products (Marks and Lang, 2007), I was able to calculate the area and density for CREMP. To calculate coral density, take the #corals/m^2 surveyed at each site. The formulas used to calculate live coral area are displayed below (See Table 1).

Table 1: A table representing the calculations used to convert the CREMP coral demographic data into live coral area (Marks and Lang, 2007; FRRP, 2011).

Coral Area Calculations	
Total Area	[Pi*(Width/2)*(Length/2)]
Old Area	[Total Area*(Old Mortality/100)]
Recent Area	[Total Area*(Recent Mortality/100)]
Live Area*	[Total Area-Old Area-Recent Area]
**Represents the area used for calculating % live coral cover in regression analysis*	

Preceding analysis, I refined the variables from the CREMP coral demographic and coral cover data into a usable format, sorting by site and subregion. In order to allow for independence of variables, I only used one year (2012) of the demographic data for the regression analysis. After live coral area was calculated for both the CREMP and FRRP datasets, I calculated the proportionate area at each site. There are 4 stations at each CREMP site. There are 440,000cm2 surveyed at each station. The equation I used to calculate CREMP's area proportionate is as follows:

$$Proportionate\ Area = (Site\ Area/4) \div (200cm*2{,}200cm) \times 100$$

There are two transects at each FRRP site. Each coral transect surveys 10,000cm2. The equation I used to calculate FRRP proportionate area is as follows:

$$Proportionate\ Area = (Site\ Area/2) \div (100cm*1{,}000cm) \times 100$$

Next, I performed simple linear regression on the CREMP data for each subregion separately to provide an analysis on whether a relationship existed between the proportionate areas to percent live coral cover, since CREMP had both coral area and cover data. The resulting linear equation is then used as a conversion formula for calculating percent live coral cover (%LCC) for the FRRP data. The FRRP data was organized "Coral Area by Site" and, as mentioned above, proportionate area was also calculated before the correct conversion formula was applied to each subregion independently. Once the data was organized it was integrated into

ArcGIS.

2.4 Integrating the coral index into ArcGIS

The final step involved producing polygon layers in ArcGIS that will indicate the current %LCC throughout the FRT within the Coral and Hardbottom Level 0 Habitats map layer created by Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute (FWRI) (See Fig. 2).

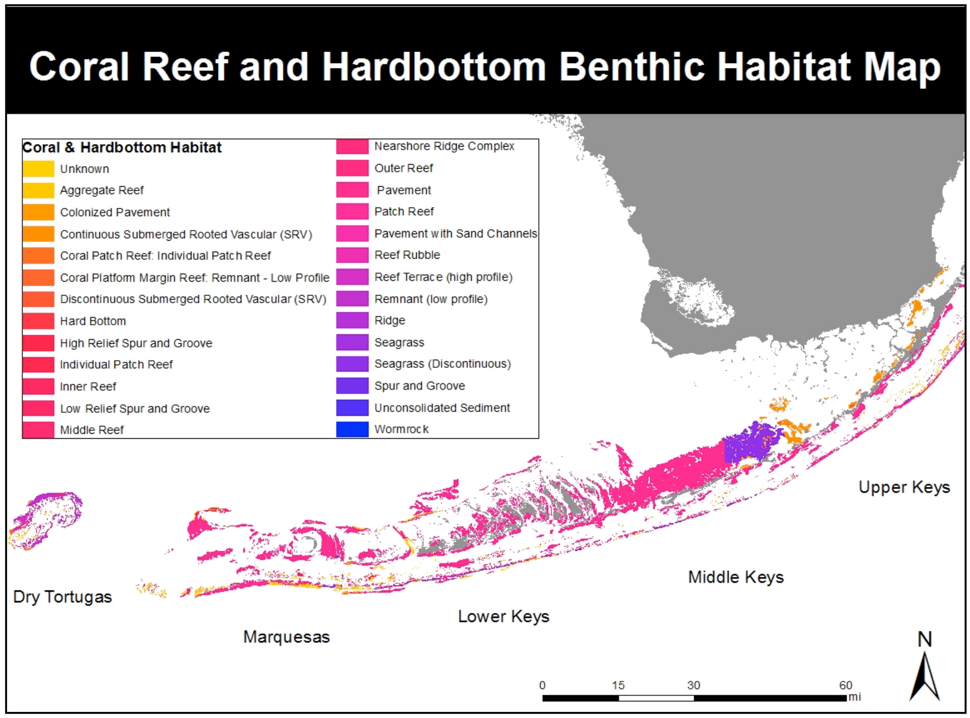

Figure 2: FWRI's Florida Coral and Hardbottom Benthic Habitat Map Level 0, Version 1.2 (http://ocean.floridamarine.org/IntegratedReefMap/UnifiedReefTract.htm)

To create a spatial interpolation of % live coral cover of the FRT by subregion, a kriging interpolation was run using the ArcGIS 10.0 Interpolation toolset within each subregion. Once the interpolation was complete, Zonal Statistics as Table were attained for each subregion and joined to the percent cover data by site. Next, the site data was joined spatially to the Coral and Hardbottom

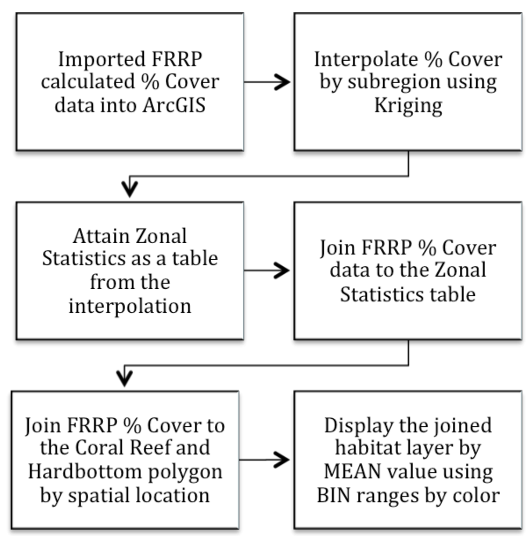

Figure 3: A flowchart showing the method to create interpolations used to extrapolate mean % LCC values across the FRT coral habitat.

Habitat polygons (See Fig. 3).

Since the data must be extrapolated to scale within the entire reef tract, the map polygons were arranged into "BIN" values of %LCC for each subregion. A bin range allows the parameters of the investigation to be sorted into a series according to their numerical value. They are used because exact cover estimates cannot be given with confidence. A "report card" style ranking system is used to display the bins of "MEAN" zonal statistic values of % LCC on the FRT. The final coral habitat map layers will be incorporated into the Coastal Resilience Wave Tool kit's interactive map.

3.0 Results

3.1 Linear Regression Analysis

A simple linear regression analysis was run on each subregion in the Florida Keys to evaluate whether a relationship between live coral area and live coral cover exists. All sizes and species were used to find a correlation between live area against live cover. The following figure shows the respective relationships within each subregion (See Fig. 4). Also below are the resulting linear equations from the regression analyses (See Table 2). Each subregion had its own equation that was then incorporated into the FRRP dataset to produce %LCC values.

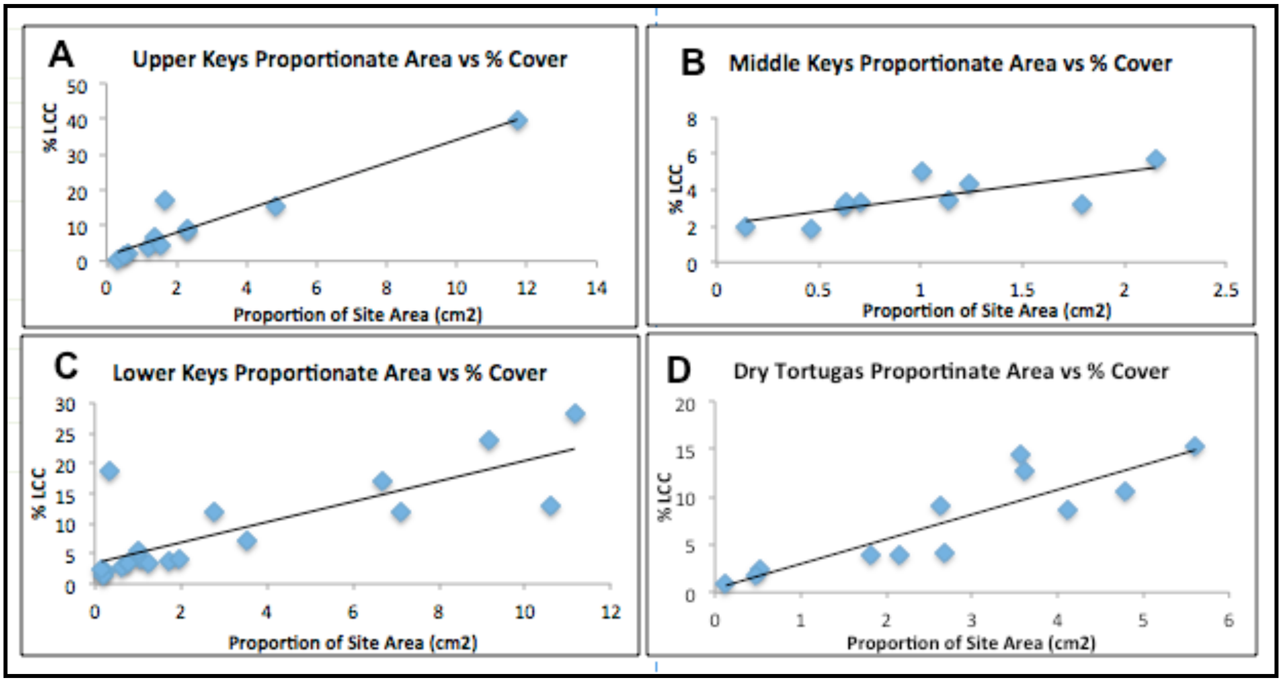

Figure 4: Scatterplots showing the average proportion of area to the average %LCC at each CREMP site throughout the Florida Keys by the respective subregions. (A) Upper Keys, R^2=0.91. (B) Middle Keys, R^2=0.55. (C) Lower Keys, R^2=0.63. (D) Dry Tortugas, R^2=0.79.

Table 2: A table displaying the results from the simple linear regression of proportionate area to %LCC within each subregion in the Florida Keys. An R^2 value closest to 1 or -1 indicates the strength of the relationship between variables.

CREMP: Florida Keys Linear Regression				
Subregion	**Equation**	**R^2**	**p-value**	**Significance**
Upper Keys (n=11)	y= 3.272x + 1.4605	0.90627	0.00001	$p < 0.05$
Middle Keys (n=10)	y= 1.4703x + 2.0612	0.55207	0.01380	$p < 0.05$
Lower Keys (n=18)	y= 1.6981x + 3.4688	0.62558	0.00009	$p < 0.05$
Dry Tortugas (n=12)	y= 2.5896x + 0.396	0.78634	0.00012	$p < 0.05$
**At each CREMP site, 4 stations were surveyed and the average coral area was taken for each site so that to conversion equation could be incorporated into the FRRP data by site.*				

3.2 % Live Coral Cover Interpolation Maps

The interpolations of the FRRP survey sites were divided between four subregions within the Florida Keys. The subregions used in the analysis included the following: Upper Keys, Middle Keys, Lower Keys, and the Dry Tortugas (See Figs. 6, 7 8, & 9). The Marquesas' subregions and three of the seven reef zones throughout the FRT were not included in this analysis because they did not contain an adequate amount of surveys (See Fig. 5). Nor does the Marquesas subregion protect any land inhabited by humans. The spatial interpolations for each subregion were classified into one of three bins: Red 0-5 % LCC, Yellow 5-10% LCC, Green >10% LCC.

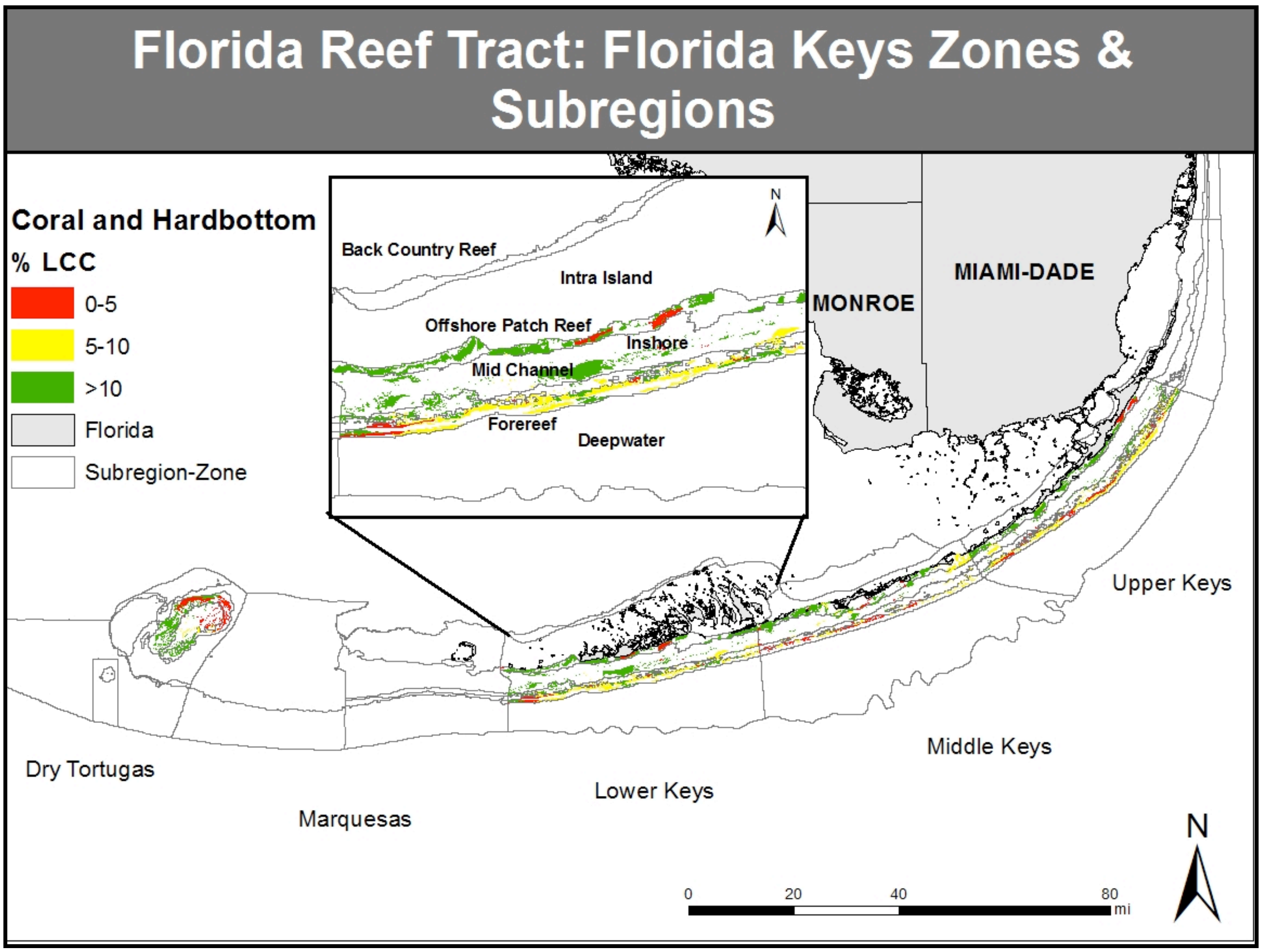

Figure 5: A map displaying the subregions and zones across the FRT. Kriging interpolations were used to spatially interpolate % LCC across the FRT's coral habitat map. As shown above, the zones—deepwater, backcountry reef and intra island—did not contain any surveys, and therefore were excluded from the kriging interpolation.

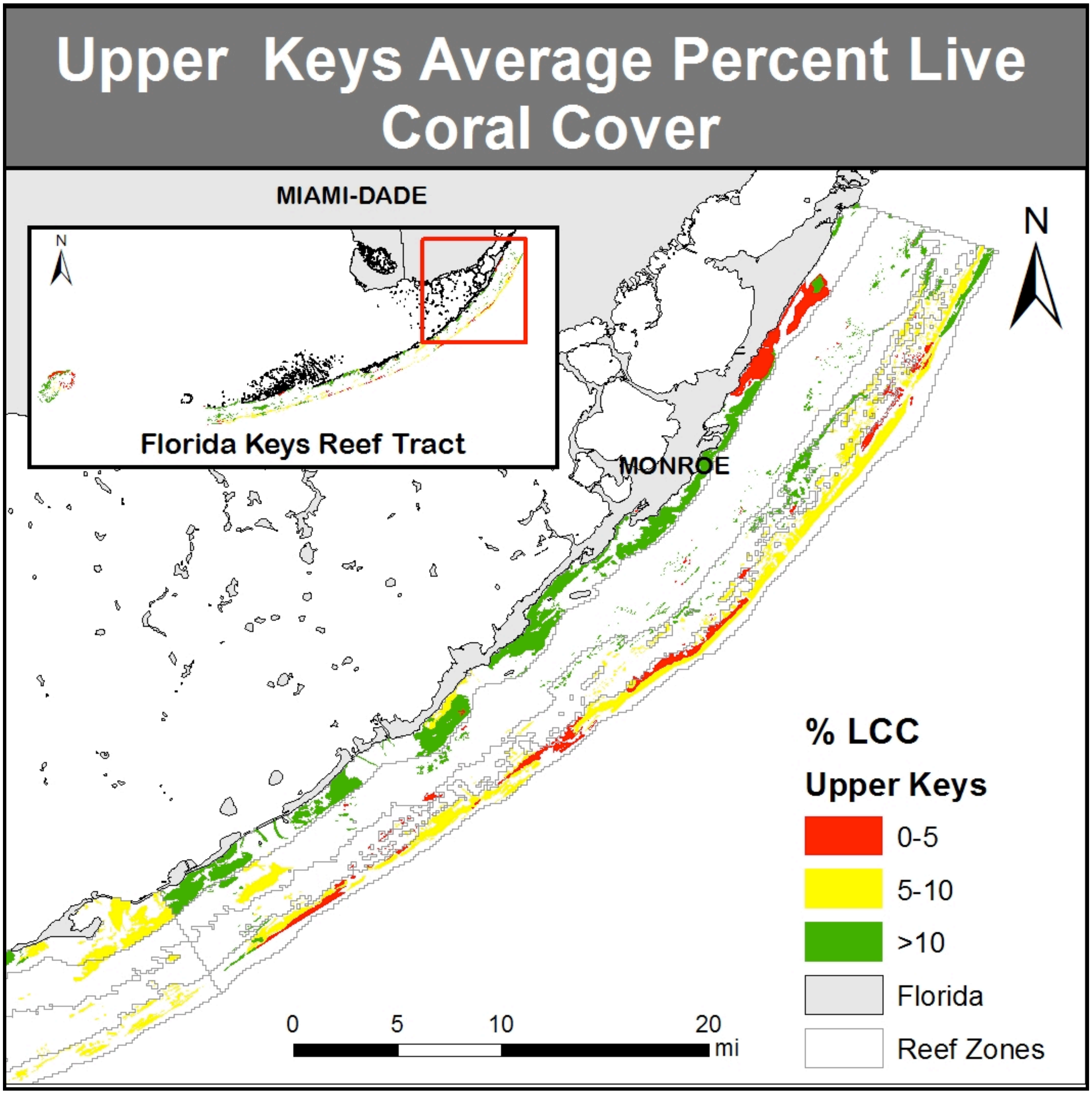

Figure 6: A map displaying the kriging interpolation of FRRP surveys showing mean % LCC values within the Upper Keys coral habitat.

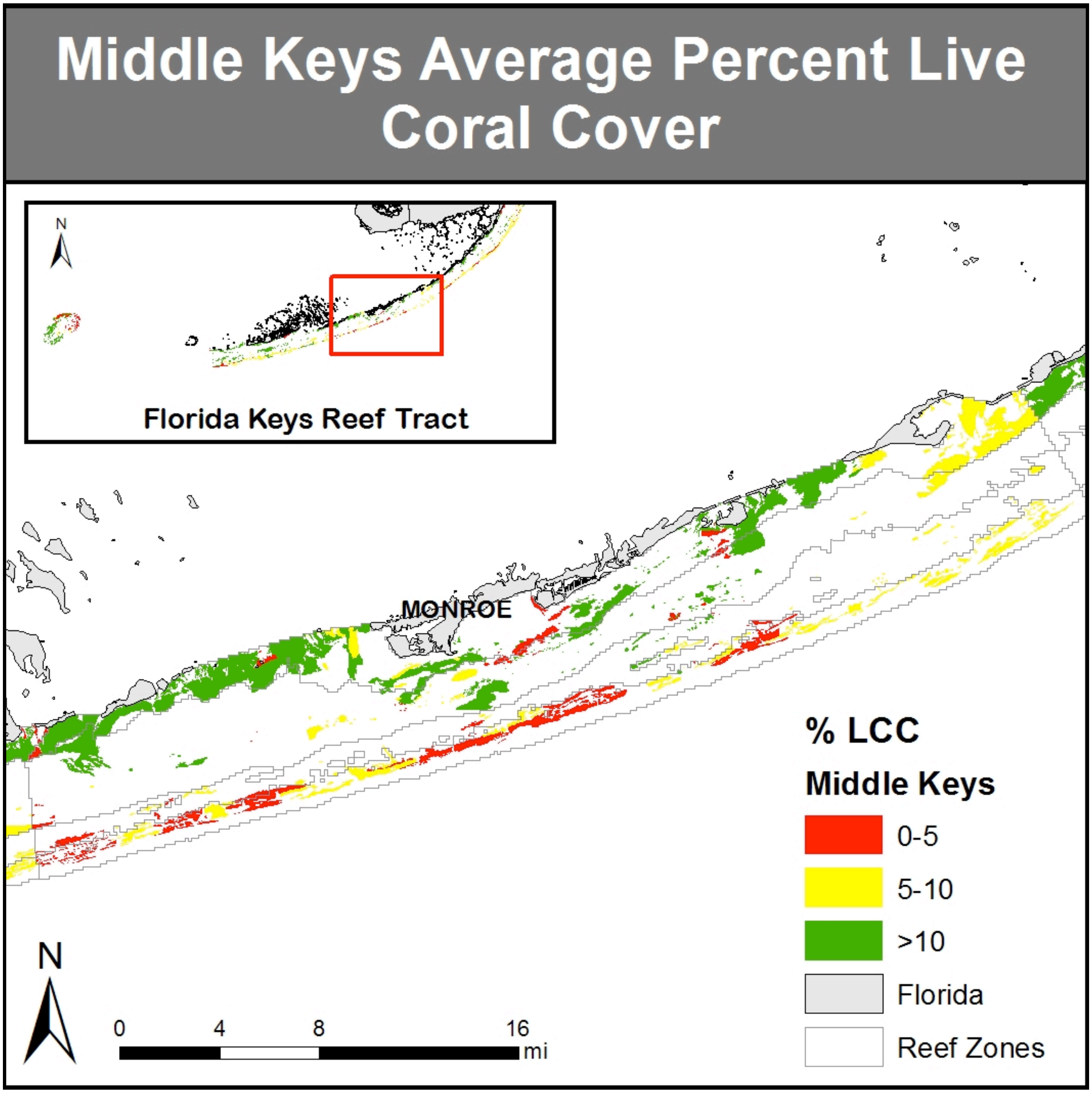

Figure 7: A map displaying the kriging interpolation of FRRP surveys showing mean % LCC values within the Middle Keys coral habitat.

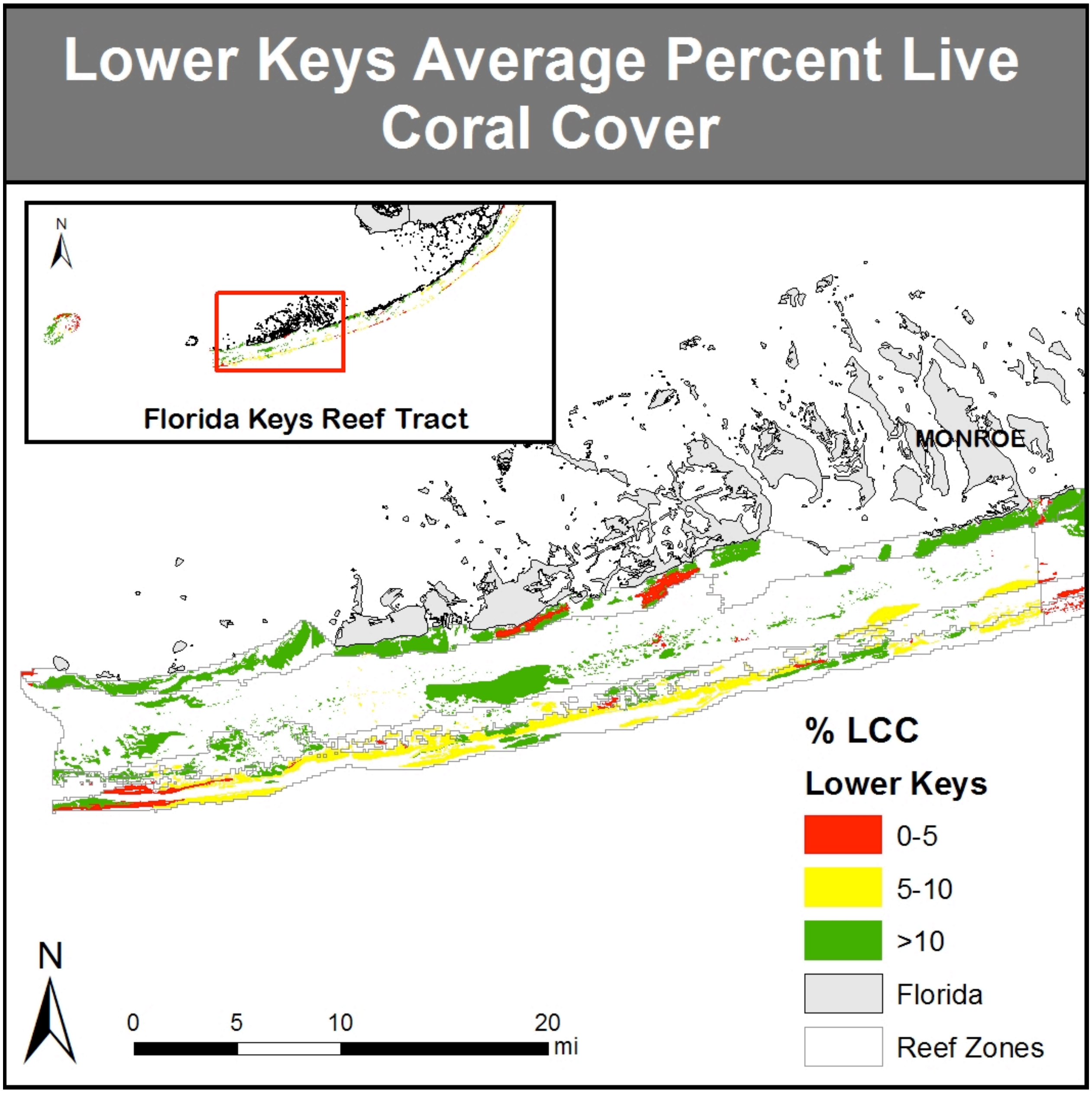

Figure 8: A map displaying the kriging interpolation of FRRP surveys showing mean % LCC values within the Lower Keys coral habitat.

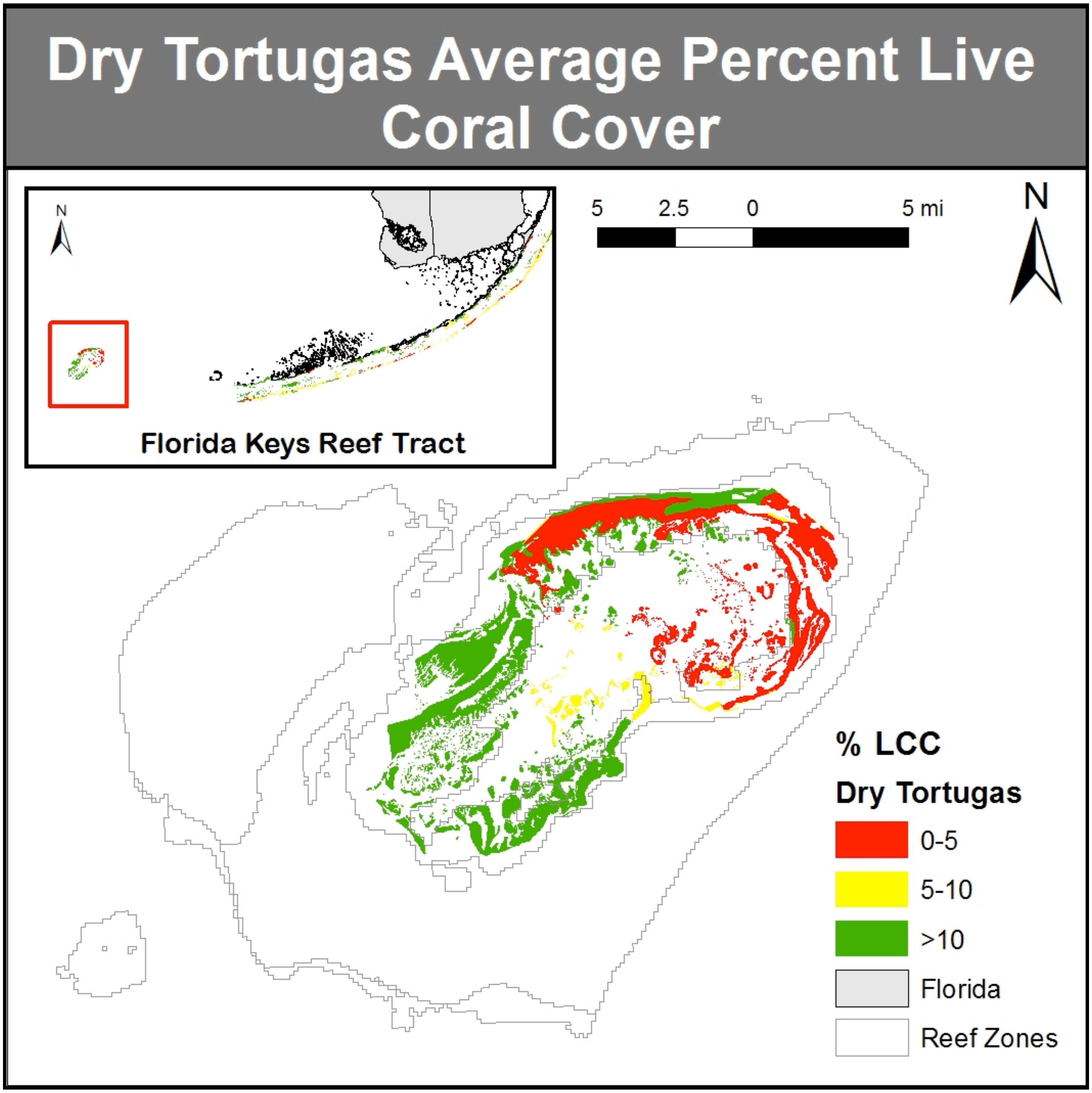

Figure 9: A map displaying the kriging interpolation of FRRP surveys showing mean % LCC values within the Dry Tortugas coral habitat.

4.0 Discussion

4.1 % LCC as a coral index for the FRT

Coral cover has long been an ecosystem indicator for coral reefs because it's collected across monitoring programs and is a good long-term indicator of the reef's condition (Kramer, 2003). Understanding the current state of Florida's reefs is as essential as understanding the original state that they were once in (Donahue et al. 2008). Coral reefs have lost nearly 50% of their makeup over the last 40 years, where reef building acroporid species suffered the greatest losses (Donahue et al., 2008; Jackson et al., 2014). In order to plan for appropriate mitigation actions, updating current live coral cover regularly should prove useful. Finding a correlation between live coral area and live coral cover may enable more monitoring programs to estimate coral cover from their own data to allow for more frequent status updates.

In finding the best linear relationship for this study, a regression analysis was run on density versus cover, as well as live area versus cover. Live coral area showed stronger correlation to live coral cover than density. Density can be very dynamic across the FRT among the regions. An R^2 value closest to 1 or -1 indicates the strength of the relationship between variables. The R^2 values for "live coral area against live coral cover" showed significant correlation to one another (See Figure 4). Therefore, their respective linear equations were used to extrapolate average live coral cover across the FRT on the FRRP dataset (See Table 2). Each subregion was positively correlated between $0.5 \leq R^2 \leq 1$. These values indicate that there is a decently strong relationship between live area and live cover, especially in the Upper Keys subregion with $R^2 = 0.90$. The relationship between variables across the whole reef tract was much weaker ($R^2 = 0.25$), which is expected since at finer scales (subregion and zone), there are more structural and species composition that make them more distinctive. Overall, higher live coral area resulted in higher live coral cover throughout the subregions denoting that there is in fact a relationship between these two variables within the FRT.

4.2 % LCC Interplation Results

As mentioned before, a study done by Perry et al. (2013) predicts that at least 10% live coral cover needs to be present to avoid becoming a net erosional ecosystem. This estimate may vary by region or subregion across Florida. They also suggest that this value should be considered “budget neutral”, meaning that the reefs would be in a state of “accretionary stasis”, which Florida and the rest of the Caribbean are believed to be in currently. So although the current reef structure is in tact, without increasing accretion rates, there will be negative implications for the future geological structure of the FRT. The table below illustrates the different average bins of % LCC used for the interpolation maps (See Table 3).

Table 3: A table showing the classes of % LCC by color used to populate the coral habitat map that indicates three potentially key responses to the amount of coral cover needed to prevent net reef erosion (Perry et al., 2013).

Florida Reef Tract: Florida Keys % Cover Report Card		
% Cover	**Rank Color**	**Response**
0-5	Red	Reef Erosion
5-10	Yellow	Stable Reef
>10	Green	Reef Accretion

The FRT is one of the northernmost living coral reefs in North America at 25° N, which is almost at the latitudinal threshold (28° N or S) for coral development (Burns, 1985; Lirman and Fong, 2007). At these lattitudes, corals are more prone to physical and frequent disturbances, such as colder temperatures and storms. Therefore, the estimated % LCC bin ranges represent the region adequately according the Perry et al. (2013). Since these values are extrapolated across the FRT as averages within range of the FRRP sites, true %LCC values are both over and underestimated. At >10% % LCC (Green), there should be reef accretion, meaning that coral cacification is outpacing bioerosion. Between 5-10 % LCC (Yellow), reefs should remain stable (neither accreting or eroding). Finally, at <5 % LCC (Red), the FRT may become net erosional. There is more red than anticipated across the maps, particularly in the middle keys (See Fig. 7). Unfortunately reef erosion has increased in recent years due to human impact and climate change. These impacts have serious consequences for the Florida Keys shoreline resilience, increasing coral mortality (causing reef rubble), which in turn can affect a reef's ability to attenuate storm and wave energy. Some healthy reefs attenuate this eneregy by approximately 80%, so a significant loss of this protection would be devastating to Florida's coastline (Sheppard et al., 2005).

When observing the separate subregions, a trend is observed by zones according to three colors—red, yellow and green. In the Upper, Middle and Lower Keys (See Figs. 6-8), the Mid-Channel and Forereef zones have lower % LCC values than the Inshore and Patch reefs. Since these zones are the first two zones that act as a barrier from the open water, storm and wave damage is most likely more severe. When refering to the same figures, inshore patch reefs had relatively higher % LCC values across the reef tract. It is suggested that inshore patch reefs have significantly higher live coral cover and growth rates, so the higher cover represented by the interpolations in these zones is not unexpected (Lirman and Fong, 2007; Kuffner et al., 2010). Since patch reefs are shown to have healthier reefs (i.e. higher live coral cover), when considering options from a management prospective, it may be best to start with protecting these patches, rather than those already degraded.

5.0 Recommendations

As was mentioned previously, one limitation of the Florida Reef Resilience Program is not collecting percent coral cover in the field. For this study, %LCC was extrapolated from the linear relationship between CREMP's coral cover to coral area data (CREMP, 2012). Therefore, the values for FRRP are estimates, rather than true values. If FRRP would incorporate %LCC collection in their surveys, it would be easier for stakeholders to keep track of the current status of FRT condition each year. FRRP randomly selects sites each year, rather than CREMP's fixed sites, so the result would mean a greater scope of coral cover across the FRT. Studies suggest loss of coral cover can decrease wave attenuation properties by reducing their three-dimensional structure (Kennedy et al. 2013; Alvarez-Filip et al. 2009). In order to determine the state of the reef, as well as its architectural structure, surveying rugosity with coral cover could prove beneficial for wave attenuation purposes. FRRP does measure for rugosity, but if others also adopted it in their survey programs, it could be more widely studied for management of climate change and sea-level rise scenarios.

By using a "report-card" response, stakeholders can easily understand which part of the FRT needs the most attention, and which should be protected because of its health. The three colors allow an easy understanding by all interested parties that may or may not have any background in science. As more programs start to collect coral cover data, it is recommended that they prepare a yearly estimate of the coral cover across the FRT.

6.0 Conclusions

Percent live coral cover can be a good assessor of a reef's long-term condition and structure. From the >1700 surveys that have been completed, a report-card response was proposed. Between 5-10 %LCC a reef may be able to maintain stability, where there is neither loss nor growth. At <5 %LCC the reef will become net erosional. These conditions would cause major concern for policymakers and stakeholders. Reef accretion will occur when %LCC is >10 (Perry et al., 2013). Inshore patch reefs showed the greatest %LCC values across the FRT. Forereef and mid-channel zones were <10 %LCC, indicating that there is little or no growth and possible erosion. If FRRP and other agencies updated their %LCC values every year, annual documentation of the current reef condition status can provide Florida's policymakers, scientists and other stakeholders a tool to help reduce ecological and socio-economic risks to coastal hazards. Increased awareness of these hazards will help prompt management actions, like more coral restoration or implementation of protected areas.

7.0 References

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Appendix A. Coastal Defense App website. The red line indicates a transect that is run across from land across the reef, blue on graph is the coral reef intersecting that transect. According the amount of coral cover available, results will be given on the amount of wave attenuation the reef can provide, as well as different sea-level rise scenarios. The tool should launch in 02/2015.