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Characterization of Benthic Communities

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An Integrated Biogeographic Assessment of Reef Fish Populations and Fisheries in Dry Tortugas: Effects of No-take Reserves

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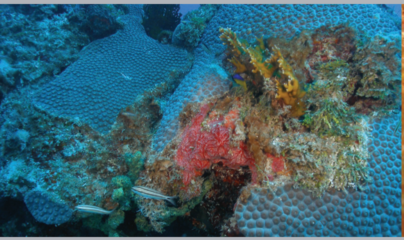

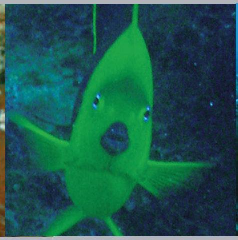
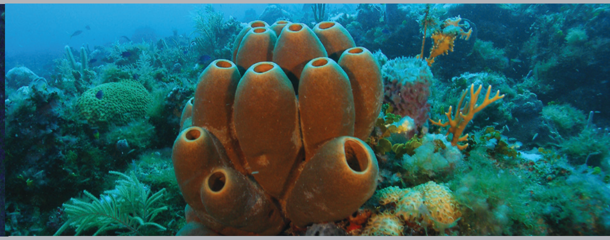

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NOAA NCCOS Center for Coastal Monitoring and Assessment

An Integrated Biogeographic Assessment of Reef Fish Populations and Fisheries in Dry Tortugas: Effects of No-Take Reserves

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Chapter 4: Characterization of Benthic Communities

Greg Piniak[1], Shay Viehman[1], Christine Addison[1] and Nicole Fogarty[2]

INTRODUCTION AND BACKGROUND

The overall objective of NOAA Center for Coastal Fisheries and Habitat Research's (CCFHR) biogeographic approach in the Tortugas was to examine the effects of implementing a marine reserve on reef fish assemblages and benthic composition. Energy flow across reef-sand boundaries is critical to understanding reef function. For example, reef fish may forage in sand, algae and seagrass flats and import significant amounts of nutrients when they return to the reef (Meyer et al., 1983). Previous work on the west Florida shelf suggests that benthic primary production is the major energetic source supporting fish biomass (Currin et al., 2000). As the majority of the Tortugas Ecological Reserve (TER) is non-coral habitat, the structure and composition of fish communities near the reef interface may be a likely area to detect a reserve effect (Burke et al., 2004). Mapping of habitat types and interface locations was conducted at a variety of scales, including satellite and aerial imagery, towed video/sonar and multibeam sonar (Chapter 2; Fonseca et al., 2006). This chapter describes the fine-scale (meters) benthic characterization designed to add a habitat component to the annual fish surveys and to provide covariates for explaining spatial patterns in fish assemblages at sand-reef interfaces (Chapter 5). This chapter also summarizes benthic habitat studies conducted by other research institutions in the Tortugas region .

DATA COLLECTION AND ANALYSIS METHODS

To test management effects, an integrated Before-After Control Impact (BACI) design was used. Thirty permanent monitoring sites (Figure 4.1) were randomly selected along the reef-sand interface in 2001 (depth 15-32 m), using the procedures outlined by Burke et al. (2004). Ten sites were established in each of three strata: "Reserve" (within TER North), "Park" (within Dry Tortugas National Park [DRTO]; several park sites are located within the RNA recently designated within DRTO) and "Open", unprotected areas. Sites within each stratum were equally allocated on either side of the predominant direction of current flow across the banks, resulting in a total of six categories: Park North (PN), Park South (PS), Reserve North (RN), Reserve South (RS), Out North (ON) and Out South (OS).

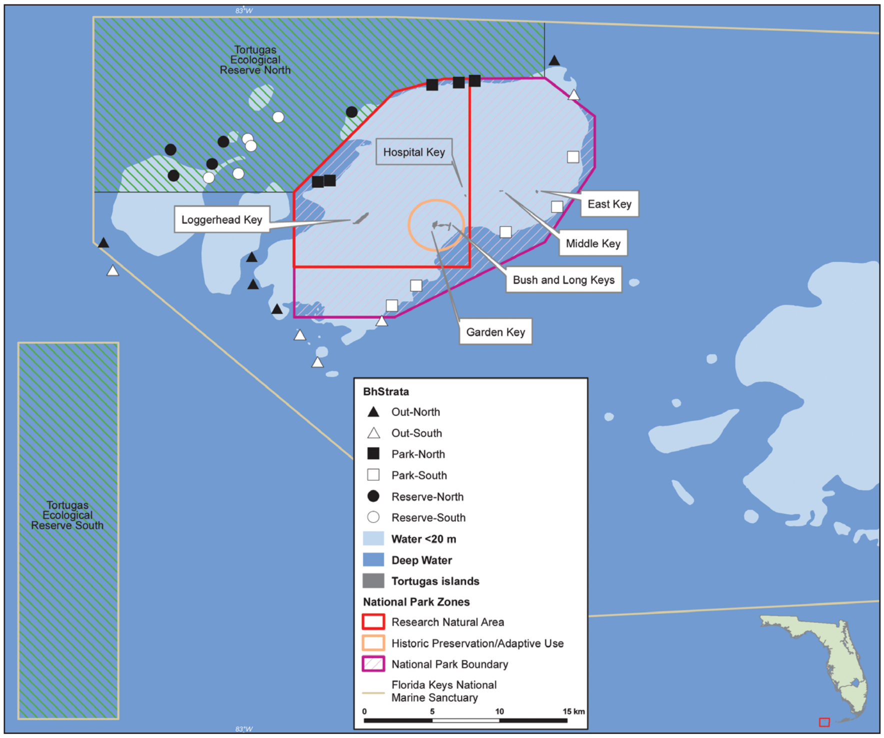

Figure 4.1. NCCOS Center for Coastal Fisheries and Habitat Research's (CCFHR) 30 permanent stations in the Tortugas.

Each year (2001-2005, 2007-2009), divers surveyed two 30 m transects perpendicular to the interface—one transect into the sand, and one onto the reef. Fish surveys and benthic transects were conducted concurrently. If the site marker could not be located in a given year, a new marker was installed in the same general area. Digital video transects of the benthos were collected from 2001-2004 along the same 30 m transects used for the fish surveys, in both the reef and sand habitats. Video was collected

1. NOAA/NOS/NCCOS/Center for Coastal Fisheries and Habitat Research
2. Smithsonian Marine Station

in 2001 at a camera height approximately 1.0 m above the bottom; however, subsequent analysis suggested the video quality at that height did not provide adequate resolution of certain taxonomic groups (e.g., benthic microalgae; crustose coralline algae, CCA: and certain scleractinian coral species). In 2002-2004, video was taken at a reduced, fixed distance of 0.4 m. Non-overlapping still photos were frame-selected from the video using Sony DVGate and analyzed using Point Count 99. Due to intensive processing time and the anticipated change to still photography, video collected in 2004 has been archived but not analyzed. Diversity and species richness were calculated for scleractinian corals only (fire corals were excluded), and “unidentified coral” (e.g., those where the photographic resolution was not detailed enough to enable identification) was included in the calculation.

Beginning in 2005, digital still images replaced video methodologies, improving resolution and significantly reducing image preparation time. Photos were taken every meter along the 30 m transect at a fixed height of 0.4 m, and percent cover was determined using Coral Point Count software (Kohler and Gill, 2006). Preliminary comparisons of the video and still photo techniques at a small subset of sites in 2005 showed no significant differences in the results of the two methods. CCFHR re-surveyed the 30 permanent transects using the still photo methodology in August 2007 with concurrent video transects for additional method calibration.

The benthic data could not be statistically analyzed using a repeated measures design due to changes in photographic techniques. Instead, years with similar methodologies were pooled for analysis (e.g., 2001, 2002-2003 and 2005) using Statistica 4.0. Percent cover data were tested for normality using Kolmogorov-Smirnov test and for homogeneity of variance using Levene’s test. Effects of management strata were tested using using Analysis of Variance (ANOVA) for 2001 and 2005; the 2002-2003 data used a two-way ANOVA to test for effects of strata and year. Post-hoc comparisons were made using Tukey’s HSD test; if the variance was not homogenous post-hoc comparisons were made using Dunnett’s test. Data that did not meet parametric assumptions after arcsine square root transformation were analyzed using nonparametric Kruskal-Wallis ANOVA or the Scheirer-Ray-Hare nonparametric two-way ANOVA. The subdivisions (north and south) in each stratum had no significant effect, so all ten sites within each stratum were pooled for analysis.

Multivariate analyses were conducted using Primer 6.0 to explore the relationship among sites and strata in a given year. Percent cover of benthic functional groups (coral, fire coral, macroalgae, sponge, octocoral, CCA, hard substrate, seagrass, microalgae and soft substrate, other invertebrates and unknown/manmade) was arcsine square root transformed and a Principal Components Analysis (PCA) was conducted to examine which benthic categories account for the variability observed among sites. Non-metric multi-dimensional scaling (MDS) ordination was applied to understand the relationships among sites. MDS results were supported by hierarchal cluster analysis based on group averages and based on Bray-Curtis similarity indices for functional groups.

RESULTS AND DISCUSSION

Benthic Cover by Management Stratum

The sand transects had scant biological cover, and the limited resolution of the photographic techniques made it difficult to reliably identify benthic microalgae. Therefore, only the reef transect data will be discussed here. Percent cover for the major benthic taxonomic and abiotic groups on the reef transects is presented in Figure 4.2. As mentioned above, the years are not always strictly comparable due to differences in photographic methodologies and therefore were analyzed separately. Relatively few statistically significant differences were found between management strata, and effects were often inconsistent across years. For example, in 2001, rock/rubble was the only category to show a statistical difference among strata, with higher cover in DRTO ($F_{2,27}$=6.617, p=0.005) than in TER (Tukey’s HSD p=0.017) or unprotected areas (p=0.005). Octocoral cover was usually lowest in DRTO, but the only statistically significant difference was in 2002-2003 ($F_{2,54}$=3.398, p=0.041), with higher cover in TER than DRTO (Tukey’s HSD p=0.033). Temporal differences could be analyzed for 2002-2003 since they shared a common methodology; the only significant difference among those years was higher primary production (macroalgae, CCA and seagrasses) in 2003 than in 2002 ($F_{1,54}$=4.743, p=0.007), with a concomitant decrease in rock rubble ($F_{1,54}$=4.101, p=0.048).

Coral cover in TER (Figure 4.2) was typically higher than in DRTO or in unprotected areas, but statistically significant only for 2002-2003 ($F_{2,54}$=6.688, p=0.003). Coral cover primarily consisted of great star coral (*Montastraea cavernosa)* and the boulder star coral (*Montastraea annularis* complex; mostly mountainous star coral, *Montastraea faveolata*); these species were present at most sites. Massive starlet coral (*Siderastrea siderea)* and boulder brain coral *(Colpophyllia natans)* form a secondary group of framework-building species at these sites, while brain coral (*Diploria* spp.) were relatively uncommon. Among non-framework builders, the most common species were cactus coral (*Mycetophillia* spp.) and lettuce coral (*Agaricia* spp.), with occasional maze coral (*Meandrina meandrites)*, mustard hill coral (*Porites astreoides)*, blushing star coral (*Stephanocoenia intersepta)* and rough starlet coral (*Siderastrea radians)*.

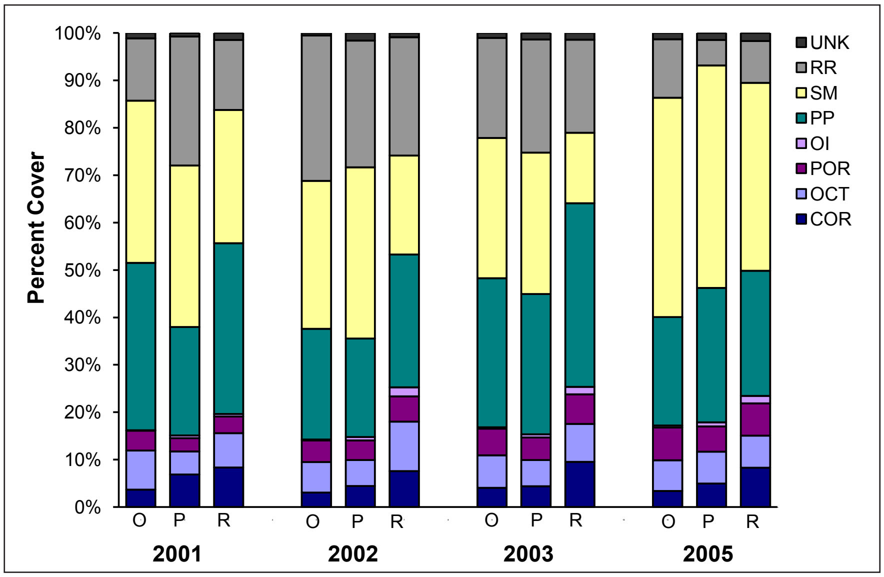

Figure 4.2. Percent cover on benthic reef transects in each of the three strata: O = unprotected, P = Dry Tortugas National Park (DRTO), R = Tortugas Ecological Reserve (TER). COR = coral, OCT = octocoral, POR = sponges, OI = other invertebrates, PP = primary producers, SM = sand and benthic microalgae, RR = rock and rubble, UNK = unknown. Source: NCCOS CCFHR.

Rare species included elliptical star coral (*Dichoecoenia stokesii)*, solitary disk coral (*Scolymia* spp.), smooth star coral *(Solenastrea bournoni)* and smooth flower coral (*Eusmilia fastigiata)*. These interface sites are relatively deep (15-32 m) and branching corals are present but not abundant. Diffuse ivory bush coral (*Oculina diffusa)*, ten-ray star coral (*Madracis decactis)*,yellow pencil coral (*Madracis mirabilis)*, and finger coral (*Porites porites*) were occasionally observed. Acroporids can be a major framework-builder on shallow Tortugas reefs, at least historically (Davis, 1982), but staghorn coral (*Acropora cervicornis*) was rare at our deep sites and elkhorn coral (*Acropora palmata*) was not observed.

Richness and diversity of scleractinian coral species in 2002-2003 tended to be higher in TER than the other strata, but this pattern was not statistically significant. Increased photographic resolution in 2005 allowed better species identification; however there were no significant differences in richness ($F_{2,27}$=0.138, p=0.872) or diversity ($F_{2,27}$=1.180, p=0.323) among strata (Figure 4.3). While diversity was correlated with depth (r=0.386, p=0.035), richness and depth were not correlated (r=0.214, p=0.256). The greater photographic resolution in 2005 also improved taxonomic identification of macroalgae. Predominant genera were *Dictyota*, *Halimeda*, and *Lobophora*; with *Codium* moderately abundant at DRTO sites.

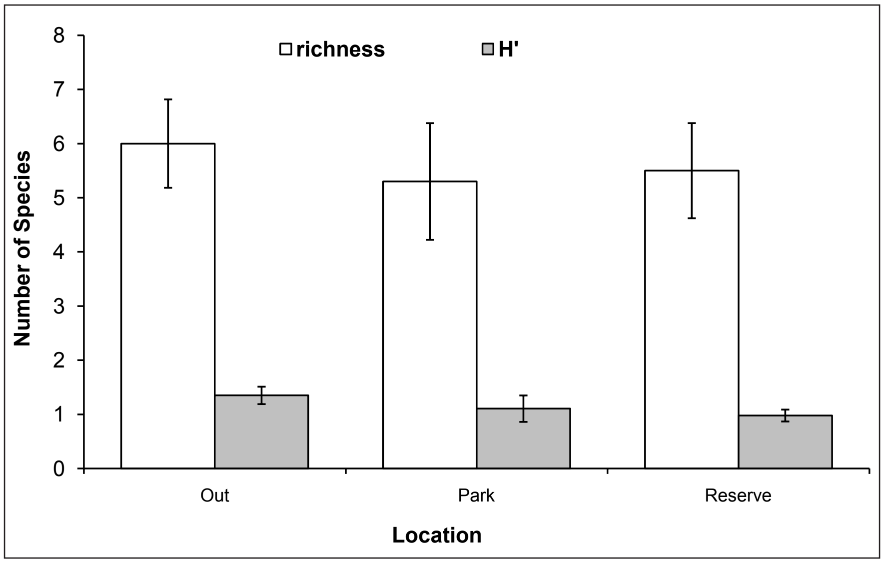

Figure 4.3. Species richness and diversity for scleractinian corals in 2005. Source: NCCOS CCFHR.

The lack of statistically significant effects among strata implies that management strategies have had little effect on benthic resources, but differences in methods and strata make temporal comparisons difficult. Furthermore, differences between sites may have swamped variability among strata. The experimental design emphasized replication at the stratum level rather than the site level, but additional transects at each site may have helped stabilize some of the site variability.

Benthic Cover by Site

Relationships among sites are best examined in years that share similar methodologies. Figures 4.4-4.11 illustrate percent cover for the major biological categories on the reef transects at each site, and are described in more detail below.

2001

Coral cover in 2001 was highest at RS10262 and PN3120 (Figure 4.4). Coral was present at all 10 unprotected sites, but the average coral cover in DRTO and TER was reduced by the presence of two sites in each of the protected areas with coral cover <0.7%. TER had the most sites with fire coral (*Millepora* sp.), though overall cover of fire coral did not differ among strata ($F_{2,27}$=2.068, p=0.146). The unprotected stratum had the sites with the highest octocoral cover (ON6772 and OS7675). Sponge cover was relatively consistent among sites. Macroalgal cover in DRTO was highly variable (i.e., stratum included the sites with the highest and lowest algal cover). Video resolution in 2001 was not sufficient to reliably identify seagrass or CCA on any of the transects. PN632 was almost entirely sand (76%), and was the only site at which no biological category had a cover greater than 5%.

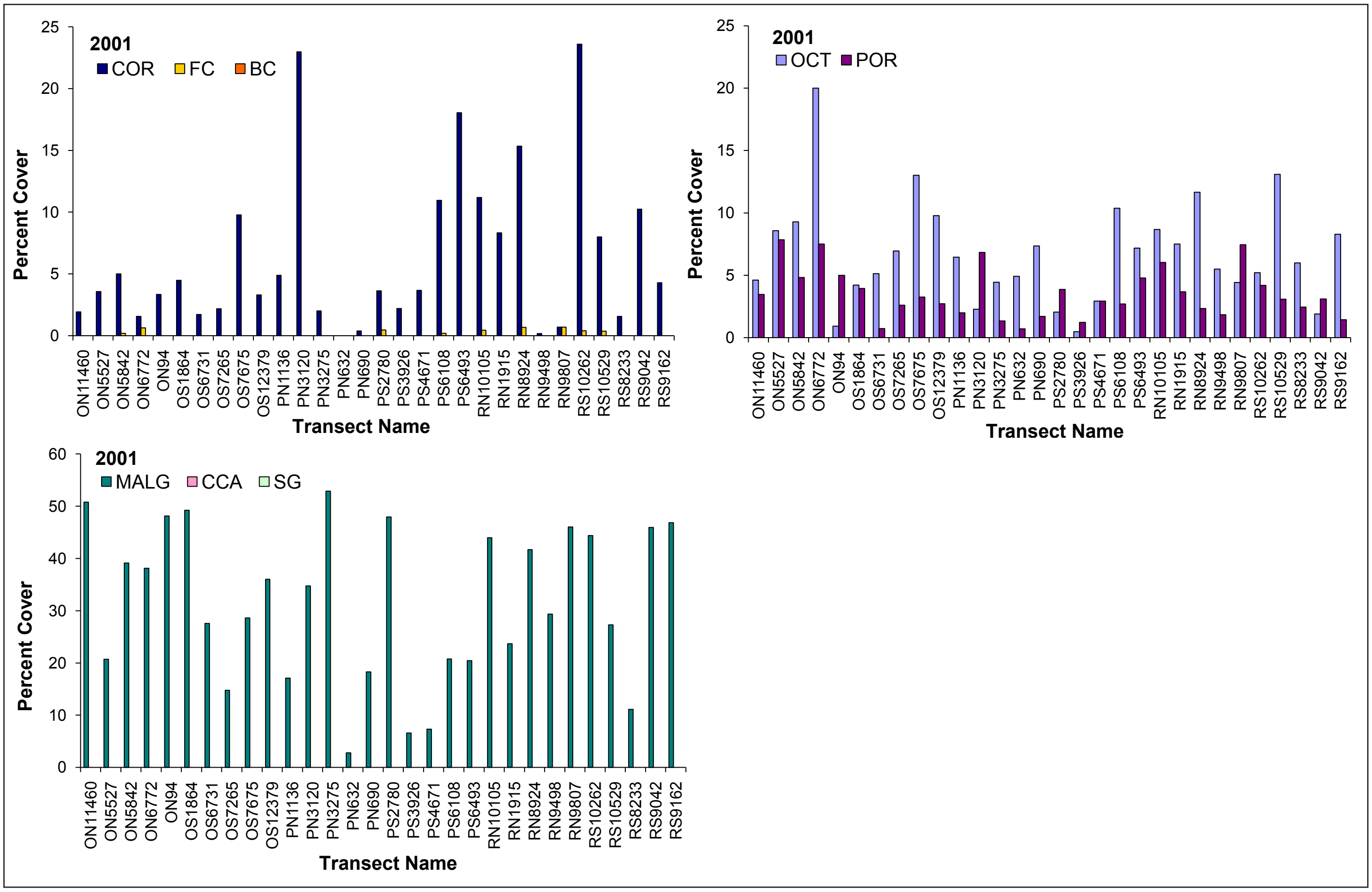

Figure 4.4. Benthic cover of biota on reef transects in 2001. COR = coral, FC = fire coral, BC = black coral, OCT = octocoral, POR = sponges, MALG = macroalgae, CCA = crustose coralline algae, SG = seagrass. Source: NCCOS CCFHR.

The PCA defined 59.7% of the variation in PC1 with the three dominant functional groups of soft substrate, macroalgae and coral. With the addition of hard substrate, PC2 increased the cumulative percent variation explained to 80.0% (data not shown). Several distinct groups were seen in the MDS plot and supported by group-averaged cluster analysis from Bray-Curtis similarities (Figure 4.5). Sites did not cluster by management stratum. The cluster on the right-hand side of the plot contains the sites with the highest proportion of sand. Within that group, the sites with the highest octocoral cover (OS7265 and RS8233) clustered together, as did the only sites in that group with macroalgal cover of >20% (OS6731 and RN9498). A second main cluster at the top of the MDS contains the two sites with the highest coverage of rock/rubble (54.4% at PN1136, 45.7% at PN690). ON94 was an outlier sharing less than 80% similarity to other sites and was the only site with virtually no octocoral (<1% cover).

The remaining sites in the left-hand cluster (Figure 4.5) have no defining characteristic. Three of the six groups in this cluster have high (>33%) macroalgae but are separated by other categories. RN9807 and PS2780 have low cover of corals and octocorals, ON5842 and OS12379 have moderate coral but high octocoral cover. RN10105 and RN8924 have high coral and octocoral cover but very little bare sand. Among the other three groups, PS6108 and PS6493 have high cover of corals but have more rock than macroalgae. ON11460 and OS1864 had virtually identical coverage of every benthic category except coral cover, while PN3275 was closely grouped but had slightly less sponge cover. The final group contains the four sites in this cluster with the highest sand cover (ON5527, RN1915, RS10529, OS7675).

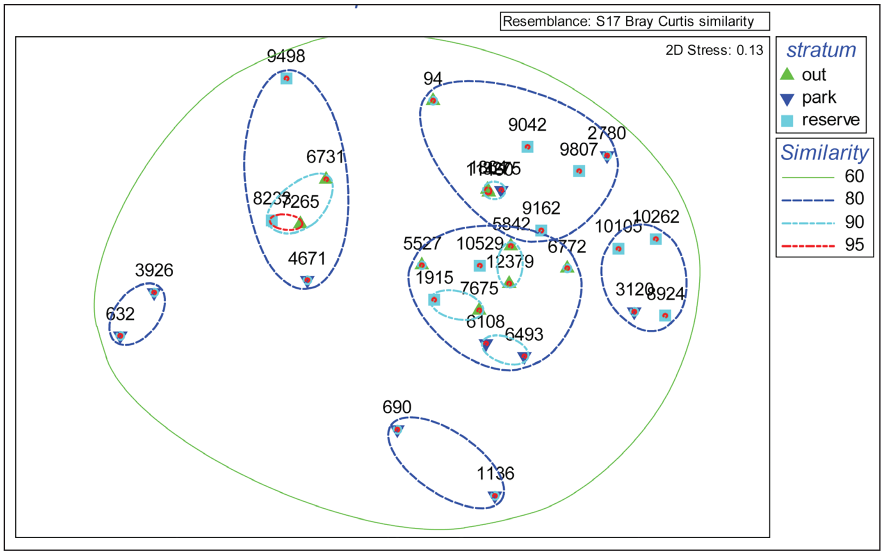

Figure 4.5. Two-dimensional multi-dimensional scaling (MDS) from Bray-Curtis similarities of 2001 Tortugas coral reef biota functional groups with superimposed group-averaged clustering obtained from the same similarities. Source: NCCOS CCFHR.

2002-2003

Coral cover was higher at many TER sites than DRTO and unprotected sites in 2002 (Figure 4.6), while in 2003 all TER sites had higher coral cover than sites in other strata (Figure 4.7). As was the case in 2001, RS10262 had the highest coral cover (14.1% in 2002 and 23.5% in 2003). ON11460 was an outlier in the unprotected stratum, with coral cover at 0.1% in 2002 and 0.3% in 2003. Fire coral was commonly observed at the reserve sites (eight and six sites in 2002 and 2003, respectively), but at only two sites did fire coral cover exceed 1% (RN9807 in 2002 and PS2780 in 2003). Black coral was observed at two sites in 2002, both of which were in DRTO. In contrast to 2001, reserve sites generally had the highest octocoral cover in 2002-2003.

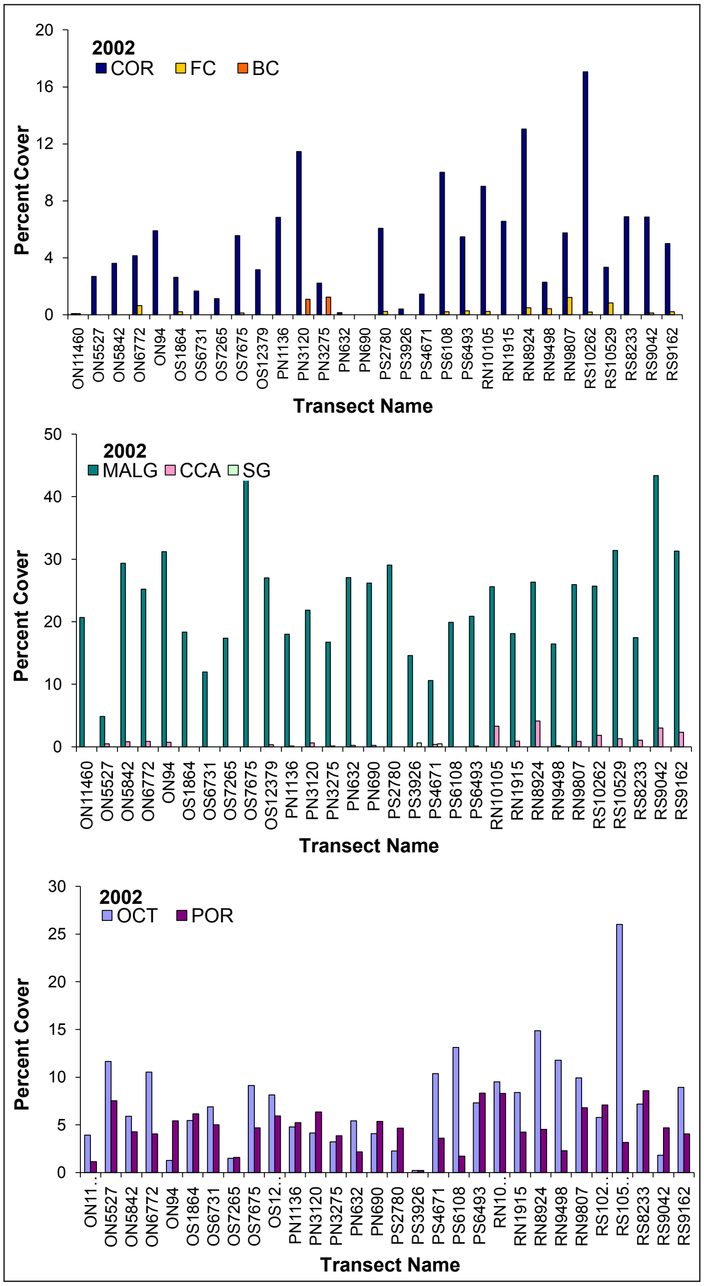

Figure 4.6. Benthic cover of biota on reef transects in 2002. COR = coral, FC = fire coral, BC = black coral, OCT = octocoral, POR = sponges, MALG = macroalgae, CCA = crustose coralline algae, SG = seagrass. Source: NCCOS CCFHR.

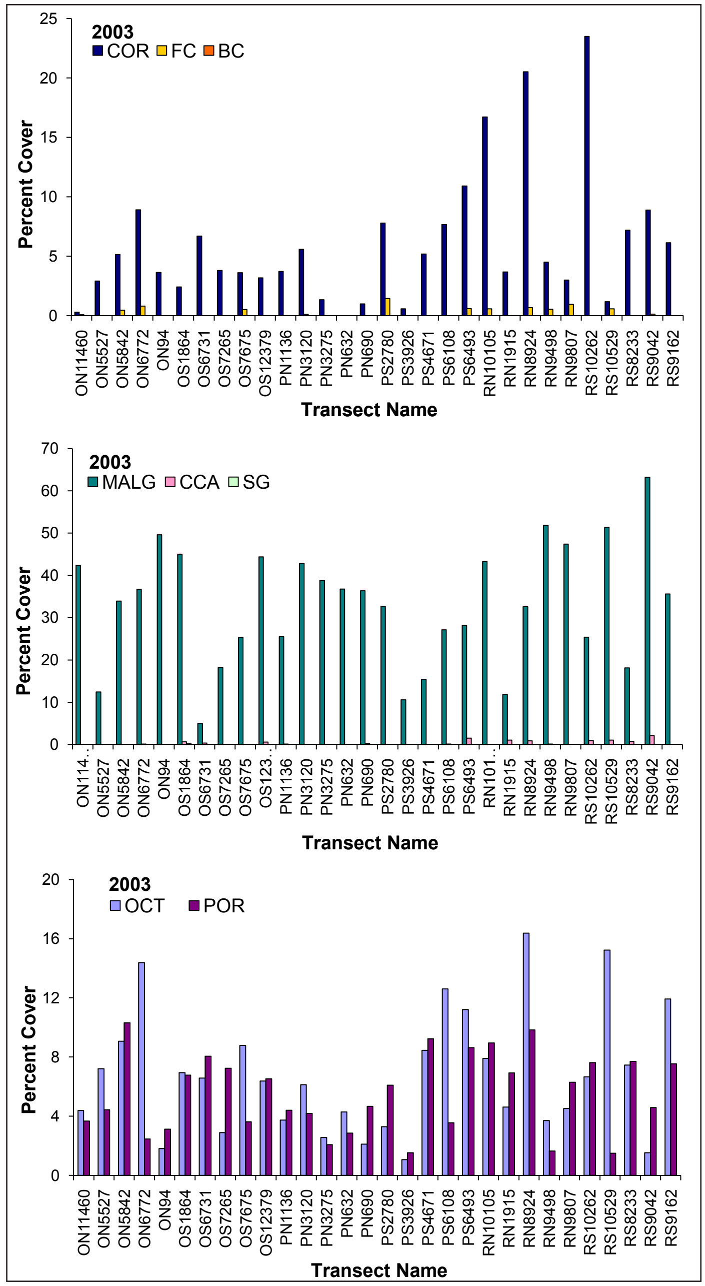

Figure 4.7. Benthic cover of biota on reef transects in 2003. COR = coral, FC = fire coral, BC = black coral, OCT = octocoral, POR = sponges, MALG = macroalgae, CCA = crustose coralline algae, SG = seagrass. Source: NCCOS CCFHR.

Macroalgal cover was highly variable. The unprotected stratum had the site with the lowest macroalgal cover in 2002, but had both the highest and lowest macroalgal sites in 2003. Every TER site in 2002 had CCA, as did seven sites in 2003. Paddle grass seagrass (*Halophila decipiens*) was present at two DRTO sites in 2002, PN3120 and PS4671, but only at OS1864 in 2003. PS3926 again appeared to be the outlier among all sites- macroalgal cover was 14.6% in 2002 and 10.6% in 2003, but no other biological category had cover >1.5%.

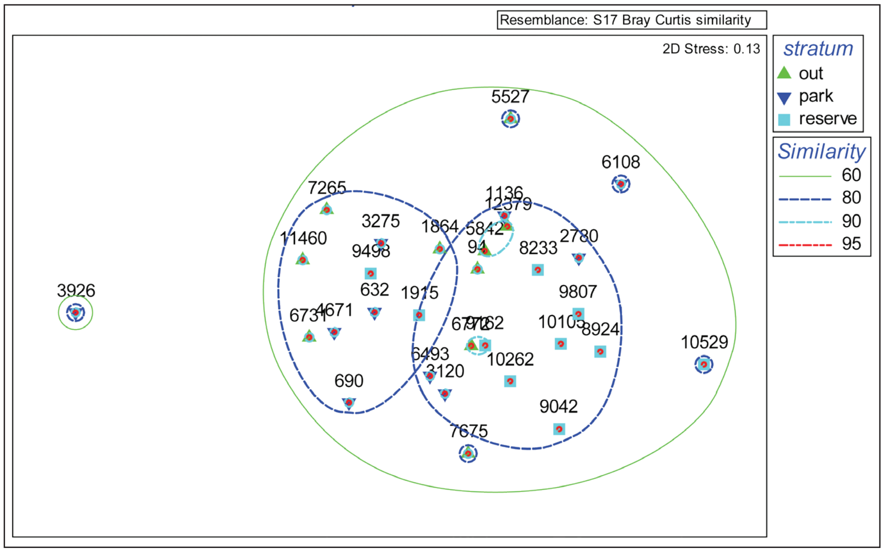

Figure 4.8. Two-dimensional multi-dimensional scaling from Bray-Curtis similarities of 2002 Tortugas coral reef biota functional groups with superimposed group-averaged clustering obtained from the same similarities. Source: NOAA CCFHR.

For 2002 data, PCA defined 52.9% of the variation in PC1 with the three dominant functional groups of microalgae and soft substrate, hard substrate and coral. With the addition of macroalgae, PC2 increased the cumulative percent variation explained to 73.9%. For 2003 data, PCA defined 49.3% of variation in PC1 by microalgae and soft substrate macroalgae and coral. The addition of hard substrate increased this to a total of 79.3% variance explained. MDS ordination plots (Figures 4.8 and 4.9) show PS3926 and RS10529 as outliers in both 2002 and 2003. PS3926 is again characterized by very high sand cover and virtually no living biological cover, while RS10529 stands out because it had the highest coverage of zoanthids in each year (5.2% in 2002, 6.1% in 2003). The other two outliers in 2002 were the sites with the highest rock/rubble cover; PS6108 had high coral cover (10%) and moderate macroalgae, while ON5527 had high sponge cover (4.5%). The other 2003 outlier, RS9042, had the highest macroalgal cover that year (63%).

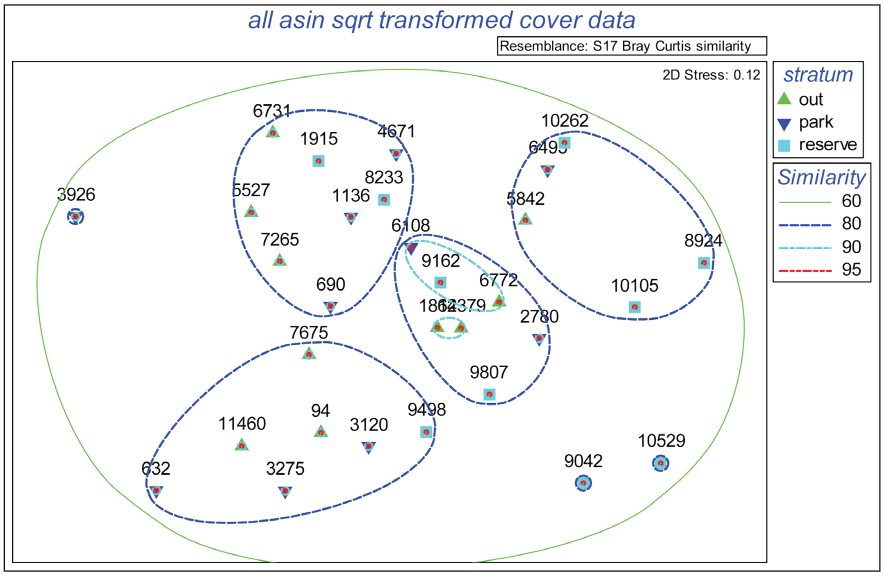

Figure 4.9. Two-dimensional multi-dimensional scaling from Bray-Curtis similarities of 2003 Tortugas coral reef biota functional groups with superimposed group-averaged clustering obtained from the same similarities. Source: NCCOS CCFHR.

In 2002 (Figure 4.8) the main cluster on the left has low coral (0.1-2.6%) and high sand (30.5-58%) cover, while the cluster on the right has moderate to high coral cover (3.1-17%). Two sites are members of both clusters—OS1864 has the highest coral cover in the left hand cluster, while RN1915 has the highest sand cover in the right-hand cluster. The groups in the left cluster are characterized by low sponge cover (OS7265 and ON11460), high rock/rubble (OS1864 and PN3275), and high octocoral cover (PS4671 and RN9498). The right-hand cluster has five groups: 3% coral (ON5842, OS12379), low sponge (ON6772, RS9162), high rock (PN1136, OS12379, RS8233), high sand (PS6493, PN3120) and high coral/octocoral (RN10105, RN8924).

Overall clustering patterns differed between 2002 and 2003. The MDS formed three main clusters in 2003 (Figure 4.9). The left cluster contains low (<11.5%) rock/rubble cover, while the right cluster contains sites with very little sand (<5.3%) and high sponge cover (4.6-10.3%). In the right cluster, the two sites with the lowest coral and highest rock cover (PS 6493 and ON5842) group together, while the other three sites have the highest coral cover observed in 2003. The middle cluster contains the remainder of the sites and has no coherent organizing characteristics. One group is distinguished by high rock cover (PS4671 and PN1136), while a second has the highest CCA cover in the cluster (RN1915 and RS8233; both are still <1%), OS12379 and OS1864 have essentially identical cover in nearly every category, including the highest amount of unidentified data points (3.2% and 1.8% respectively). The last group (PS6108, RS9162, PS2780, ON6772) has moderate cover of both coral (6.1-8.9%) and macroalgae (24.1-36.7%).

2005

The switch to digital still cameras gave a slightly smaller field of view than was obtained with the video; however, average coral cover for all sites (5.5%) was comparable to previous years (6.0% in 2003, 5.0% in 2002, 6.3% in 2001). Six of the seven sites with the highest coral cover in 2005 were found in TER (Figure 4.10). In all previous years coral was most abundant at RS10262, but in 2005 RN8924 had the highest coral cover (24.5%, the highest observed in any year of this study). Seven of the TER sites had fire coral, including the highest coverage observed in this study (3.7% at RS10529). Black coral was again observed in DRTO (site PN1136) and was rare but present in TER (<0.25% cover at RS10529 and RS8233). There was no apparent pattern in octocoral or sponge cover among sites. Half of the sites had macroalgal cover greater than the highest observed coral cover, compared to 22 sites in each of 2002-2003 and 19 sites in 2001. Paddle grass seagrass was observed at two park sites (PN1136, PS2780), and one TER site (RN1915). CCA was again most commonly observed at TER sites, although the unprotected and DRTO strata each had more sites with CCA than in previous years.

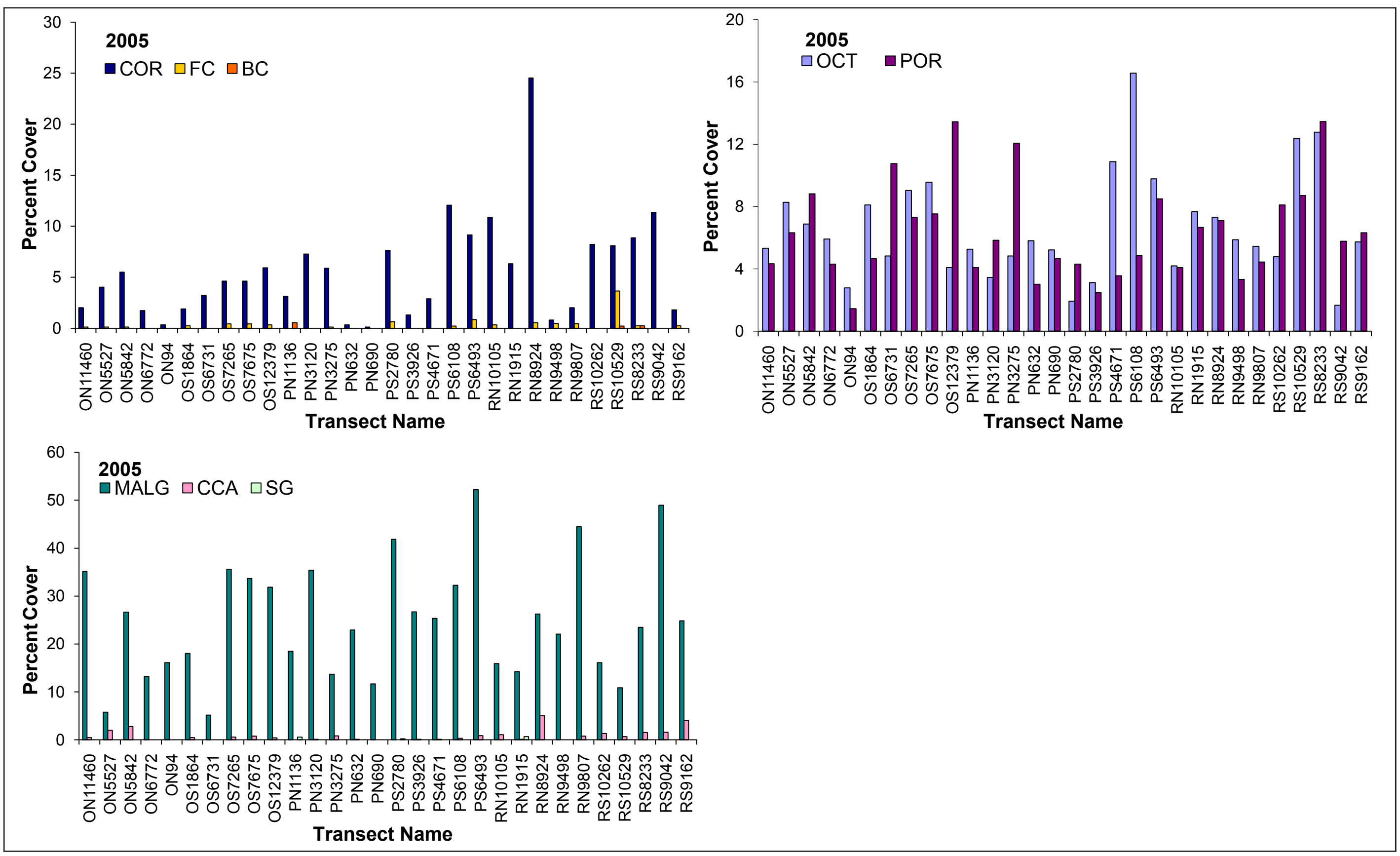

Figure 4.10. Benthic cover of biota on reef transects in 2005. COR = coral, FC = fire coral, BC = black coral, OCT = octocoral, POR = sponges, MALG = macroalgae, CCA = crustose coralline algae, SG = seagrass. Source: NCCOS CCFHR.

For 2005 biotic functional group data, PCA defined 48.0% of the variation in PC1 with the three dominant functional groups of microalgae and soft substrate, macroalgae, and coral. With the addition of hard substrate, PC2 increased the cumulative percent variation explained to 76.2%. In the MDS plot (Figure 4.11), RS10529 is an outlier, as was the case in 2002 and 2003. However, in this case the site is probably isolated as it has far more fire coral than any other site. The other outlier in 2005 was PS2780, which had an unusually high cover of zoanthids.

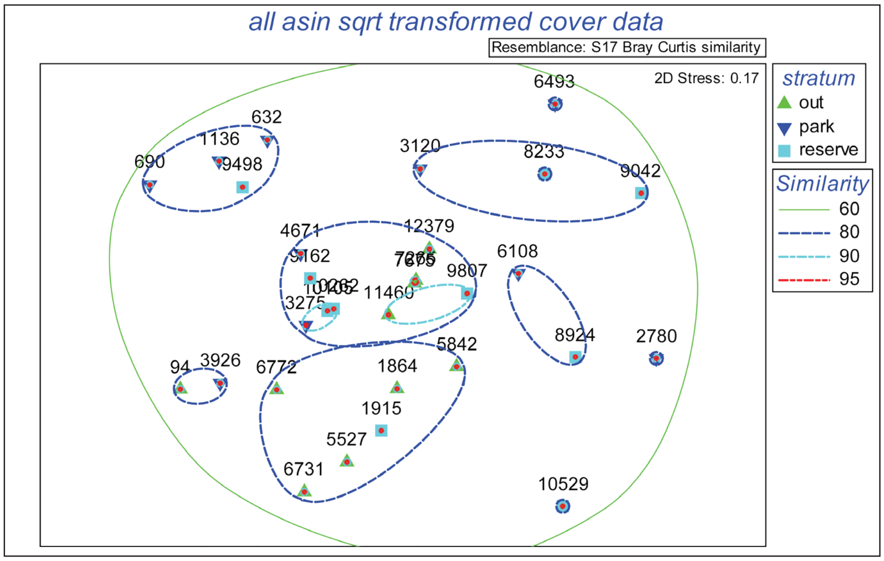

Figure 4.11. Two-dimensional multi-dimensional scaling from Bray-Curtis similarities of 2005 Tortugas coral reef biota functional groups with superimposed group-averaged clustering obtained from the same similarities. Source: NCCOS CCFHR.

The MDS ordination showed three main clusters in 2005. The left cluster contains sites with moderate to high macroalgae (23.5-52.3%). Groups within this cluster include sites with low coral cover (RN9807, ON11460) and low rock/rubble (OS12379, OS7265, OS7675). Sites with high sand cover (54.3-75.7%) form the cluster on the right, with sites grouped by low coral cover (PN1136, RN9498), high coral cover (PN3275, RN10105, RX10262) and high rock/moderate macroalgae (PN632, PS3926). The cluster at the bottom of the plot is intermediate, with low macroalgae (5.2-18%) and moderate sand cover (39.4-58.1%). The two sites with the highest macroalgal cover in this cluster (OS1864, RN1915) grouped together.

OTHER BENTHIC HABITAT STUDIES IN THE DRY TORTUGAS

Many historic benthic habitat studies were conducted in the Dry Tortugas (see Shinn and Jaap, 2005). More recently, there have been several intensive studies using different approaches, methodologies and sites to assess coral reef benthic habitat condition and change.

University of North Carolina Wilmington, University of Miami, Rosenstiel School of Marine and Atmospheric Science and the National Marine Fisheries Service Multi-scale Mapping, Benthic Cover and Fish Surveys

A large-scale assessment of the community structure and condition of hard-bottom and coral reef habitats, coral population structure, and potential habitat change at multiple spatial scales has been conducted since 1999 by the National Undersea Research Center (NURC) at the University of North Carolina Wilmington. This study provides complementary habitat information for fishery-independent reef fish surveys and modeling efforts for evaluating essential fishery habitat (NOAA National Marine Fisheries Service [NMFS] and University of Miami Rosenstiel, School of Marine and Atmospheric Science [UMRSMAS]). The survey design is scaled at three management zones: Tortugas Bank Fished (commercial and recreational fishing), DRTO (recreational hook and line only) and North TER (closed to all fishing since 2001; Ault et al., 2006) as well as by reef, habitat type and regions of the south Florida shelf (Miller et al., 2006).

Independent sample sites were selected randomly from a digital benthic habitat map stratified by nine categories of hard-bottom and coral reef habitat types (Franklin et al., 2003). Each site has four random transects. Surveys use the linear point-intercept method and strip transects to measure coverage, octocoral abundance, species richness, coral size and condition, juvenile coral abundance and size, urchin abundance and size, anemone and corallimorph abundance and algae coverage by functional group (Miller et al., 2000; Miller et al., 2006).

Habitat surveys included 24 sites in 1999, 36 in 2000, 24 in 2002, 46 in 2006, and ranged from 5-27 m depth (Miller et al., 2000; Miller et al., 2006). Physical damage from the 2005 storms was patchy and more apparent on the south side of the park. In 2006, many sites were no longer dominated by gorgonians and sponges. In some high cover areas, coral cover has declined from near 50% in 2004 to approximately 35% in 2006 due to higher amounts of encrusting fan-leaf algae (*Lobophora variegata)* and coral disease (Miller et al., 2006). Stony coral cover means ranged from 0.25% to 31% among 42 of the 46 sites. Sponge species richness was greater than or equal to combined stony corals and gorgonian species richness. Juvenile corals ranged from $0.16/m^2$ to $5.77/m^2$, with higher densities within DRTO high-relief habitats. These results are similar to the 1999-2000 Tortugas surveys as well as other Florida Keys surveys. Disease prevalence was relatively low (<5%), but some medium-profile reefs and patchy hard-bottom habitat sites on the northern and northeastern areas had higher incidence of disease (15-37%). No bleaching was observed in 2006 (Miller et al., 2006).

Florida Fish and Wildlife Research Institute Long-term Permanent Monitoring for Coral Cover

The state of Florida has a history of research in the Dry Tortugas since 1975. The current Coral Reef Evaluation and Monitoring Project (CREMP) goal is to assess regional coral reef ecological status and trends by annual resource monitoring using repetitive underwater video transects and station species inventories, which includes information on species richness, distribution, and mean percent cover of stony corals and selected functional groups.

Three Dry Tortugas sites (12 stations) were established in 1999, of which two are inside DRTO and one is now within the Florida Keys National Marine Sanctuary (FKNMS) TER. Four additional park sites were added in 2004 (Wheaton et al., 2007). Sites range in depth from 2-12.5 m, and each site has two to four stations marked with permanent markers at start and end points for 22 m long transects. Repeated video transects and species inventories were used to estimate the biodiversity, distribution, coverage, and species richness of stony corals and octocorals, clionid sponge assessment, selected disease conditions, benthic algae coverage and long-spined sea urchin (*Diadema antillarum)* incidence (Wheaton et al., 2007). Similarities between sites and stations were analyzed using MDS of Bray-Curtis similarity indices for functional groups, including coral species.

CREMP monitoring shows coral in the Dry Tortugas has been influenced by disease, bleaching, tropical storm and hurricane activity, and unknown factors. In 2005, 29 total stony coral species (*Millepora* and *Scleractinia*) were identified at 23 Tortugas stations, and mean coral cover ranged from 1.6-13.8% (Wheaton et al., 2007). Stony coral cover averaged 7.2% in 2004 and increased to 6.7% in 2005; however this reduction was not statistically significant. Coral species richness decreased significantly at two sites from when the site was established (1999 or 2001) and 2005, which was attributed to tropical storm activity 2003-2005 (Wheaton et al., 2007). Shallow reefs formerly dominated by acroporids have shown a dramatic decline, for example at one staghorn coral dominated site, coral cover declined from 14.4% in 1990 to 9.5% by 1999 (Wheaton et al., 2007). However, *Acropora* populations have historically fluctuated in the Dry Tortugas due to hurricanes, cold water and other factors (Jaap and Lyons, 1989). Macroalgae cover was relatively low, <10.4%, for all sites in 2004 and 2005 (Wheaton et al., 2007). Octocoral cover varied inversely with coral cover (Shinn and Jaap, 2005). CREMP data showed a decline in *M. annularis* spp. complex and *C. natans* cover from 2003 to 2005, which was attributed to an unknown coral disease (Wheaton et al., 2007). In 2005, 18 of 23 stations showed signs of coral disease or bleaching and 18 of 29 inventoried coral species showed bleaching. staghorn coral had a “white” disease at two stations, and an unknown disease affected *M. annularis* complex species and *S. siderea* (Wheaton et al., 2007).

Environmental Protection Agency Long-term Permanent Monitoring: Coral Disease and Bleaching

Monitoring of coral disease and bleaching prevalence in the Dry Tortugas has been conducted by the Environmental Protection Agency (EPA). Three permanent sites were established in the Dry Tortugas (two at Bird Key and one at Loggerhead Key) as part of a larger study with 30 sites throughout the Florida Keys to characterize coral community composition, abundance, age class structure and species survival. Sites were selected randomly from a spatially-balanced grid. A radial arc transect was used for disease and bleaching surveys and coral colony counts (Santavy et al., 2005). In 2005, five stations in the Dry Tortugas were surveyed and estimates of total coral surface area and percent living coral tissue were added to the methodology (Fisher et al., 2006; Fisher et al., 2007).

In 2000, survey sites throughout the Florida Keys and including the Dry Tortugas had less than 13% disease prevalence, while approximately 80% of the reef area had lower than 5% disease prevalence (Fisher et al., 2006). Dry Tortugas stations had a higher total coral surface area than Key West stations, in addition to differences in size distribution, species diversity and the contribution of different species to total coral surface area. In both Key West and the Dry Tortugas, knobby brain coral (*Diploria clivosa)*, mustard hill coral (*Porites astreoides)* and finger coral had a high percentage of live coral, but boulder brain coral and mountainous star coral had a low percentage of live coral. High numbers of small corals were surveyed and an inverse relationship between abundance and size was found (Santavy et al., 2005). Each colony encountered at the five stations had between 76.4-84.1% live coral calculated. At each station, estimates of total coral surface area ranged from 29.0 m^2 to 42.4 m^2 and estimates of living coral surface area ranged from 22.7-32.4 m^2. At 35.7% *D. clivosa* had the greatest total surface area per species and comprised 33.9% of total coral colonies.

SUMMARY AND CONCLUSIONS

Despite differences in methodologies and site depths, the average and range in coral cover in the CCFHR study were consistent with those reported by the other Tortugas monitoring projects over the same time period. Storm damage, evident at relatively shallow CREMP sites between 2003 and 2005 and at NURC sites in 2006, was not evident at CCFHR sites at the most recent August 2005 survey. However, Hurricane Katrina passed through the area less than two weeks later and was followed by other hurricanes and storms. Coral disease and bleaching, while not specifically addressed by CCFHR benthic habitat studies, has not been prevalent during site visits. In general these other studies have shown an overall reduction in percent coral cover in the TER and other areas of the Tortugas region. Whether or not the TER can mitigate observed changes in benthic composition (e.g., loss of corals) remains to be seen.

The intent of CCFHR's research was to characterize resources at the reef-sand interface in the Tortugas and to monitor the effects of implementing TER. On average half of each reef transect was comprised of non-living substrate (rock and sand). Macroalgae were the most common biological component, with an average cover of 25-33% in a given year. Coral cover was 5-6% in each year but was highly variable among sites, ranging from 0-24.5%. Coral cover was consistently higher at sites within the TER compared with DRTO and unprotected sites for all years (see Figure 4.2), but relationships among sites were not consistent over time. Sampling sites were randomly selected using a rigorous statistical approach, but the resultant variability among sites makes it difficult to detect whether or not TER implementation had an effect on benthic composition. The variability could be constrained over time as additional years have been sampled, which may aid in detecting TER effects. However, the fact that the reserve had consistently higher coral cover than DRTO and unprotected sites suggest that reef habitats within TER initially were of better quality than unprotected sites, assuming that higher coral cover is indicative of habitat quality. The CCFHR survey/site methodologies were optimized for fish data collection, and the benthic characterization was intended to identify fine-scale habitat metrics that (1) would help elucidate fish-habitat fish species habitat relationships, (2) could be used as covariates to help explain spatial and temporal patterns in fish assemblages among management strata, and (3) help parse out natural variation in fish assemblages (i.e. that due to habitat differences) from variation due to protection (i.e. TER effect). Chapter 5 provides a characterization of reef fishes among three management strata in the Tortugas region, and describes fish-habitat associations based on fine-scale habitat presented in this chapter.

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