Florida DEP Technical Report

# Coral reef resilience to climate change in the Florida Reef Tract

Jeff Maynard, James Byrne, Kristi Kerrigan, Dieter Tracey, Karen Bohnsack, Francisco Pagan, Joanna Walczak and Gareth Williams

Florida Department of Environmental Protection
The Nature Conservancy
NOAA National Oceanic and Atmospheric Administration U.S. Department of Commerce
NOAA Coral Reef Conservation Program
National Marine Sanctuaries
SymbioSeas

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Final Report

Prepared By:

Jeff Maynard, James Byrne, Kristi Kerrigan, Dieter Tracey, Karen Bohnsack, Francisco Pagan, Joanna Walczak and Gareth J. Williams

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## Executive Summary

Climate change and a range of human activities threaten the natural resilience of coral reef ecosystems. Reef resilience is the ability to resist and recover from disturbances while retaining essentially the same function and structure. Managers can support the natural resilience of reefs by reducing their sensitivity to climate-related disturbances, such as coral bleaching, by reducing stress on reefs caused by human activities. The challenge for natural resource managers in Florida, as with everywhere else reefs occur, lies in deciding which actions to implement and where, to best support resilience. Understanding spatial variation in resilience to climate change in the Florida Reef Tract was the goal of this project, with the aim being to produce information that can inform management decisions. This project is a collaboration co-funded by NOAA's Coral Reef Conservation Program, the Florida Department of Environmental Protection, and The Nature Conservancy's Florida office. This study addresses this priority from Florida's Climate Change Action Plan – *Determine and map areas of high and low resilience to climate change in order to prioritize management efforts.*

The following seven indicators are included in the assessment of relative resilience: coral cover, macroalgae cover, bleaching resistance, coral diversity, coral disease, herbivore biomass, and temperature variability. Data used to develop these indicators come from field reef monitoring surveys (excepting temperature variability, which is remotely sensed) conducted ***in 2016*** (*no* other years are included) as part of the National Coral Reef Monitoring Program and Florida Reef Resilience Program. Both monitoring programs use a stratified random sampling design whereby surveys are completed within all of the various habitat types and sub-regions of the Florida Reef Tract. For this analysis, the data collected are summarized using weighted averages within 'strata', which combine habitat type and reef vertical complexity (i.e. 'PR_HR' Patch reef high relief in Tortugas). There are eight strata in Tortugas, seven in FL Keys and eight in SE Florida. A single value for each indicator is produced for each of these 23 strata. Indicator scores are then made uni-directional (high score is a good score), the scores are normalized to the maximum value to standardize scores to a 0-1 scale, and the scores are averaged and re-normalized to produce the final resilience scores. The strata are then ranked from highest to lowest score and classified as follows, based on the average (AVG) final resilience score (0.77) and standard deviation (SD) (0.16): High (>AVG+1SD), Med-high (>AVG & <AVG+1SD), Med-low (<AVG & >AVG-1SD), and Low (<AVG-1SD).

The average score for the 'raw' resilience scores was 0.5 and ranged from 0.31 to 0.65. The average of the normalized, final resilience scores was 0.77 and ranged from 0.31 to 0.65. The standard deviation around this average was 0.16. Relative categories are set as High (>AVG+1SD; >0.93), Med-high (>AVG & <AVG+1SD; >0.77&<0.93), Med-low (<AVG & >AVG-1SD; <0.77&>0.61), and Low (<AVG-1SD; <0.61) (see Table 1). Among the 23 strata, there are 5 with relatively high resilience, 9 medium-high, 6 medium-low, and 3 with relatively low resilience (Figure 2 and Table 1). The Tortugas had 1 high, 4 med-high, and 3 med-low resilience strata. The FL Keys had 4 high, 2 med-high, and 1 med-low resilience strata. SE Florida had 5 med-low and 3 low resilience strata.

The strata with relatively high resilience are:

F_D_LR [1] – Forereef deep low relief in FL Keys
MC_PR [2] – Mid-channel patch reef in FL Keys

PR_HR [3] – Patch reef high relief in Tortugas
RF_HR [4] – Reef high relief in FL Keys
F_M_LR [5] – Forereef mid-depth low relief in FL Keys

The strata with relatively low resilience are:

NEAR [21] – Nearshore in SE Florida
RR_C [22] – Reef-ridge complex in SE Florida
RF_D [23] – Reef deep in SE Florida

Results of a multivariate statistical analysis (canonical analysis of principal coordinates) results indicate that high resilience sites generally had high values for herbivore biomass, coral diversity, coral cover and bleaching resistance; the opposite is true for sites with medium-low or low resilience (Figure 2).

Results are shared within the report as maps and show spatial variation in relative resilience, as well as spatial variation in each of the 7 resilience indicators included in the analysis. Highlight results from examining the resilience indicators include:

Average coral cover among the 23 strata in 2016 was 7.05% in 2016. Hard coral cover was relatively high (>AVG+1SD) in 2016 in MC_PR, OF_PR (Offshore patch reef in FL Keys), IN_PR (Inshore patch reef in FL Keys), and CONT_HR (continuous high relief reef in Tortugas).

Average macroalgae cover among the 23 strata in 2016 was 57.03% in 2016. Macroalgae cover was relatively high (>AVG+1SD) in 2016 in RF _MD (Mid-depth reef in SE Florida), RF_IR, NEAR (Nearshore reef in SE Florida), RF_D (Deep reef in SE Florida), and F_S_LR (Forereef shallow low relief in FL Keys)

Average herbivore biomass was 3.26 g/100m$^2$. Herbivore biomass was relatively high in 2016 in F_D_LR, RF_HR (Reef high relief in FL Keys), and RF_MD (Reef mid-depth in SE Florida). Herbivore biomass was relatively low in 2016 only in RR_C (Reef ridge complex in SE Florida).

The report concludes with a list of suggested future research and communication activities, including: compile past reef monitoring data to examine trends in resilience indicators and resilience over this last 10 years; examine spatial variation in the resilience of other (than stony corals) key habitat builders, such as barrel sponges, sea fans and soft corals; examine site-based data to review resilience at a higher-resolution than strata; produce fact sheets to educate senior policy and decision-makers on resilience concepts; use resilience information to predict survivorship of corals transplanted from nurseries; and develop a dashboard that makes reef monitoring data and resilience summaries available as interactive maps to managers and the public.

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# List of Acronyms

| | |
|---|---|
| AVG | Average |
| CAP | Canonical Analysis of Principal Coordinates |
| CNMI | Commonwealth of the Northern Mariana Islands |
| FRRP | Florida Reef Resilience Program |
| FRT | Florida Reef Tract |
| LPI | Line Point Intercept |
| NCRMP | National Coral Reef Monitoring Program |
| NOAA | National Oceanic and Atmospheric Administration |
| RVC | Reef Visual Census |
| SD | Standard deviation |
| TNC | The Nature Conservancy |
| USVI | United States Virgin Islands |

# 1. INTRODUCTION

Coral reef managers everywhere seek to reduce vulnerability to climate change. In the most popular vulnerability assessment framework, vulnerability is a function of exposure to climate stress (e.g., the high sea temperatures that cause coral bleaching) and the resilience of the system to that stress (i.e., the system sensitivity and adaptive capacity, Turner et al. 2003). Reef resilience is defined as the ability of coral reefs to resist and recover from such disturbances while retaining essentially the same function and structure (Mumby et al. 2007). To reduce vulnerability, managers need to support the natural resilience of reefs by reducing their sensitivity to climate-related disturbances (Maynard et al. 2015). This requires reducing local stressors on reefs. The challenge for natural resource managers in Florida, as with everywhere else reefs exist, lies in deciding which actions to implement and where, to maximize the extent to which climate vulnerability is reduced. Understanding spatial variation in resilience can inform such management decisions.

Coral reefs are dynamic and complex ecosystems, whose function is controlled by myriad factors. However, recent research on the characteristics of resilient reefs has shown that despite this complexity, a few factors can be isolated as the most highly influential drivers of resilience. In particular, in their 2012 study McClanahan et al. identified 11 key indicators for reef resilience based on both the strength of empirical evidence, expert opinion, and feasibility of study; from this prioritized list, they developed a methodology for assessing resilience and informing site-specific management. Recently, Maynard et al. (2015; in press) translated the framework put forward by McClanahan et al. into guidance for the scientific and management community on how to assess coral reef resilience to support decision-making and inform management and conservation planning. Such resilience assessments have been completed in CNMI (Maynard et al. 2015), Hawaii (Maynard et al. 2016), Australia (Maynard et al. 2010), USVI, Indonesia and a range of other locations throughout the Pacific, Caribbean and Southeast Asia.

*The overarching goal of this project was to assess the relative resilience of coral reefs in Florida to climate change.*

, Coral reefs along the FRT are located close to shore and co-exist with intensely urbanized areas, particularly in southeast Florida. They are subject to impacts from a variety of natural and human stressors including, among others, coral bleaching and disease, invasive species, marine debris, land based sources of pollution, recreational and commercial misuse, and coastal construction. Identifying resilient reef areas and better understanding their interaction with human stressors can help inform management strategies to better protect coral reefs in the future.

This project is a collaboration co-funded by NOAA’s Coral Reef Conservation Program, the Florida Department of Environmental Protection, and The Nature Conservancy’s Florida office.

### 1.1. Objectives

This is one of the few reports that takes a holistic view of the Florida Reef Tract. Though divided among different counties and other management regimes, reefs within the FRT have similar ecology and have similar values socially. It is critically important that the scientific and management community examine the entire FRT in identifying areas with relatively more and less resilience to climate change.

The project objectives were to: 1) assess the relative resilience of reefs within the FRT to climate change, and 2) identify next steps for this research area and for sharing and translating information within the report into management and conservation action.

### 1.2. Meeting management and action plan targets

This study addresses this priority from Florida's Climate Change Action Plan – *Determine and map areas of high and low resilience to climate change in order to prioritize management efforts.*

## 2. METHODS

### 2.1. Assessing relative resilience

#### *2.1.1. Data collection*

The following seven indicators are included in the assessment of relative resilience: coral cover, macroalgae cover, bleaching resistance, coral diversity, coral disease, herbivore biomass, and temperature variability. Data used to develop these indicators come from field reef monitoring surveys (except temperature variability, which is remotely sensed) conducted ***in 2016*** (*no* other years are included) as part of the National Coral Reef Monitoring Program and Florida Reef Resilience Program. Both monitoring programs use a stratified random sampling design whereby surveys are completed within all of the various habitat types and sub-regions of the Florida Reef Tract. For this analysis, the data collected are summarized using weighted averages within 'strata', which combine habitat type and reef vertical complexity (i.e. 'PR_HR' Patch reef high relief in Tortugas). There are eight strata in the Dry Tortugas, seven in FL Keys and eight in SE Florida. A single value for each indicator is produced for each of these 23 strata (Figure 1). Data collection methods are described briefly below for each of the seven indicators.

*Coral cover* (CC) and *Macroalgae cover* (MA) are the proportion of the benthic community made up by coral and macroalgae. Coral and macroalgae cover are calculated from Line-Point Intercept (LPI) transects conducted as part of the NCRMP. LPI transects involve classifying the benthos at 15 cm intervals for a total of 100 points over 15 m. The proportion of the points that are coral is the coral cover, and the proportion of the points that are macroalgae is the macroalgae cover.

*Bleaching resistance* (BR) is the proportion of the stony coral community made up by corals that are relatively resistant to bleaching. Coral species observed were classified on a 1-5 scale following examining 10 years of bleaching observations under the FRRP, as follows: 1 – highly susceptible to bleaching, 2 – susceptible to bleaching, 3 – resistant to bleaching, 4 – very resistant to bleaching, 5 – rarely bleaches. Coral species with a score $\geq$3 were considered ‘resistant to bleaching’ for calculating the bleaching resistance indicator; the proportion of the community made up by resistant species.

Resistance classifications are shown for all coral species in Table A2. Data on the coral species present and their abundance come from coral demographics surveys conducted as part of the NCRMP and from surveys conducted as part of the FRRP. Coral demographics surveys are concurrent with and along the same transects as the LPI surveys, using 10m x 1m belt transects. All coral species are recorded, as is information on size and condition (percent live vs. dead, bleaching, disease). The FRRP surveys include the same area (10m x 1m belt transects) and record the same information.

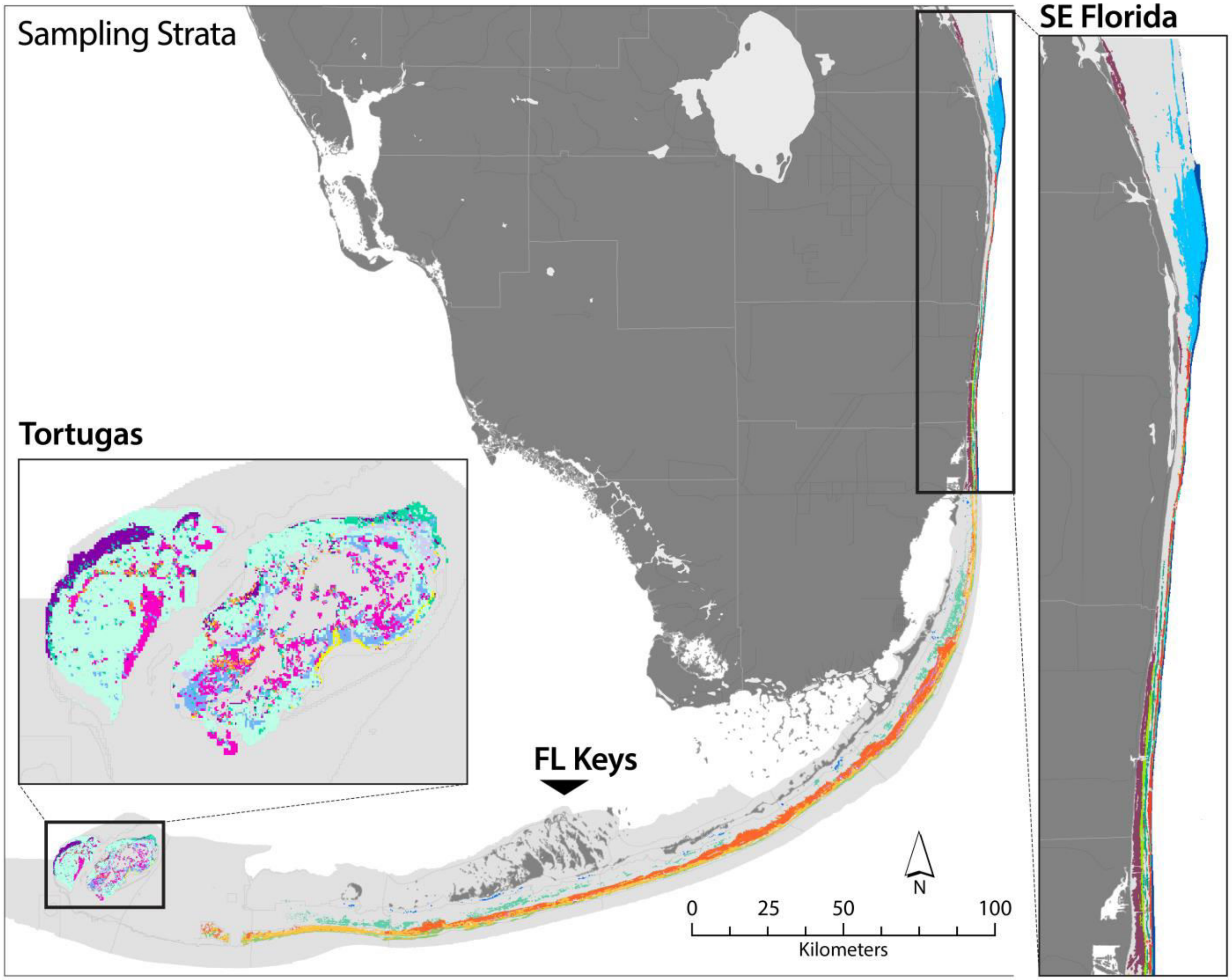
*Coral diversity* (DI) is the inverse of the Simpson’s Index of Diversity, which asks; how likely (0-1 probability) is it that if two species are pulled from a community at random that they will be different species? The greater the likelihood species will be different, the greater the diversity, and hence the higher the diversity score on the 0-1 scale. Coral diversity is calculated from the species abundance data collected at each of the benthic transects conducted as part of the NCRMP and FRRP.

*Coral disease* (CD) is the number of coral colonies with disease observed during the benthic monitoring surveys (10m x 1m belt transects) conducted as part of the NCRMP and FRRP surveys. *These data are not likely to be representative of spatial variation in disease abundance during the 2015-2017 coral disease outbreak as: they represent averages of surveys completed only once (i.e. transects were not re-visited), most surveys were completed during non-peak times for coral disease in Florida, and specific disease types were not identified during any surveys (i.e., cannot differentiate between the outbreak disease(s) versus background disease(s)).*

> Note from NCRMP monitoring protocols:
>
> *Precise designations of coral condition (e.g., specific disease types, minor bleaching/paling conditions) are specifically not included due to the low temporal resolution of the NCRMP sampling (i.e., biennial and potentially not seasonally consistent). The survey protocol is designed to capture the most easily recognized colony conditions likely to be encountered, specifically recent mortality (i.e., dead white skeleton) and bright-white bleaching on a partial or an entire coral colony.*

*Herbivore biomass* (HB) is the average biomass in g/100 $m^2$ of herbivorous reef fishes observed during Reef Visual Census (RVC) surveys conducted as part of the NCRMP. RVCs are stationary point counts of reef fish within a cylinder (15 m diameter) of the water column that includes the benthos diameter and lasts 5 minutes. All fish species in the cylinder are recorded and the length of each fish is estimated. The relationship between the length of each fish and weight is calculated as W=aLb where W is body weight (g), L is total length (cm), a is a coefficient related to body form and b is an exponent indicating isometric growth when equal to 3. The biomass of all herbivorous fish ***is summed*** for each RVC and this biomass is averaged among all the RVCs conducted within each strata in 2016. A list of herbivorous fish species observed in 2016 is provided in Table A3.

*Temperature variability* (TV) is calculated as the standard deviation of the warm season temperatures during the 1982-2012 period. Warm season is defined as the three-month period inclusive of the warmest month (August or September in Florida (it varies)) and one month either side. These data are a sub-set for Florida of a global dataset presented within Heron et al. (2016).




| TORTUGAS | STRATA | n trans. | n RVCs |
|---|---|---|---|
| CONT_HR | Continuous reef high relief | 22 | 61 |
| CONT_LR | Continuous reef low relief | 17 | 51 |
| CONT_MR | Continuous reef medium relief | 25 | 52 |
| PR_HR | Patch reef high relief | 17 | 53 |
| PR_LR | Patch reef low relief | 12 | 55 |
| PR_MR | Patch reef medium relief | 19 | 2 |
| SG_HR | Spur and groove high relief | 10 | 15 |
| SG_LR | Spur and groove low relief | 5 | 6 |
| **FL KEYS** | | | |
| F_D_LR | Forereef deep low relief | 5 | 33 |
| F_M_LR | Forereef med. depth low relief | 68 | 31 |
| F_S_LR | Forereef shallow low relief | 50 | 111 |
| IN_PR | Inshore patch reef | 16 | 64 |
| MC_PR | Mid-channel patch reef | 39 | 17 |
| OF_PR | Offshore patch reef | 21 | 75 |
| RF_HR | Reef high relief | 33 | 27 |
| **SE FLORIDA** | | | |
| NEAR | Nearshore | 30 | 27 |
| PR_D | Patch reef deep | 4 | 20 |
| PR_S | Patch reef shallow | 9 | 49 |
| RF_D | Reef deep | 15 | 25 |
| RF_IR | Reef inner | 19 | 9 |
| RF_MD | Reef middle | 22 | 52 |
| RF_OF | Reef Offshore | 34 | 12 |
| RR_C | Reef-Ridge Complex | 5 | 6 |

**Figure 1.** Locations of 'strata' – the sampling unit used for the resilience assessment; i.e. a single value was produced for each strata for each indicator, using weighted averaging. Strata combine categorical habitat type (i.e. Patch reef) with vertical complexity (i.e. high relief); NCRMP database codes for strata were converted for this report to more intuitive codes (see Table A1). These are analysis strata developed as part of the National Coral Reef Monitoring Program. Sampling effort within each strata area varied during 2016; the number of benthic transects and reef fish visual census (RVC) surveys are shown in brackets next to the strata descriptions (transects, RVCs).

### *2.1.2. Data Analysis*

<u>Resilience Data</u> for all indicators is normalized to a 0-1 scale by dividing by the maximum value for the indicator among the 23 strata. This makes all scores for indicators relative to values for these indicators in the Florida Reef Tract only, and only for 2016. The 0-1 scale is made uni-directional, where a high score is always a good score, by taking the inverse (1-value) for macroalgae cover and coral disease. For this analysis, all seven indicators are considered to be equally important to reef resilience so are weighted equally. Resilience scores are first calculated by averaging the normalized uni-directional scores for the seven indicators. These raw resilience scores are then normalized by dividing by the maximum value, setting resilience in our dataset as relative to the strata with the greatest average indicator score. The strata are then ranked from highest to lowest score and classified as follows, based on the average (AVG) final resilience score (0.77) and standard deviation (SD) (0.16): High (>AVG+1SD), Med-high (>AVG & <AVG+1SD), Med-low (<AVG & >AVG-1SD), and Low (<AVG-1SD).

<u>Indicator variability</u> We used a canonical analysis of principal coordinates (CAP, Anderson and Willis 2003) to examine which indicators were driving differences in resilience potential across the four relative classifications for the inter- and intra-island analyses. The CAP was based on Bray-Curtis similarity matrices where variables that might be responsible for group differences are investigated by calculating the Spearman-Rank correlations of canonical ordination axes with the original indicator variables (Anderson et al. 2008).

## 3. RESULTS

### 3.1. Resilience

***Resilience is assessed here as an average of the normalized (0-1 scale) scores for 7 resilience indicators. Resilience scores are also normalized, so final resilience scores for each strata are expressed relative to the strata with the greatest average indicator score.***

The average score for the 'raw' resilience scores was 0.5 and ranged from 0.31 to 0.65 (Table 1).

The average of the normalized, final resilience scores was 0.77 and ranged from 0.31 to 0.65. The standard deviation around this average was 0.16. Relative categories are set as High (>AVG+1SD; >0.93), Med-high (>AVG & <AVG+1SD; >0.77&<0.93), Med-low (<AVG & >AVG-1SD; <0.77&>0.61), and Low (<AVG-1SD; <0.61) (see Table 1).

Among the 23 strata, there are 5 with relatively high resilience, 9 medium-high, 6 medium-low, and 3 with relatively low resilience (Figure 2 and Table 1). The Tortugas had 1 high, 4 med-high, and 3 med-low resilience strata. The FL Keys had 4 high, 2 med-high, and 1 med-low resilience strata. SE Florida had 5 med-low and 3 low resilience strata.

The strata with relatively high resilience are:

F_D_LR [1] – Forereef deep low relief in FL Keys
MC_PR [2] – Mid-channel patch reef in FL Keys
PR_HR [3] – Patch reef high relief in Tortugas
RF_HR [4] – Reef high relief in FL Keys

F_M_LR [5] – Forereef mid-depth low relief in FL Keys

The strata with relatively low resilience are:

NEAR [21] – Nearshore in SE Florida
RR_C [22] – Reef-ridge complex in SE Florida
RF_D [23] – Reef deep in SE Florida

Squared canonical correlation values ($\delta^2$) of the first and second ordination axes are 0.914 and 0.117, respectively. These correlation values represent the amount of variation, as a proportion, in the dataset that each CAP explains; the axes are not fully independent, which is why the value exceeds 1 when the two are added. The CAP results indicate that high resilience sites generally had high values for herbivore biomass, coral diversity, coral cover and bleaching resistance; the opposite is true for sites with medium-low or low resilience (Figure 2).

The CAP results had a total allocation success of 82.6% back into the groupings made based on average and standard deviation values. The CAP analysis suggests four strata were mis-classified. Most notably, the number 1 site for relative resilience – F_D_LR (Forereef deep low relief in FL Keys) – was classified by CAP with the Med-low resilience sites. Two other high resilience sites, F_M_LR (Forereef mid-depth low relief in FL Keys) and PR_MR (Patch reef medium relief in Tortugas) were classified by CAP as Med-high. Based on the CAP results, the strata that are distinctly different from all others and with the greatest relative resilience (according to this analysis) are: PR_HR [3] (Patch reef high relief in Tortugas) and RF_HR [4] – Reef high relief in FL Keys.

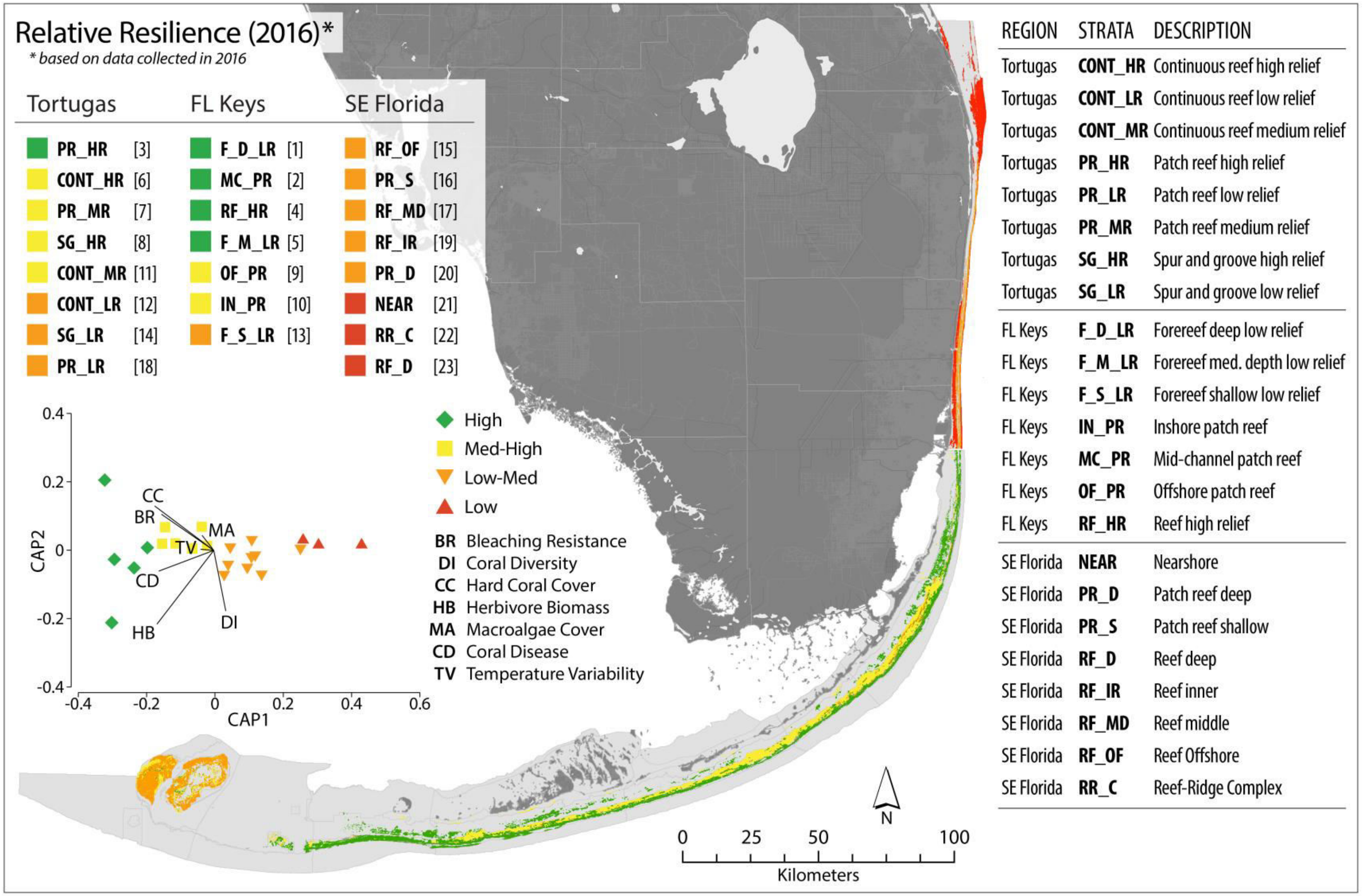
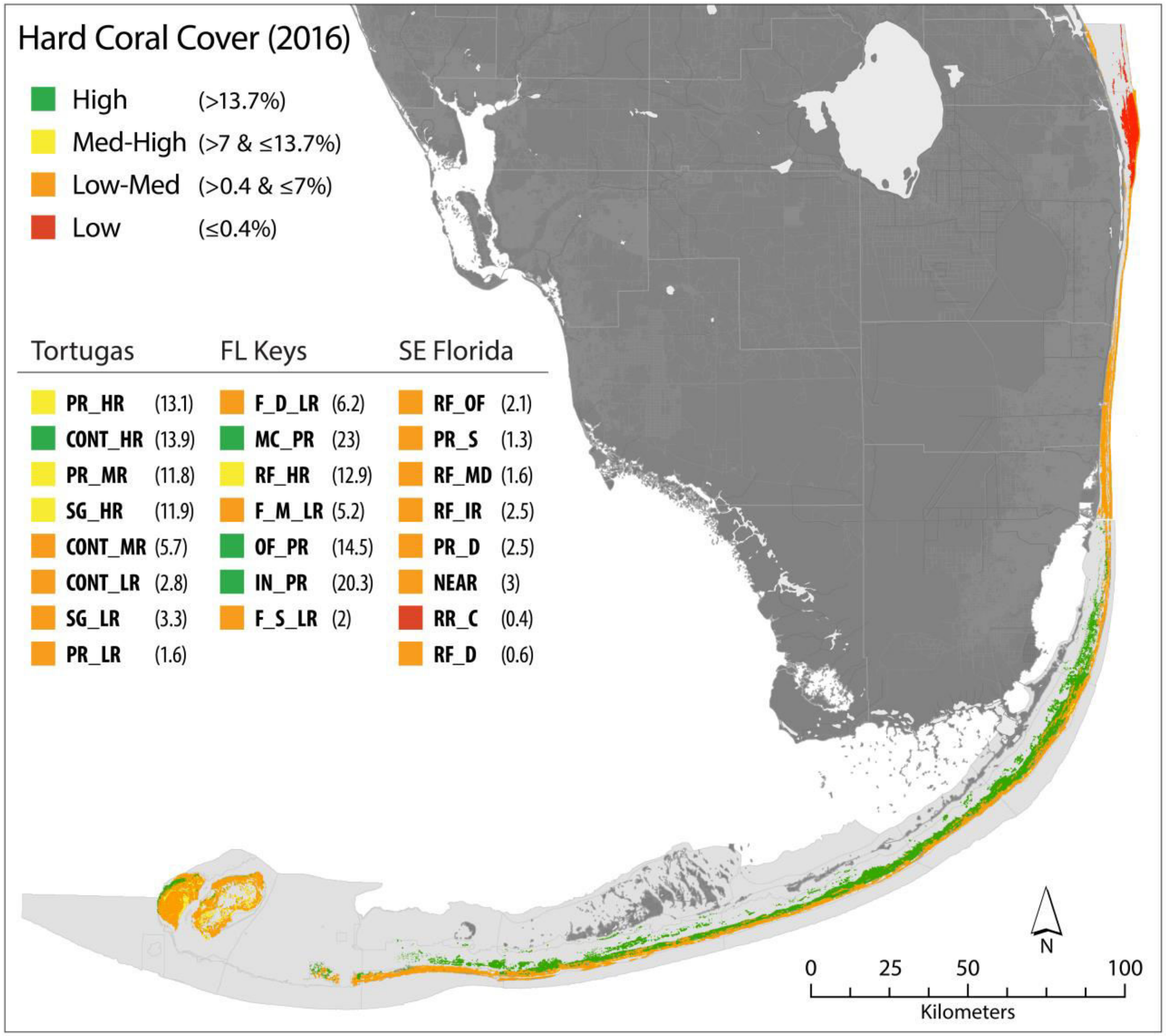



**Figure 2.** Relative resilience to climate change in the Florida Reef Tract, based on data collected in 2016. Rankings from highest to lowest relative resilience (1-23) are shown after strata codes top left, and descriptions for strata codes are right. Relative resilience is greatest in the FL Keys and lowest in SE Florida. Results of a canonical analysis of principal (CAP) coordinates are inset and show strong groupings among the relative categories in multivariate space. High resilience sites are strongly associated with high values for coral cover, bleaching resistance, and herbivore biomass and low levels of coral disease; the opposite is true for low resilience sites.

| Region | Strata | Resilience Rank | Final Resilience Score | Raw Resilience Score | CC | MA | BR | DI | CD | HB | TV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FL Keys | F_D_LR | 1 | 1.00 | 0.65 | 0.27 | 0.33 | 0.09 | 0.95 | 1.00 | 1.00 | 0.92 |
| FL Keys | MC_PR | 2 | 0.99 | 0.64 | 1.00 | 0.55 | 0.94 | 0.86 | 0.00 | 0.21 | 0.92 |
| Tortugas | PR_HR | 3 | 0.98 | 0.64 | 0.57 | 0.28 | 0.39 | 0.99 | 0.89 | 0.46 | 0.89 |
| FL Keys | RF_HR | 4 | 0.97 | 0.63 | 0.56 | 0.37 | 0.51 | 0.89 | 0.58 | 0.63 | 0.87 |
| FL Keys | F_M_LR | 5 | 0.94 | 0.61 | 0.23 | 0.16 | 1.00 | 0.89 | 0.75 | 0.34 | 0.91 |
| Tortugas | CONT_HR | 6 | 0.92 | 0.60 | 0.60 | 0.29 | 0.42 | 0.98 | 0.75 | 0.24 | 0.90 |
| Tortugas | PR_MR | 7 | 0.90 | 0.59 | 0.51 | 0.24 | 0.50 | 0.99 | 0.84 | 0.16 | 0.88 |
| Tortugas | SG_HR | 8 | 0.86 | 0.56 | 0.52 | 0.33 | 0.22 | 1.00 | 0.81 | 0.17 | 0.88 |
| FL Keys | OF_PR | 9 | 0.86 | 0.56 | 0.63 | 0.38 | 0.40 | 0.85 | 0.38 | 0.31 | 0.97 |
| FL Keys | IN_PR | 10 | 0.85 | 0.55 | 0.88 | 0.29 | 0.13 | 0.73 | 0.70 | 0.13 | 1.00 |
| Tortugas | CONT_MR | 11 | 0.77 | 0.50 | 0.25 | 0.12 | 0.44 | 0.95 | 0.69 | 0.17 | 0.88 |
| Tortugas | CONT_LR | 12 | 0.74 | 0.48 | 0.12 | 0.30 | 0.16 | 0.92 | 0.91 | 0.09 | 0.88 |
| FL Keys | F_S_LR | 13 | 0.72 | 0.47 | 0.09 | 0.10 | 0.54 | 0.74 | 0.72 | 0.22 | 0.87 |
| Tortugas | SG_LR | 14 | 0.70 | 0.46 | 0.15 | 0.32 | 0.04 | 0.87 | 0.78 | 0.15 | 0.89 |
| SE Florida | RF_OF | 15 | 0.70 | 0.45 | 0.09 | 0.30 | 0.18 | 0.72 | 0.65 | 0.44 | 0.78 |
| SE Florida | PR_S | 16 | 0.67 | 0.44 | 0.05 | 0.25 | 0.04 | 0.63 | 0.92 | 0.37 | 0.79 |
| SE Florida | RF_MD | 17 | 0.67 | 0.44 | 0.07 | 0.10 | 0.14 | 0.74 | 0.68 | 0.51 | 0.82 |
| Tortugas | PR_LR | 18 | 0.67 | 0.44 | 0.07 | 0.45 | 0.10 | 0.58 | 0.94 | 0.07 | 0.85 |
| SE Florida | RF_IR | 19 | 0.65 | 0.43 | 0.11 | 0.00 | 0.13 | 0.76 | 0.80 | 0.31 | 0.87 |
| SE Florida | PR_D | 20 | 0.63 | 0.41 | 0.11 | 0.53 | 0.03 | 0.89 | 0.35 | 0.22 | 0.75 |
| SE Florida | NEAR | 21 | 0.54 | 0.35 | 0.13 | 0.02 | 0.14 | 0.50 | 0.72 | 0.10 | 0.86 |
| SE Florida | RR_C | 22 | 0.51 | 0.33 | 0.02 | 0.30 | 0.00 | 0.20 | 1.00 | 0.04 | 0.75 |
| SE Florida | RF_D | 23 | 0.48 | 0.31 | 0.03 | 0.06 | 0.04 | 0.49 | 0.68 | 0.13 | 0.75 |

**Table 2.** Raw data values for resilience indicators and sampling effort in each strata,

| Region | Strata | Resilience Rank | Effort (n transects) | Effort (n RVCs) | CC (%) | MA (%) | BR (%) | DI | CD (n cols/T) | HB (g/100m²) | TV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FL Keys | F_D_LR | 1 | 5 | 33 | 6.20 | 52.20 | 1.25 | 0.76 | 0.00 | 11.56 | 0.34 |
| FL Keys | MC_PR | 2 | 39 | 17 | 22.96 | 34.52 | 12.77 | 0.69 | 2.69 | 2.38 | 0.35 |
| Tortugas | PR_HR | 3 | 17 | 53 | 13.15 | 55.72 | 5.27 | 0.80 | 0.29 | 5.36 | 0.33 |
| FL Keys | RF_HR | 4 | 33 | 27 | 12.89 | 48.96 | 6.94 | 0.71 | 1.12 | 7.34 | 0.33 |
| FL Keys | F_M_LR | 5 | 68 | 31 | 5.24 | 65.45 | 13.55 | 0.72 | 0.66 | 3.89 | 0.34 |
| Tortugas | CONT_HR | 6 | 22 | 61 | 13.86 | 55.08 | 5.65 | 0.79 | 0.68 | 2.82 | 0.34 |
| Tortugas | PR_MR | 7 | 19 | 2 | 11.78 | 59.27 | 6.77 | 0.80 | 0.42 | 1.79 | 0.33 |
| Tortugas | SG_HR | 8 | 10 | 15 | 11.86 | 51.86 | 3.00 | 0.80 | 0.50 | 2.01 | 0.33 |
| FL Keys | OF_PR | 9 | 21 | 75 | 14.45 | 47.68 | 5.37 | 0.68 | 1.67 | 3.64 | 0.36 |
| FL Keys | IN_PR | 10 | 16 | 64 | 20.32 | 54.82 | 1.74 | 0.59 | 0.81 | 1.53 | 0.38 |
| Tortugas | CONT_MR | 11 | 25 | 52 | 5.67 | 67.83 | 5.93 | 0.76 | 0.84 | 1.99 | 0.33 |
| Tortugas | CONT_LR | 12 | 17 | 51 | 2.85 | 54.24 | 2.14 | 0.74 | 0.24 | 1.01 | 0.33 |
| FL Keys | F_S_LR | 13 | 50 | 111 | 1.98 | 69.92 | 7.37 | 0.60 | 0.76 | 2.55 | 0.33 |
| Tortugas | SG_LR | 14 | 5 | 6 | 3.33 | 52.33 | 0.60 | 0.70 | 0.60 | 1.78 | 0.33 |
| SE Florida | RF_OF | 15 | 34 | 12 | 2.13 | 54.35 | 2.47 | 0.58 | 0.94 | 5.13 | 0.30 |
| SE Florida | PR_S | 16 | 9 | 49 | 1.25 | 57.75 | 0.56 | 0.51 | 0.22 | 4.32 | 0.30 |
| SE Florida | RF_MD | 17 | 22 | 52 | 1.60 | 70.07 | 1.85 | 0.59 | 0.86 | 5.94 | 0.31 |
| Tortugas | PR_LR | 18 | 12 | 55 | 1.57 | 42.63 | 1.32 | 0.47 | 0.17 | 0.78 | 0.32 |
| SE Florida | RF_IR | 19 | 19 | 9 | 2.50 | 77.50 | 1.77 | 0.61 | 0.53 | 3.62 | 0.33 |
| SE Florida | PR_D | 20 | 4 | 20 | 2.50 | 36.75 | 0.37 | 0.72 | 1.75 | 2.50 | 0.28 |
| SE Florida | NEAR | 21 | 30 | 27 | 3.01 | 75.71 | 1.84 | 0.40 | 0.77 | 1.16 | 0.32 |
| SE Florida | RR_C | 22 | 5 | 6 | 0.40 | 54.40 | 0.01 | 0.16 | 0.00 | 0.44 | 0.28 |
| SE Florida | RF_D | 23 | 15 | 25 | 0.59 | 72.59 | 0.55 | 0.39 | 0.87 | 1.54 | 0.28 |




### 3.2. Resilience indicators

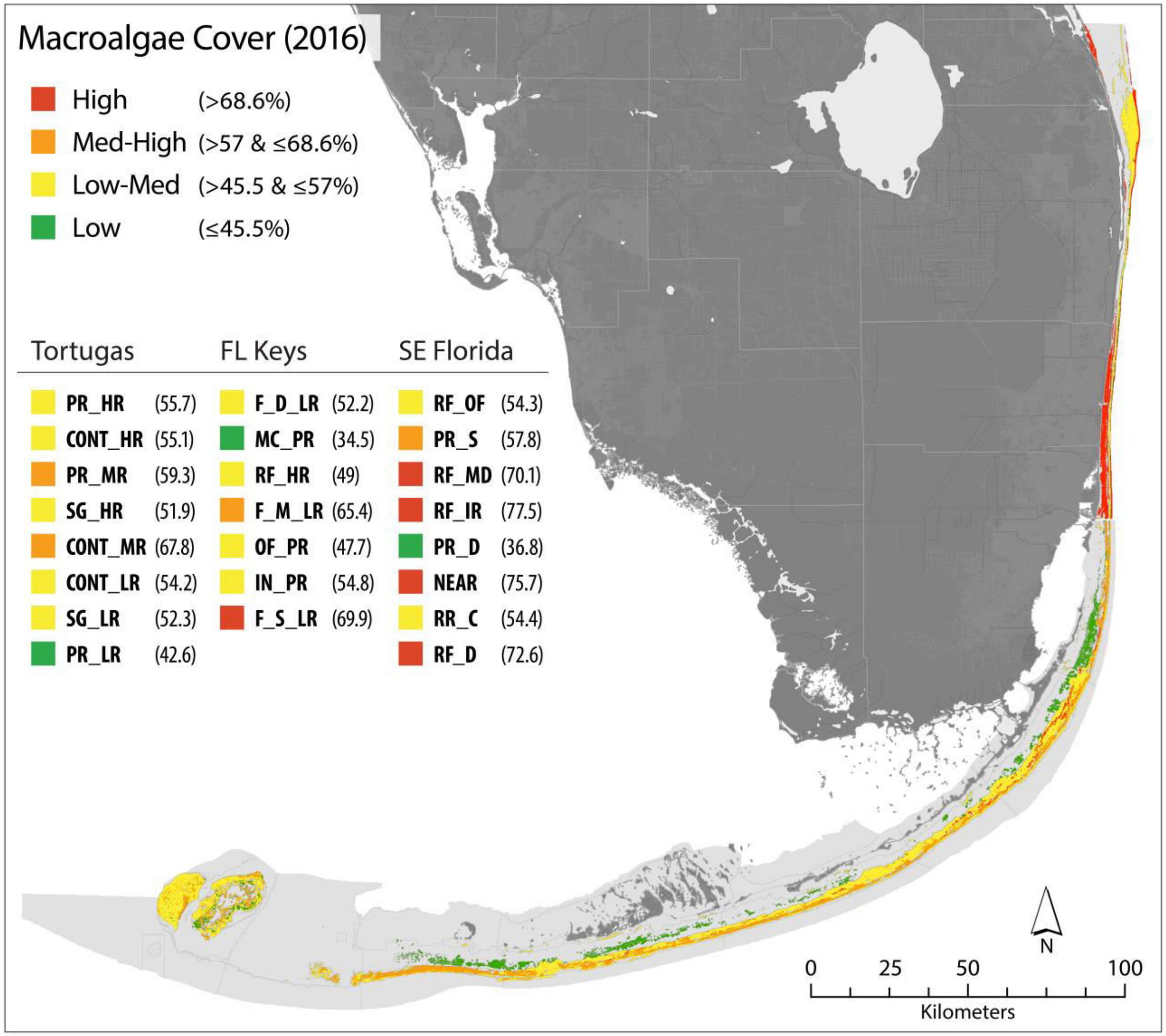



**Figure 4.** Macroalgae cover data for each strata, from data collected under the NCRMP and FRRP monitoring programs in 2016. Bracketed values after strata codes are the raw data values. See Figure 1 for descriptions of strata codes.

***Macroalgae cover is the average percent cover observed in 2016 on NCRMP and FRRP benthic reef monitoring transects.***

- Macroalgae cover in 2016 ranged from 34.5% (MC_PR – Mid-channel patch reef in FL Keys to 77.5% (RF_IR – Inner reef in SE Florida, Figure 4)
- Average macroalgae cover among the 23 strata in 2016 was 57.03% in 2016
- Macroalgae cover was relatively high (>AVG+1SD) in 2016 in RF _MD (Mid-depth reef in SE Florida), RF_IR, NEAR (Nearshore reef in SE Florida), RF_D (Deep reef in SE Florida), and F_S_LR (Forereef shallow low relief in FL Keys)
- Macroalgae cover was relatively low (<AVG-1SD) in 2016 in PR_LR (Patch reef low relief in Tortugas), MC_PR, and PR_D (Patch reef deep in SE Florida)

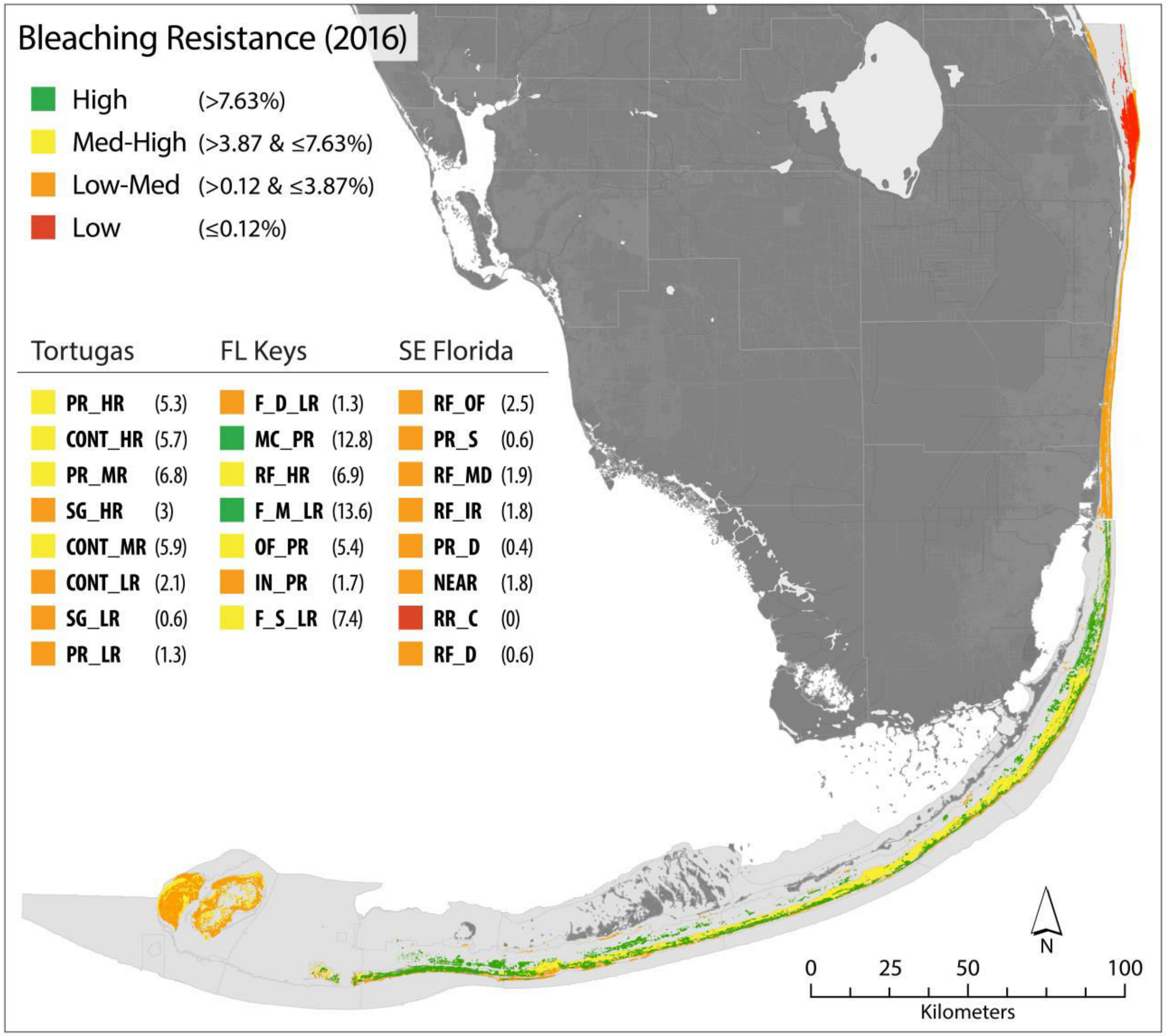



**Figure 5.** Bleaching resistance data for each strata, from data collected under the NCRMP and FRRP monitoring programs in 2016. Bracketed values after strata codes are the raw data values. See Figure 1 for descriptions of strata codes.

***Bleaching resistance is the percent of the stony coral community in 2016 made up by coral species that are relatively resistant to bleaching (see Table A2 in Appendix for list of bleaching susceptibility rankings for coral species)***

- Bleaching resistance in 2016 ranged from 0% (RR_C – Reef ridge complex in SE Florida) to 13. 6% (F_M_LR – Forereef mid-depth low relief in FL Keys, Figure 5)
- Average bleaching resistance among the 23 strata was 3.87% in 2016
- Bleaching resistance was relatively high in 2016 in MC_PR (Mid-channel patch reef in FL Keys) and F_M_LR (Forereef mid-depth low relief in FL Keys)
- Bleaching resistance was relatively low in 2016 only in RR_C (Reef-ridge complex)

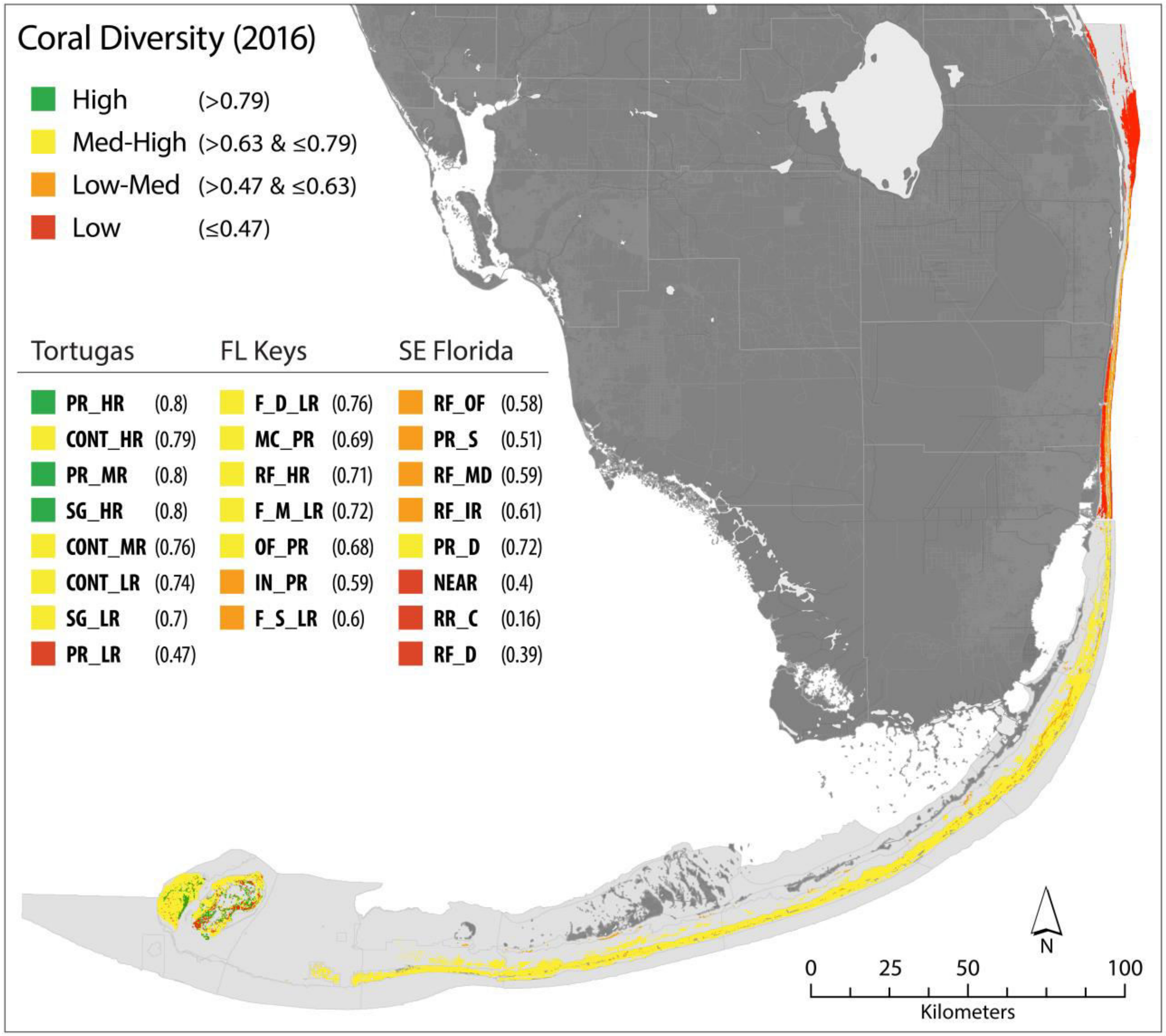



**Figure 6.** Coral diversity data for each strata, from data collected under the NCRMP and FRRP monitoring programs in 2016. Bracketed values after strata codes are the raw data values. See Figure 1 for descriptions of strata codes.

***Coral diversity is the inverse of the Simpson's index of diversity; it describes the likelihood that two coral species taken at random from the communities in each strata will not be the same species (the greater the likelihood they are different the greater the value; i.e. closer to 1).***

- Coral diversity in 2016 ranged from 0.16 (RR_C – Reef ridge complex in SE Florida) to 0.8 (PR_MR and SG_HR; Patch reef medium relief and Spur and groove high relief in Tortugas, Figure 6)

- Average coral diversity was 0.63 in 2016

- Coral diversity was relatively high in PR_HR (Patch reef high relief in Tortugas), PR_MR (Patch reef medium relief in Tortugas), and SG_HR (Spur and groove high relief in Tortugas)

- Coral diversity was relatively low in PR_LR (Patch reef low relief in Tortugas) and NEAR (Nearshore reef in SE Florida), RR_C, and RF_D (Reef deep in SE Florida)

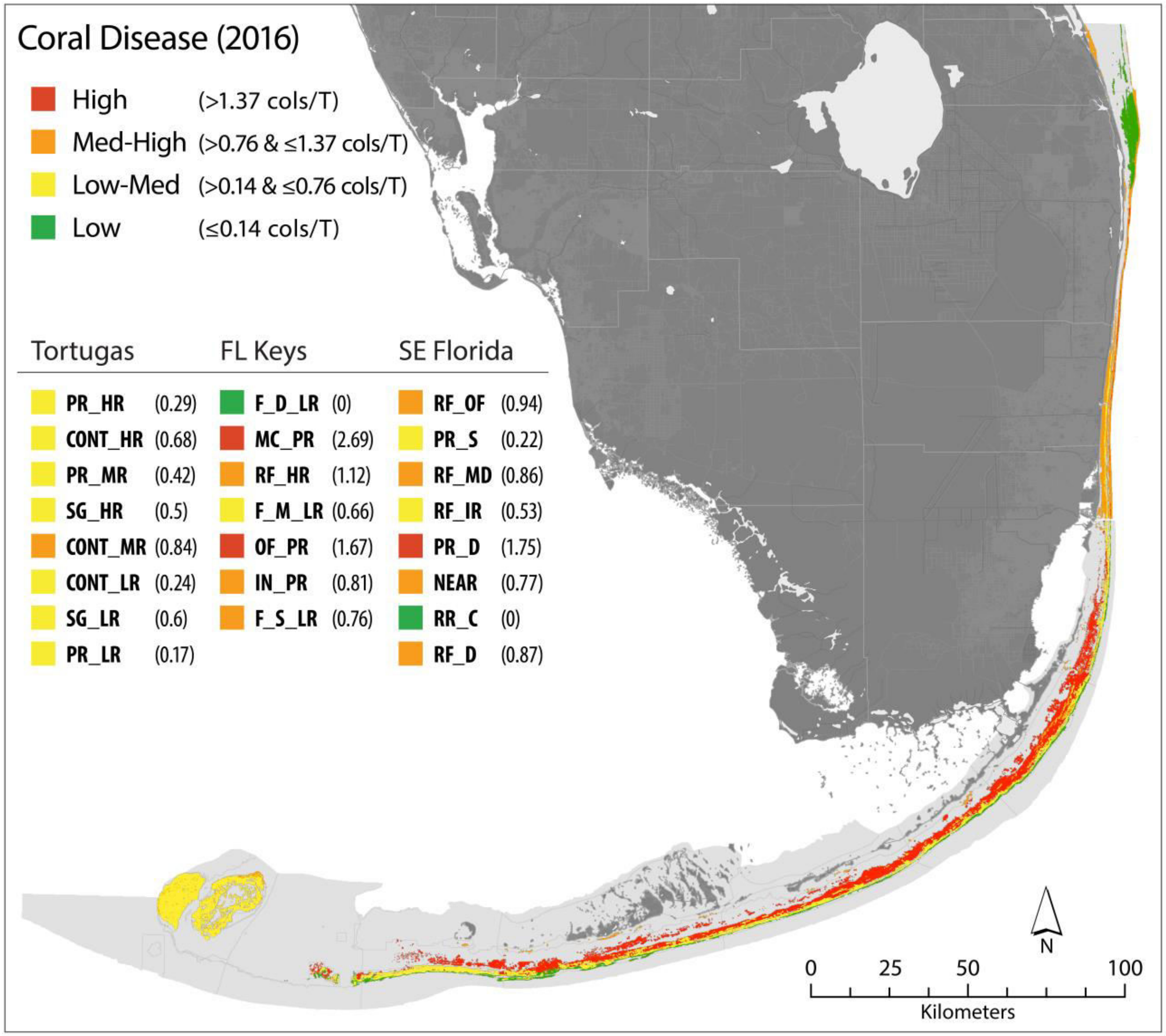



**Figure 7.** Coral disease abundance data for each strata, from data collected under the NCRMP and FRRP monitoring programs in 2016. Bracketed values after strata codes are the raw data values. See Figure 1 for descriptions of strata codes.

***Coral disease is abundance; the number of diseased colonies observed per benthic transect surveyed.***

- Coral disease ranged from 2.69 cols/T (MC_PR – Mid-channel patch reef in FL Keys) to 0 cols/T (RR_C – Reef ridge complex in SE Florida), and F_D_LR (Forereef deep low relief in FL Keys, Figure 7)
- Average coral disease abundance was 0.76 cols/T
- Coral disease abundance was relatively high in 2016 in MC_PR, OF_PR (Offshore patch reef in FL Keys), and PR_D (Patch reef deep in SE Florida
- Coral disease abundance was relatively low in 2016 in F_D_LR (Forereef deep low relief in FL Keys) and RR_C (Reef-ridge complex in SE Florida)

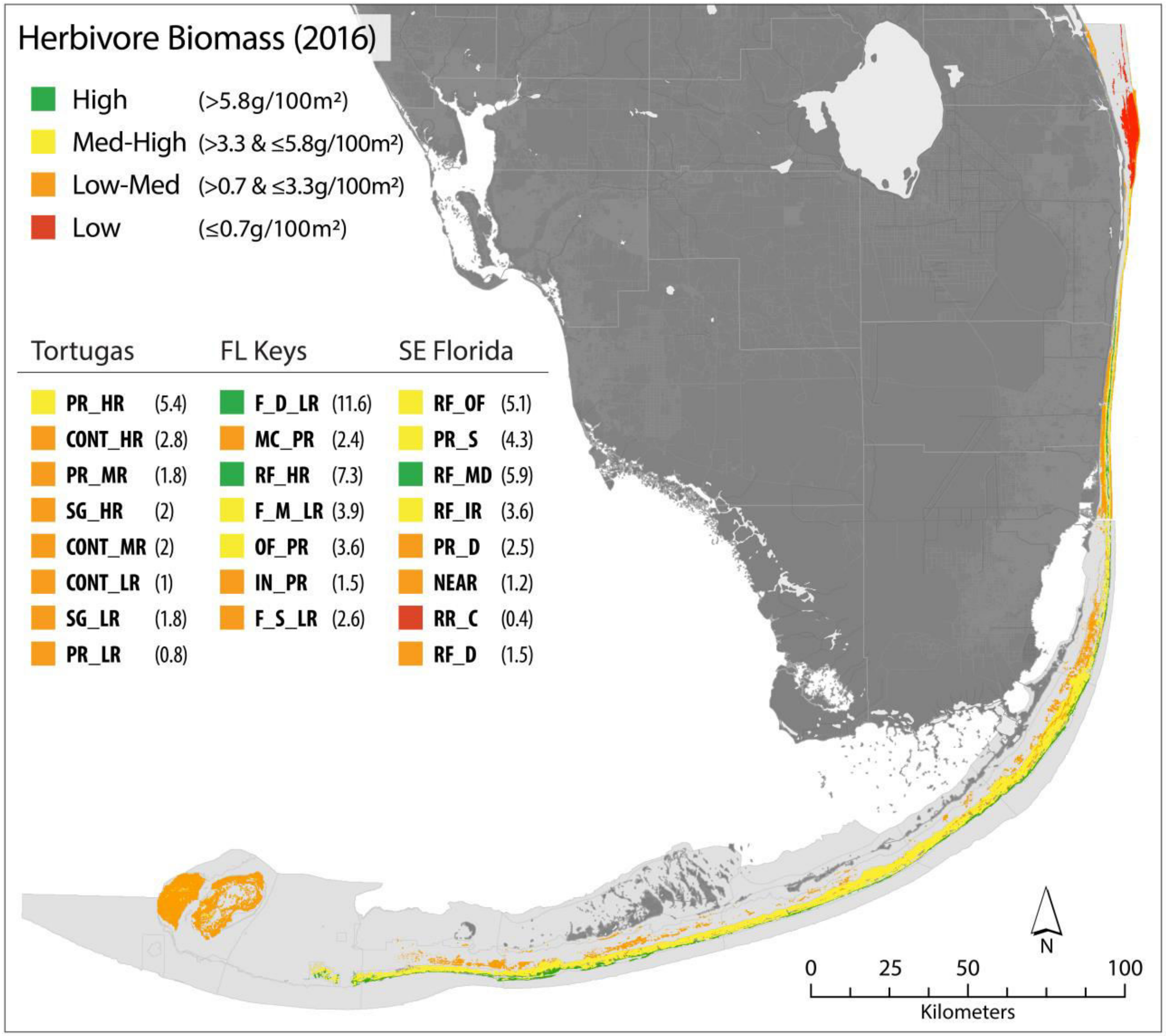



**Figure 8.** Herbivore biomass data for each strata, from data collected under the NCRMP monitoring program in 2016. Bracketed values after strata codes are the raw data values. See Figure 1 for descriptions of strata codes.

***Herbivore biomass is the average biomass in g/100m² of herbivorous fishes observed during stationary point counts***

- Herbivore biomass ranged from 0.4 g/100m² in RR_C (Reef ridge complex in SE Florida) to 11.6 g/100m² in F_D_LR (Forereef deep low relief in FL Keys, Figure 8)
- Average herbivore biomass was 3.26 g/100m²
- Herbivore biomass was relatively high in 2016 in F_D_LR (Forereef deep low relief in FL Keys), RF_HR (Reef high relief in FL Keys), and RF_MD (Reef mid-depth in SE Florida)
- Herbivore biomass was relatively low in 2016 only in RR_C (Reef-ridge complex in SE Florida)

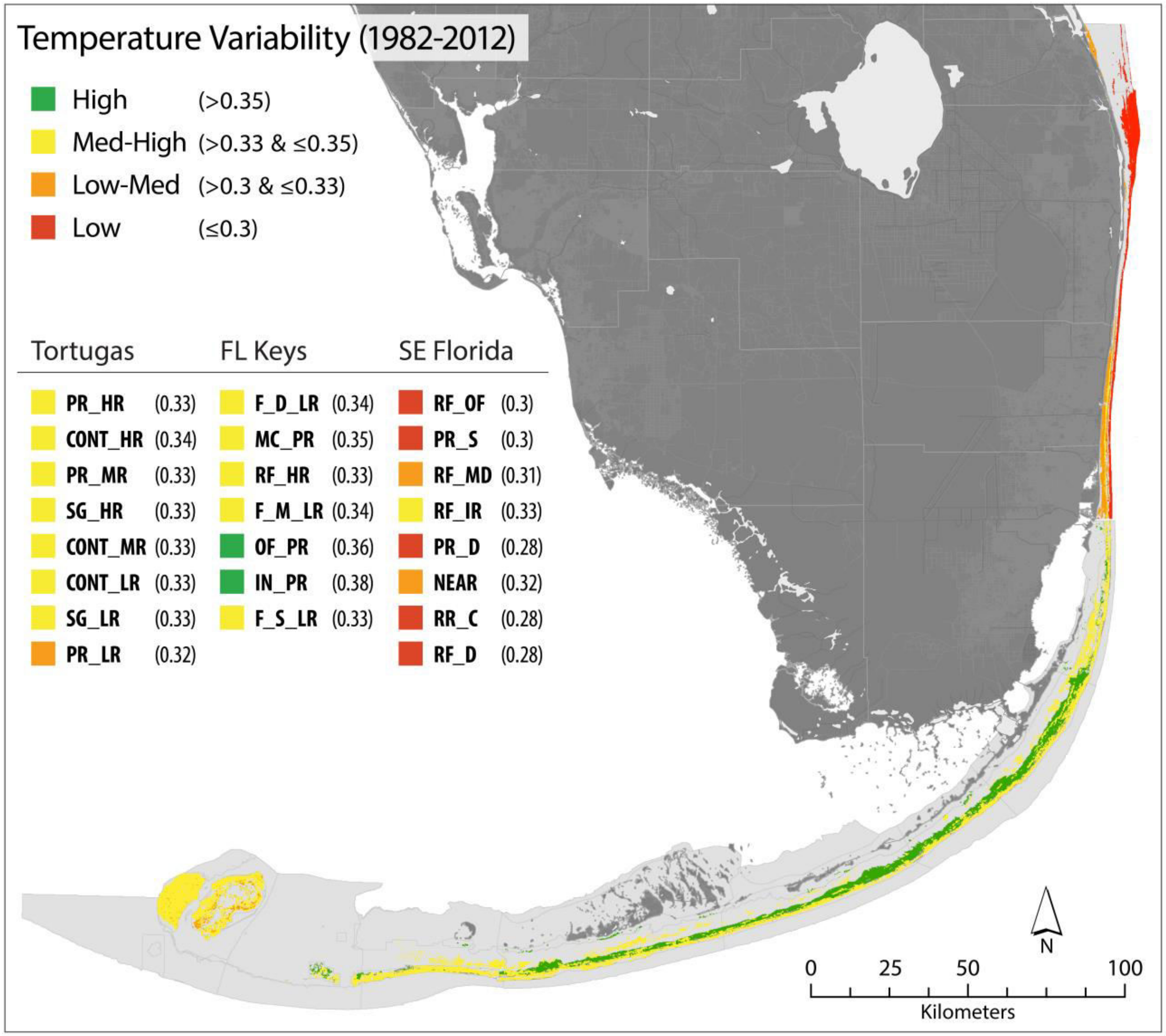



**Figure 9.** Temperature variability data for each strata, from Pathfinder v5.1 sea surface temperature Data, 1982-2012, summarized within Heron, Maynard et al. 2016. Bracketed values after strata codes are the raw data values. See Figure 1 for descriptions of strata codes.

***Temperature variability is calculated as the standard deviation of the warm season temperatures; warm season is three-month period inclusive of the warmest month (August/September in Florida) and one month either side.***

- Temperature variability ranged from 0.3 (RF_OF and PR_S; Reef offshore and Patch reef shallow in SE Florida) to 0.38 (IN_PR – Inshore patch reef in FL Keys, Figure 9)
- Average temperature variability during the 1982-2012 period was 0.33
- Temperature variability was relatively high between 1982 and 2012 in IN_PR and OF_PR (Offshore patch reef in FL Keys)
- Temperature variability was relatively low between 1982 and 2012 in RF_OF, PR_S, PR_D (Patch reef deep in SE Florida), RR_C (Reef ridge complex in SE Florida) and RF_D (Reef deep in SE Florida)

## 4. FUTURE RESEARCH AND SUGGESTED NEXT STEPS

The following list represents timely research projects and communication and reporting activities that can build on the research and work presented within this report.

- This report covers only a snapshot in time – 2016. Trends in resilience indicators and relative resilience can be examined for this last ~10 years, by summarizing existing reef monitoring data in the same analysis strata (Figure 1) used for this report. This would enable a range of analyses of 'demonstrated resilience' versus the 'resilience potential' we examine here; i.e., strata can be ranked based on the rate and extent of change (negative and positive) in, for example, coral cover and herbivore biomass. Predictions of future ecological state could then be made based on projecting trajectories of key indicators in combination with climate change projections and information on current and future human-related threats.

- Resilience is necessarily expressed here as relative to enable comparisons among strata. Another approach would be to use available empirical research (limited in this area) and expert judgment to determine the likely values of the resilience indicators required for reef areas to resist and recover from disturbance. This 'tipping points' style analysis could help determine which strata are in safe operating spaces, approaching or beyond tipping points. Such an analysis would complement the research presented here, and provide more information managers could use to target management actions and effort.

- Resilience indicators are weighted equally here as deciding on weighting schemes is challenging due to the limited quantitative evidence of the relative importance of the indicators. Some previous resilience assessments (as in CNMI in Maynard et al. 2015) weight the indicators based on survey results presented within McClanahan et al. (2012). This analysis could be repeated in the future following a workshop with Florida reef experts to judge differences among the indicators in the strength of connection to the processes of resistance and recovery.

- The coral disease abundance data used may not be representative of disease patterns during the 2015-2017 coral disease outbreak. This analysis could be repeated in the future if/when more representative data on coral disease abundance or prevalence becomes available.

- This project team has seen in USVI that relative resilience has some capacity to predict coral transplant survivorship. Further, collaborators in Florida are building multivariate models to help determine where nursery-raised corals should be outplanted. The resilience information presented in this report should be built into models that rate or rank reef areas in the FRT for coral transplantation and reef restoration.

- This is a coral-centric study, yet we found the average stony coral cover among strata in the Florida Reef Tract in 2016 was ~7%. Barrel sponges, sea fans, soft corals, and other gorgonians and invertebrates cover much more of the benthos in Florida than stony corals, and provide most of the structure for the high biodiversity of reef fish and other organisms. Future studies could examine spatial variation in the climate resilience and vulnerability of some of these other key habitat builders on Florida's reefs.

- The analysis strata used provide information on within-region variation in the resilience indicators. The strata themselves include large areas of reef and are typically larger than the scale of the kinds of management actions that might be implemented. Future research could compile existing site-based data and conduct a resilience assessment at a higher-resolution than strata.

- Few policymakers read scientific papers or have the bandwidth to skim online articles on research advances. Summaries for policymakers could be developed that translate the research presented here into fact sheets and brochures for dissemination among policymakers and other senior decision-makers. This is already a key action under Florida's Climate Change Action Plan.

- Development of this report in May and June of 2017 required significant effort in developing spatial data packages to aid in visualizing data being produced by NCRMP and FRRP monitoring teams. With that work complete, the analysis presented here could be completed very cost-efficiently in future years. Continuously updating the maps and analysis will enable ongoing trend analyses for the indicators and resilience, as is suggested above could be done for this last 10 years.

- Managers need up-to-date information on reef condition, resilience, and impacts to guide decision-making and inform communication activities. A reef condition and resilience 'dashboard' can be developed that enables users to interact with the information online. R Shiny, from the R Studio team, helps make spatial data interactive online and is free software so only requires funding for the labor to plan and develop the site. An online interactive dashboard could be developed that provides everyone with easy access to map and table-based summaries of monitoring data. This will require streamlining and standardizing timing of transfer of data products to a team that can visualize the data and build the dashboard. Managers and monitoring teams can then collaboratively develop a process that ensures the dashboard is updated at least annually. Such a dashboard meets the need described in Florida's Climate Change Action Plan to *"Integrate monitoring results into a coastal observing network that informs the evolving questions underlying protection and management of marine resources."* Building such a dashboard would help to maximize management 'returns on investment' from monitoring which, in turn, helps to justify and maximize support for ongoing monitoring.

## 5. REFERENCES


Anderson, M. J., & Willis, T. J. (2003). Canonical analysis of principal coordinates: a useful method of constrained ordination for ecology. *Ecology*, *84*(2), 511-525.

Anderson, M. J. (2008). Animal-sediment relationships re-visited: Characterising species' distributions along an environmental gradient using canonical analysis and quantile regression splines. *Journal of Experimental Marine Biology and Ecology*, *366*(1), 16-27.

Heron, S. F., Maynard, J. A., & Ruben van Hooidonk, C. (2016). Warming trends and bleaching stress of the World's coral reefs 1985–2012. *Scientific reports*, *6*.

Maynard, J. A., Marshall, P. A., Johnson, J. E., & Harman, S. (2010). Building resilience into practical conservation: identifying local management responses to global climate change in the southern Great Barrier Reef. *Coral Reefs*, *29*(2), 381-391.

Maynard, J. A., Mckagan, S., Raymundo, L., Johnson, S., Ahmadia, G. N., Johnston, L., ... & Van Hooidonk, R. (2015). Assessing relative resilience potential of coral reefs to inform management. *Biological Conservation*, *192*, 109-119.

Maynard, J., Conklin, E., Minton, D., Most, R., Couch, C., Williams, G.J., Gove, J., Schumacher, B., Walsh, W., Martinez, J., Harper, D., Jayewardene D., Parker, B., Watson, L. 2016. *Relative resilience potential and bleaching severity in the West Hawaii Habitat Focus Area in 2015*. Silver Spring, MD: NOAA Coral Reef Conservation Program. NOAA Technical Memorandum CRCP 26, 53 pp. DOI: 10.7289/V5T43R4Z

McClanahan, T. R., Donner, S. D., Maynard, J. A., MacNeil, M. A., Graham, N. A., Maina, J., ... & Eakin, C. M. (2012). Prioritizing key resilience indicators to support coral reef management in a changing climate. *PloS one*, *7*(8), e42884.

Mumby, P. J., Hastings, A., & Edwards, H. J. (2007). Thresholds and the resilience of Caribbean coral reefs. *Nature*, *450*(7166), 98-101.

Turner, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., ... & Polsky, C. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the national academy of sciences*, *100*(14), 8074-8079.

## 6. APPENDIX

**Table A1.** The National Coral Reef Monitoring Program codes for strata within their database were converted for this report to codes we felt were more intuitive. This change ensured we could provide an intuitive description for each strata code that would help readers interpret the codes when viewing the maps in the report.

| REGION | NCRMP Strata Code | **CODE USED HERE** | Description |
|---|---|---|---|
| SE Florida | NEAR0 | **NEAR** | Nearshore |
| SE Florida | PTDP0 | **PR_D** | Patch reef deep |
| SE Florida | PTSH2 | **PR_S** | Patch reef shallow |
| SE Florida | DPRC0 | **RF_D** | Reef deep |
| SE Florida | INNR0 | **RF_IR** | Reef inner |
| SE Florida | MIDR0 | **RF_MD** | Reef middle |
| SE Florida | OFFR0 | **RF_OF** | Reef offshore |
| SE Florida | RGDP0 | **RR_C** | Reef-ridge complex |
| FL Keys | FDLR | **F_D_LR** | Forereef deep low relief |
| FL Keys | FMLR | **F_M_LR** | Forereef medium depth low relief |
| FL Keys | FSLR | **F_S_LR** | Forereef shallow low relief |
| FL Keys | INPR | **IN_PR** | Inshore patch reef |
| FL Keys | MCPR | **MC_PR** | Mid-channel patch reef |
| FL Keys | OFPR | **OF_PR** | Offshore patch reef |
| FL Keys | HRRF | **RF_HR** | Reef high relief |
| Tortugas | CONT_HR | **CONT_HR** | Continuous reef high relief |
| Tortugas | CONT_LR | **CONT_LR** | Continuous reef low relief |
| Tortugas | CONT_MR | **CONT_MR** | Continuous reef medium relief |
| Tortugas | ISOL_HR | **PR_HR** | Patch reef high relief |
| Tortugas | ISOL_LR | **PR_LR** | Patch reef low relief |
| Tortugas | ISOL_MR | **PR_MR** | Patch reef medium relief |
| Tortugas | SPGR_HR | **SG_HR** | Spur and groove high relief |
| Tortugas | SPGR_LR | **SG_LR** | Spur and groove low relief |

**Table A2.** Bleaching resistance scores (1-5) for coral species observed during NCRMP reef monitoring surveys in 2016, along with the species codes used by the NCRMP program. Resistance scores are: 1 – highly susceptible to bleaching, 2 – susceptible to bleaching, 3 – resistant to bleaching, 4 – very resistant to bleaching, 5 – rarely bleaches. Coral species with a score ≥3 were considered 'resistant to bleaching' for calculating the bleaching resistance indicator; the proportion of the community made up by resistant species.

| FL NCRMP Code | Coral Species | Bleaching resistance score | FL NCRMP Code | Coral Species | Bleaching resistance score |
|---|---|---|---|---|---|
| ACR CERV | Acropora cervicornis | 3 | MYC LAMA | Mycetophyllia lamarckiana | 2 |
| ACR PALM | Acropora palmata | 4 | MYC SPE. | Mycetophyllia spp | 4 |
| AGA FRAG | Agaricia fragilis | 2 | OCU DIFF | Oculina diffusa | 2 |
| AGA LAMA | Agaricia lamarcki | 2 | OCU SPE. | Oculina spp | 2 |
| AGA SPE. | Agaricia spp | 1 | ORB ANNU | Orbicella annularis | 3 |
| CLA ABRU | Cladocora arbuscula | 4 | ORB ANCX | Orbicella annularis species complex | 3 |
| COL NATA | Colpophyllia natans | 2 | ORB FAVE | Orbicella faveolata | 3 |
| DIC STOK | Dichocoenia stokesii | 4 | ORB FRAN | Orbicella franksi | 3 |
| DIP LABY | Diploria labyrinthiformis | 3 | ORB SPE. | Orbicella spp | 4 |
| EUS FAST | Eusmilia fastigiata | 3 | POR ASTR | Porites astreoides | 3 |
| FAV FRAG | Favia fragum | 4 | POR BRAN | Porites branneri | 4 |
| HEL CUCU | Helioceris cucullata | 2 | POR DIVA | Porites divaricata | 2 |
| ISO RIGI | Isophyllastrea rigida | 4 | POR FURC | Porites furcata | 2 |
| ISO SINU | Isophyllia sinuosa | 4 | POR PORI | Porites porites | 2 |
| MAD AURE | Madracis auretenra | 4 | POR SPE. | Porites spp | 1 |
| MAD DECA | Madracis decactis | 4 | PSE CLIV | Pseudodiploria clivosa | 3 |
| MAD FORM | Madracis formosa | 4 | PSE STRI | Pseudodiploria strigosa | 3 |
| MAD SPE. | Madracis spp | 5 | SCO CUBE | Scolymia cubensis | 5 |
| MAN AREO | Manicina areolata | 3 | SCO SPE. | Scolymia spp | 4 |
| MEA MEAN | Meandrina meandrites | 3 | SID RADI | Siderastrea radians | 2 |
| MON CAVE | Montastraea cavernosa | 4 | SID SIDE | Siderastrea siderea | 2 |
| MUS ANGU | Mussa angulosa | 4 | SOL BOUR | Solenastrea bournoni | 3 |
| MYC ALIC | Mycetophyllia aliciae | 5 | SOL HYAD | Solenastrea hyades | 3 |
| MYC FERO | Mycetophyllia ferox | 5 | STE INTE | Stephanocoenia intersepta | 3 |

**Table A3.** Herbivorous reef fishes observed during 2016 RVC / NCRMP surveys. The resilience indicator herbivore biomass is the average biomass of these fishes (g/100m$^2$) observed during stationary point count surveys in each of the strata.

| FL NCRMP Code | Family | Species name | Common name |
|---|---|---|---|
| ACA BAHI | Acanthuridae | *Acanthurus bahianus* | Ocean Surgeon |
| ACA CHIR | Acanthuridae | *Acanthurus chirurgus* | Doctorfish |
| ACA COER | Acanthuridae | *Acanthurus coeruleus* | Blue Tang |
| ACA SPE. | Acanthuridae | *Acanthurus sp.* | Surgeonfish Species |
| CEN ARGI | Pomacentridae | *Centropyge argi* | Cherubfish |
| KYP SECT | Kyphosidae | *Kyphosus sectatrix* | Bermuda Chub |
| MIC CHRY | Pomacentridae | *Microspathodon chrysurus* | Yellowtail Damselfish |
| NIC USTA | Scaridae | *Nicholsina usta* | Emerald Parrotfish |
| SCA COEL | Scaridae | *Scarus coelestinus* | Midnight Parrotfish |
| SCA COER | Scaridae | *Scarus coeruleus* | Blue Parrotfish |
| SCA GUAC | Scaridae | *Scarus guacamaia* | Rainbow Parrotfish |
| SCA ISER | Scaridae | *Scarus iseri* | Striped Parrotfish |
| SCA SPE. | Scaridae | *Scarus sp.* | Parrotfish Species |
| SCA TAEN | Scaridae | *Scarus taeniopterus* | Princess Parrotfish |
| SCA VETU | Scaridae | *Scarus vetula* | Queen Parrotfish |
| SPA ATOM | Scaridae | *Sparisoma atomarium* | Greenblotch Parrotfish |
| SPA AURO | Scaridae | *Sparisoma aurofrenatum* | Redband Parrotfish |
| SPA CHRY | Scaridae | *Sparisoma chrysopterum* | Redtail Parrotfish |
| SPA RADI | Scaridae | *Sparisoma radians* | Bucktooth Parrotfish |
| SPA RUBR | Scaridae | *Sparisoma rubripinne* | Yellowtail Parrotfish |
| SPA SPE. | Scaridae | *Sparisoma sp.* | Parrotfish Species |
| SPA VIRI | Scaridae | *Sparisoma viride* | Stoplight Parrotfish |
| STE ADUS | Pomacentridae | *Stegastes adustus* | Dusky Damselfish |
| STE DIEN | Pomacentridae | *Stegastes diencaeus* | Longfin Damselfish |
| STE LEUC | Pomacentridae | *Stegastes leucostictus* | Beaugregory |
| STE PART | Pomacentridae | *Stegastes partitus* | Bicolor Damselfish |
| STE PLAN | Pomacentridae | *Stegastes planifrons* | Threespot Damselfish |
| STE VARI | Pomacentridae | *Stegastes variabilis* | Cocoa Damselfish |