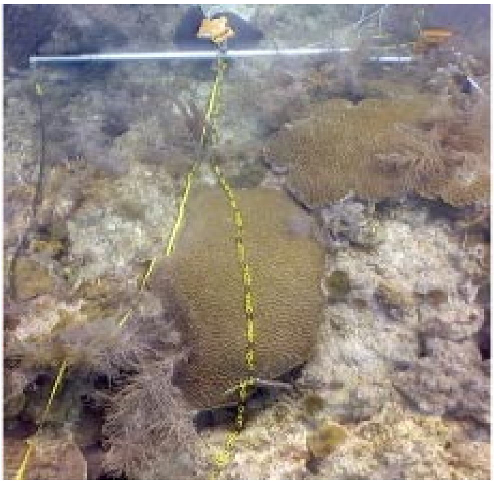
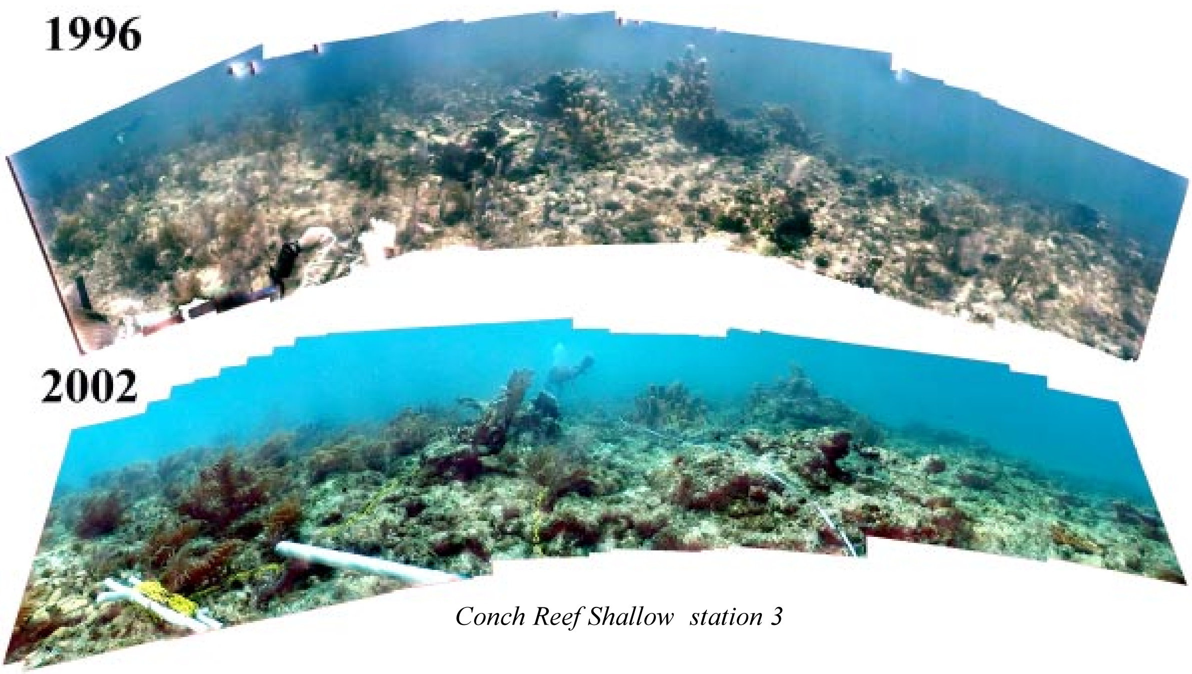
EPA/NOAA Coral Reef Evaluation and Monitoring Project

2002 Executive Summary, July 2003



Healthy Brain Coral, Bird Key Reef 2001

Recently dead Brain Coral, Bird Key Reef 2002



Conch Reef Shallow station 3

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A report of the Florida Fish and Wildlife Conservation Commission and the University of Georgia pursuant to USEPA grant award number X-97468002-0, and NOAA grant award number NA16OP2554.

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ABSTRACT

In 1994, the Florida Keys Coral Reef Evaluation Monitoring Project (CREMP) was initiated to provide status and trends data needed to evaluate the success of future management actions in the Florida Keys. Forty sampling sites were selected within the FKNMS using a stratified random sampling procedure (USEPA E-map) and permanent station markers were installed. Annual sampling began in 1996 and continued through 2002. Three additional sites were installed in the Dry Tortugas in 1999 for annual sampling. Starting in 2002, additional sampling techniques were incorporated into the project including clionid sponge surveys of abundance and cover, a more definitive stony coral disease survey, and a stony coral recruitment survey.

Results are reported for regions defined as Upper Keys (north Key Largo to Conch Reef), Middle Keys (Alligator Reef to Molasses Keys), Lower Keys (Looe Key to Smith Shoal), and Tortugas (Dry Tortugas to Tortugas Banks).

Sanctuary-wide from 1996 to 2002, the number of stony coral species declined at 74 stations (70%), increased at 21 stations (20%), and remained unchanged at 10 stations (10%). A slight decline in the number of stony coral species was recorded in all habitat types. The offshore deep and patch reef stations had the greatest numbers of stony coral taxa with 18 and 16 species, respectively; the fewest number of stony coral species, an average of nine species per station occurred at the hardbottom stations. Between 1996 and 2002 the number of stony coral species decreased at 23 of 30 (77%) stations in the Upper Keys, increased at 2 stations, and remained unchanged at 5 stations. In the Middle Keys, the number of stony coral species decreased at 20 of 29 (69%) stations, increased at 7 stations, and remained unchanged at 2 stations. In the Lower Keys, the number of stony coral species decreased at 31 of 46 (67%) stations, increased at 12 stations, and remained unchanged at 3 stations.

Overall, there were increases in the number of stations containing diseased stony corals, the number of stony coral species with disease, and the different types of diseases that were observed. The number of stations where white disease was found increased from five stations in 1996 to 90 stations in 2002. In 2002, the number of stations where "other disease" was recorded declined slightly from 95 in 2001 to 94 in 2002.

Sanctuary-wide, a decline in stony coral cover has been observed since 1996. Between 1996 and 2002, a 38% decline in stony coral cover was observed sanctuary-wide. This trend was confirmed by nonparametric hypothesis testing at the sanctuary level. The decline in mean percent coral cover from 1997 to 1998 and from 1998 to 1999 was significant with a p-value of 0.03 or less for the Wilcoxon rank-sum test. Between 1997 and 1998 coral cover declined from 11.4% to 9.6%. The downward trend continued between 1998 and 1999 when coral cover declined from 9.6% to 7.4%. The changes observed from 1996 to 1997, and 1999 to 2002 were determined to be statistically insignificant. Sanctuary-wide coral cover has not changed significantly since 1999.

For the 103 stations with sufficient stony coral cover for analysis, 57 (55%) stations had a significant decrease in stony coral cover, 39 (38%) stations showed no significant change, and only seven (7%) stations had a significant increase.

Percent cover data for functional groups were analyzed for the geographic regions from 1996 to 2002. Sanctuary-wide, in 2002, the benthic community within CREMP sites was composed of 66.8% substrate, 11.0% octocoral, 9.3 % macroalgae, 7.5% stony coral, 2.5% sponge, 2.2% zooanthids, and 0.6% seagrass.

From its inception in 1996, the CREMP has successfully documented long-term changes in the status and trends of coral reefs throughout the 2,800-square-nautical-mile FKNMS. The cessation of the rapid decline documented in the early stages of the project is encouraging. There is a general consensus that multiple stressors acting at local, regional, and global scales are continuing to have negative impacts on coral reefs in the Florida Keys and elsewhere.

The Coral Reef Evaluation and Monitoring Project will continue to collect data relative to benthic habitat condition at the established 40 sites. A coral disease survey, stony coral abundance survey, measurements of temperature and rugosity, and sampling for human enterovirus will be conducted at nine of these sites. The CREMP will also mine such sources as remote sensing data and *in-situ* sensor data to define cause and affect relationships within the Florida Reef Tract.

INTRODUCTION

In 1994, the Florida Keys Coral Reef Monitoring Project (CRMP) was initiated to provide status and trends data needed to evaluate the success of future management actions in the Florida Keys. Today, the program is a cooperative effort between the National Oceanic and Atmospheric Administration (NOAA), the U.S. Environmental Protection Agency (USEPA), and the Florida Fish and Wildlife Conservation Commission. The CRMP was designed to be part of a Water Quality Protection Program (WQPP), which has the goal of monitoring seagrass habitats, coral reefs, hardbottom communities, and water quality in the Florida Keys (Hankinson and Conklin, 1996). The major criteria for monitoring the coral reefs included determining the sanctuary-wide spatial coverage of the coral communities, repeatedly sampling them, and statistically documenting the status and trends of the coral communities. The sampling strategy and methods were developed in conjunction with USEPA, Florida Keys National Marine Sanctuary (FKNMS), Continental Shelf Associates (CSA), and the Principal Investigators.

In the project design planning meetings (1994-1995), EPA, NOAA, and CSA suggested that a comprehensive reef monitoring plan for the FKNMS should include hardbottom, patch reef, and offshore reef habitats. The CRMP team used US EPA e-map protocol to randomly select sites from north Key Largo to beyond Key West. Spatial stratification includes nearshore hardbottom, offshore (shallow and deep), and patch reefs in the upper, middle, and lower keys. Permanent station markers were installed at forty sites (Figure 1) in 1995.

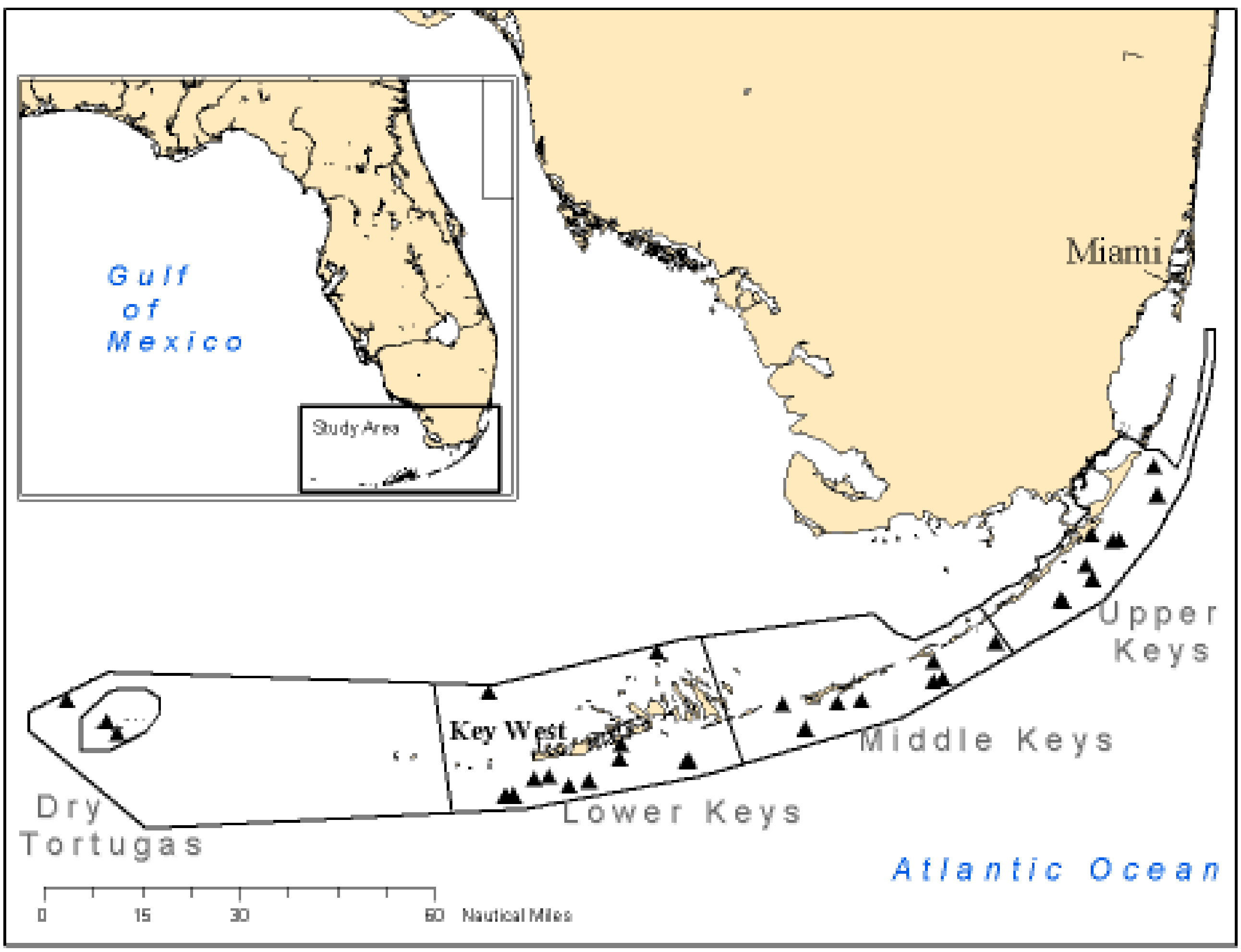


Figure 1. CREMP site distribution.

Annual sampling began in 1996, and has continued through 2002. Three sites were installed in the Dry Tortugas in 1999. Starting in 2001, additional sampling techniques were incorporated into the project to help researchers better understand the causes of coral decline and the effects of multiple stressors on coral reefs. These techniques included a bio-eroding sponge survey, a more definitive evaluation of stony coral disease, and a stony coral population survey. The enhanced monitoring project has adopted the name Coral Reef Evaluation and Monitoring Project (CREMP).

METHODS

Each site consists of two to four monitoring stations delineated by permanent markers. Stations are approximately 2 x 22 meters and are generally perpendicular to the reef crest. Within each station, field sampling consists of a station species inventory (SSI), video transects (three transects per station) and a bio-eroding sponge survey (Figure 2). Nine sites (3 in each of the geographical areas) have been designated Value Added Sites. In addition to SSI, video transects, and bio-eroding sponge surveys, sampling at these sites includes diseased coral surveys, stony coral abundance surveys, and temperature surveys.

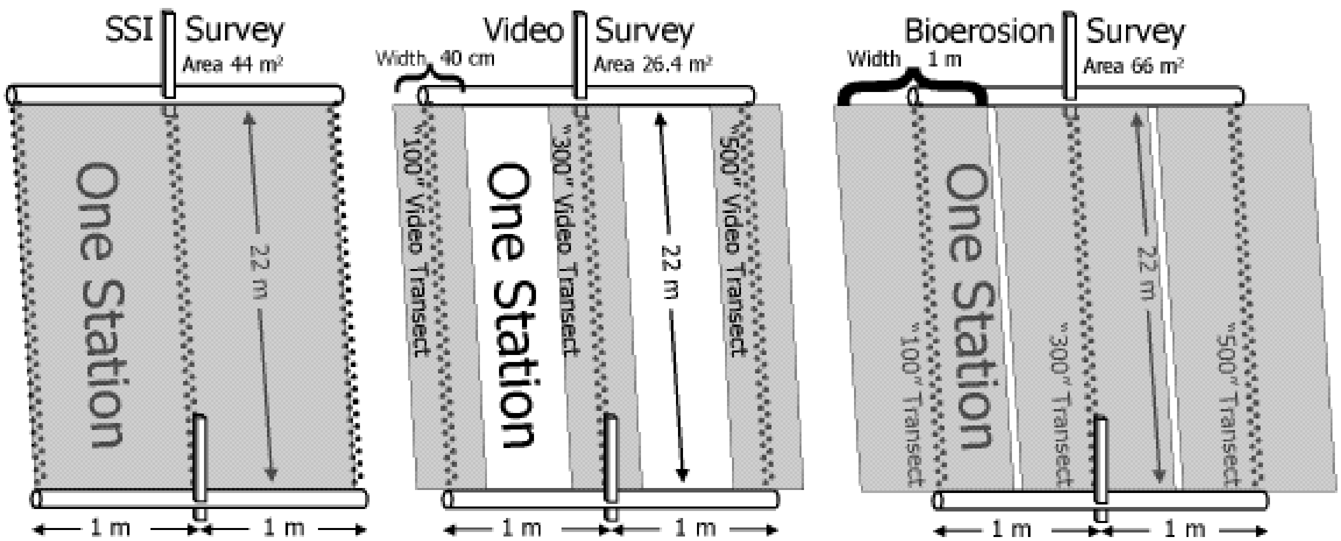


Figure 2. Layout of CREMP stations and area sampled by each method.

Station Species Inventory (SSI)

Stony coral species (Milleporina and Scleractinia) presence is recorded at each station. Two observers conduct simultaneous, timed (15 minute) inventories within SSI area and enter the data on underwater data sheets. Each observer records all stony coral taxa and enumerates long-spined urchins (*Diadema antillarum*) within the station boundaries. During the species inventory, any species within a station that exhibits specific signs of either bleaching or disease is documented on the data sheet. Diseases are sorted into three categories: black band, white complex (including white plague, white band, white pox), and other (dark spot, yellow band, and idiopathic diseases).


Two observers conducting a species inventory

After conducting the survey, the observers compare data (5 minutes) underwater and each confirms the species recorded by each observer. Data sheets are verified aboard the vessel and forwarded to Florida Marine Research Institute for data entry and processing. This method facilitates robust data collection with broad spatial coverage at optimal expenditure of time and labor.

Video Transects


Videographer filming chain transect

Video was selected as the method for cover evaluation because it is a rapid and efficient means of field data collection that provides a permanent data record. Traditional transect and quadrat methods used in terrestrial environments are too time consuming for underwater use in addition to being less accurate and precise. The CREMP video sampling protocol is based on preliminary testing for sampling sufficiency. We concluded that each station should include at least 24 m^2 (96m^2 per site). Collecting imagery with these spatial characteristics requires a camera system that can capture 150 to 180 images per station (1,800 to 2,160 per site). Standard camera systems (Nikonos, SLR, and digital still cameras) are capable of only 36 to 180 high quality images per film or media load. The video camera collects all site images on a single videocassette. Video data can be verified immediately after sampling and provides a permanent record. Still images (Jpeg and Bitmap) are created from the videotape for analysis. The method selected is very compatible with that of other coral reef monitoring and research programs in the Caribbean and Australia (Aronson, et al., 1994; Carlton and Done, 1995; Sweatman, 1998; and McField, 2001).

Percent cover of live coral, sessile benthic biota, and selected substrates is determined annually from video transects filmed at each station (Figure 2). The videographer films a clapperboard prior to filming each transect. This provides a complete record of date and location of each segment recorded. Three video transects are filmed at a constant distance above the substrate at each station. Two lasers converge 40 cm from the camera lens and guide the videographer in maintaining the camera at a uniform distance above the reef surface. Filming is conducted perpendicular to the substrate and at a constant swim speed of about 4 meters per minute. Artificial lights are used when necessary to ensure image quality. All sampling through 1999 was filmed with a Sony CCD-VX3 using full automatic settings. Beginning in 2000, the project upgraded to digital video filming with a SONY TRV 900. The minimum number of digital images necessary to represent each station are framegrabbed and then written to and archived on CD-ROM.

Analysis of benthic cover images is predicated on selecting video frames that abut, with minimal overlap between images. At the filming distance of 40 cm above the reef surface, the field of view is approximately 40 cm wide. Through 2000, a subset of still images was frame grabbed based on swim speed. From this subset, the analyst selected images that approximated a non-overlapping mosaic. Starting with 2001 video data, a set of abutting images that best covers the station was grabbed directly from the video tape eliminating error caused by analyst frame selection, creating a more representative data set.

Image analysis is conducted using a custom software application PointCount for coral reefs, developed specifically for the CREMP. The software places ten random points on each image. Under each point, selected benthic taxa (stony coral species, octocoral, zoanthid, sponge, seagrass and macroalgae) and substrate are identified. The software has a “point and click” feature that feeds the identification data into a backend spreadsheet. After all images are analyzed, the data are converted to an ASCII file for Quality Assurance and entry into the master ACCESS data set.

Bio-eroding Sponge Survey

Observer conducting sponge survey

In 2001, the project began monitoring the abundance and percent cover of bio-eroding sponge species. Bio-eroding sponge data were collected at all 117 CREMP stations. The three clionid sponge species (*Cliona delitrix, C. lampa*, and *C. caribboea*) recorded by CREMP are known to be aggressive coral bio-eroders and over-growers. Clionid sampling methodology was developed based on existing project station layout. Three 1-meter-wide belt transects provide the maximum spatial coverage within each station. A 30-meter survey tape marks the center of reference for each transect. A diver delineates the survey area by swimming directly above the tape holding a meter stick perpendicular to the tape and parallel to the reef surface. The location, species, and size of each clionid sponge colony is recorded. The species of stony coral affected by the clionid colony is also recorded. Area is measured by means of a 40-cm by 40-cm quadrat frame subdivided into 5 cm squares. The area occupied by the clionid colony is recorded to the nearest half square.

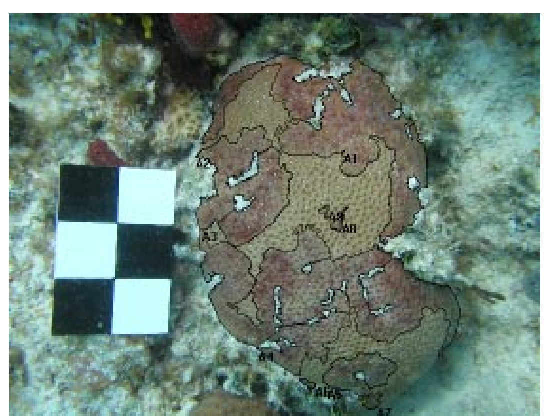
Stony Coral Population Dynamics

The CREMP sampling protocol for station species inventory is a qualitative census producing a list of all species of stony corals within each station. Although this information is important, it provides only presence/absence data and lacks data pertaining to the relative importance of a species in time or space. A quantitative survey such as those performed at value added sites provides information on the relative abundance and size classification of individual coral colonies. These data have value for defining both recruitment and community structure. Analyses of these data provide relative abundance by size for individual coral species as well as community indices such as species diversity, dominance, and eveness, as well as inferential statistical testing.

At each of 18 value-added stations, abundance and size-class distribution data are collected for all stony corals. Twenty 1 m^2 quadrats are surveyed within a sampling station. A 1m^2 quadrat is placed along either side of a centerline that extends between the permanent stakes marking each site. A diver records the species and size classification for each species of stony coral within the quadrat. Size classifications are 0-3 cm, 3-10 cm, 10-50 cm, and >50 cm. Size is measured at the point of greatest aerial coverage within a colony.

Disease Coral Survey (DCS)

Since it's inception in 1996, the CREMP has documented a increase in the number of stations with disease. In 1996, disease was observed at 26 of 140 CREMP stations. By 2001, coral disease was reported at 131 stations. The number of coral species affected has also increased from 11 in 1996 to 36 species in 2001. The CREMP protocol for disease calls for notation of the presence of black band, white category, and other types of disease by station and species. Although this protocol provides a quick assessment of coral disease, it has limited value for determining the intensity and long-term effect of a disease.



Example of diseased coral photograph

The Disease Coral Survey (DCS) was therefore designed to determine whether or not coral diseases significantly influence the survival of coral in the Florida Keys. This study quantifies the abundance and distribution of different diseases on different species of corals. Colonies are assessed by annually photographing individual coral specimens at each of the 18 Value-Added Stations in the Florida Keys CREMP. All colonies affected by either bleaching or disease within the 40 m^2 area (2 m-wide by 20 m-long) at each station are located and photographed. A digital still camera is used to take two photographs (side view with morbid or bleached area and aerial) of affected corals with a clapperboard in the field of view for metadata and scale. The precise position of each colony within the transect is recorded for their relocation during subsequent resurveying. The fate of each colony is tracked through time. This method provides a detailed look at the magnitude and the consequences of coral disease to individual coral colonies at VAS sites.

Temperature Study

Temperature data are being collected to document possible trends of increasing water temperatures within FKNMS sampling sites. Small *in situ* temperature loggers were installed at all value-added sites during 2002 and early 2003. These data-loggers record water temperature hourly and will be recovered, downloaded and re-deployed quarterly. Data analyses will begin at end of the 2003 field season.

Statistical Analyses

Statistical analyses are conducted by independent consultants who analyze the percent cover, species richness, and disease/condition data. The decision to reject or not to reject the null hypothesis that there is no significant difference in the data for certain years is based on the minimum detectable difference for different significance levels and powers. Combinations for significance level (α) and power (1- β) were considered: $\alpha = 0.05$, $1\text{-}\beta = 0.75$; $\alpha = 0.10$, $1\text{-}\beta = 0.75$. When the one-sided alternative is tested, the above values for α must be divided by two. The output consists of the minimum detectable difference for a certain pair (α, 1-β), which can be used to construct a (1-α) % confidence interval and provides a measure of the test accuracy.

Benthic Cover Analyses

Hypotheses testing of benthic cover data looked at differences in proportions of stony coral cover (millipora and scleractinia) at the station level for the periods 1996-2002, 1998-2001 pooled vs. 2002 and 1999-2001 pooled vs. 2002. Specifically, the tests were:

$$H_o : p^i_{2002} = p^i$$
vs.
$$H_{a:}\ p^i_{2002} \neq p^i$$

where p = the proportion of stony coral cover at station i for the period 1996-2002, 1998-2001, or 1999-2001. The significance level of *alpha* was fixed at $\alpha = 0.05$. This type of test focuses on differences observed in the 2002 data and is different from the tests used in previous reports where comparisons were made on a pair-wise basis. The advantage of this type of test is that it reduces the probability of a *Type I* error. A *Type I* error occurs when a true null hypothesis is rejected.

Station Species Inventory (SSI) Analyses

To investigate whether there is a difference in the proportion of the number of stations where each species is present, data from 2001-2002 was pooled and compared to pooled data from 1996-2000. These analyses identified species that were observed at significantly fewer stations for the period 2001-2002. Significance levels of $\alpha = 0.05$, and $\alpha = 0.10$ were used. Results reported herein are for each coral species sanctuary-wide.

Disease and Condition Analyses

Hypothesis testing for coral disease and coral condition examined the percent change in the number of stations with white disease, other disease, and bleaching present for 2001-2002 versus 1996-2000 at the significance level of $\alpha = 0.05$.

Station Reduction

Prior to the 2001 sampling season, the statistical consultants re-evaluated the sampling stations in the Keys proper and concluded that certain sampling stations could be eliminated and still allow the project to maintain its spatial coverage and robust data set. The decision to eliminate one or two of the four stations at an individual site was based on statistical analyses of the similarity in stony coral cover. Hypothesis testing was used to identify differences in the proportion of stony coral cover at the four stations within each site (Fleiss, 1981). This exercise reduced the original sampling of 160 stations (40 sites) to sampling 105 stations (37 sites). Though sampling has been halted at 55 of the original stations, the permanent station markers remain in place for future reference. All 12 Dry Tortugas stations have been retained in the sampling regime. A total of 117 CREMP stations contine to be sampled.

RESULTS

Results are reported for the regions defined as follows: Upper Keys (north Key Largo to Conch Reef), Middle Keys (Alligator Reef to Sombrero Reef), Lower Keys (Looe Key to Smith Shoal), and Tortugas (Dry Tortugas to Tortugas Banks) (Figure 1). In order to make valid comparisons between 2002 data and data from previous years, 1996-2000 data were recalculated using only data from stations which continued to be sampled after station reduction. This report presents data for those 117 stations (105 in Keys proper and 12 in Dry Tortugas). Dry Tortugas data are presented separately because sampling there was not initiated until 1999.

Stony Coral Species Richness

Sanctuary-wide from 1996 to 2002, the number of stony coral species declined at 74 stations (70%), increased at 21 stations (20%), and remained unchanged at 10 stations (10%) (Table 1). In 2002, the project documented a decline in stony coral species number in all habitat types (Figure 3). The offshore deep and patch reef stations had the greatest numbers of stony coral taxa, with 18 and 16 species, respectively. Hardbottom stations contained the fewest, averaging nine species per station. Looe Key Shallow Station 2 displayed a maximum gain of four stony coral species, and Grecian Rocks Station 1 had the greatest loss in stony coral species number (9) at a single station.

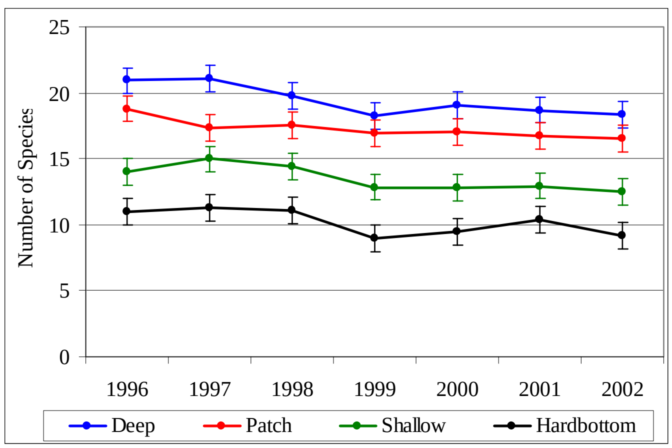


Figure 3. Mean species number by habitat type Sanctuary-wide, 1996-2002.

Between 1996 and 2002, the number of stony coral species declined at 21 of 29 (72%) patch reef stations, increased at 3 stations, and remained unchanged at 5 stations (Table 1). For shallow reef stations, the number of stony coral species declined at 28 of 39 (72%), increased at 10 stations, and remained unchanged at one station. The number of stony coral species declined at 19 of 26 (73%) deep reef stations, increased at 5 stations, and remained unchanged at 2 stations. For hardbottom stations, the number of stony coral species declined at 6 of 11 (55%) stations, increased at 3 stations, and remained unchanged at 2 stations.

Table 1. Number of stations with change in species number by habitat type.

	Patch Stations with:			**Shallow** Stations with:			**Deep** Stations with:			**Hardbottom** Stations with:			**Total** Stations with:		
Years	No Change	Gain	Loss	No Change	Gain	Loss	No Change	Gain	Loss	No Change	Gain	Loss	No Change	Gain	Loss
96vs97	5	3	21	6	24	9	4	11	11	1	6	4	16	44	45
97vs98	7	13	9	7	10	22	4	4	18	2	4	5	20	31	54
98vs99	7	8	14	6	6	27	5	4	17	1	0	10	19	18	68
99vs00	8	12	9	8	14	17	7	14	5	2	5	4	25	45	35
00vs01	5	11	13	9	17	13	3	9	14	1	7	3	18	44	43
01vs02	6	11	12	8	12	19	5	10	11	1	4	6	20	37	48
96vs02	5	3	21	1	10	28	2	5	19	2	3	6	10	21	74

In the Upper Keys from 1996 to 2002, the number of stony coral species declined at 23 of 30 stations (77%), increased at 2 stations, and remained unchanged at 5 stations (Figure 4).

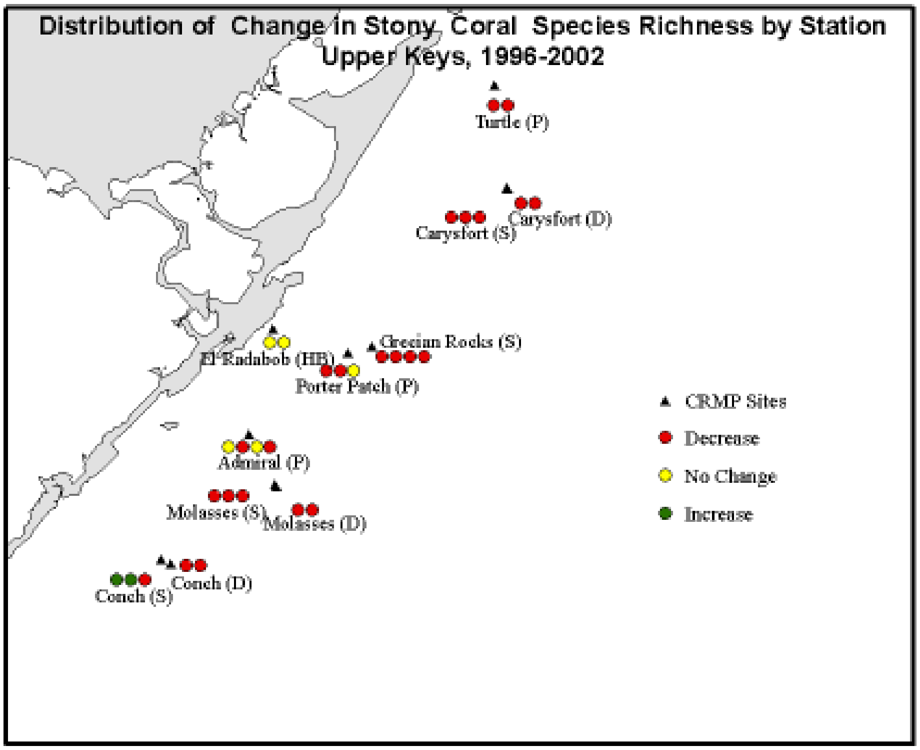


Figure 4. Distribution of change in stony coral species richness 1996-2002, Upper Keys stations.

In the Middle Keys, the number of stony coral species decreased in 20 of 29 stations (69%), increased in 7 stations, and remained unchanged in 2 stations (Figure 5).

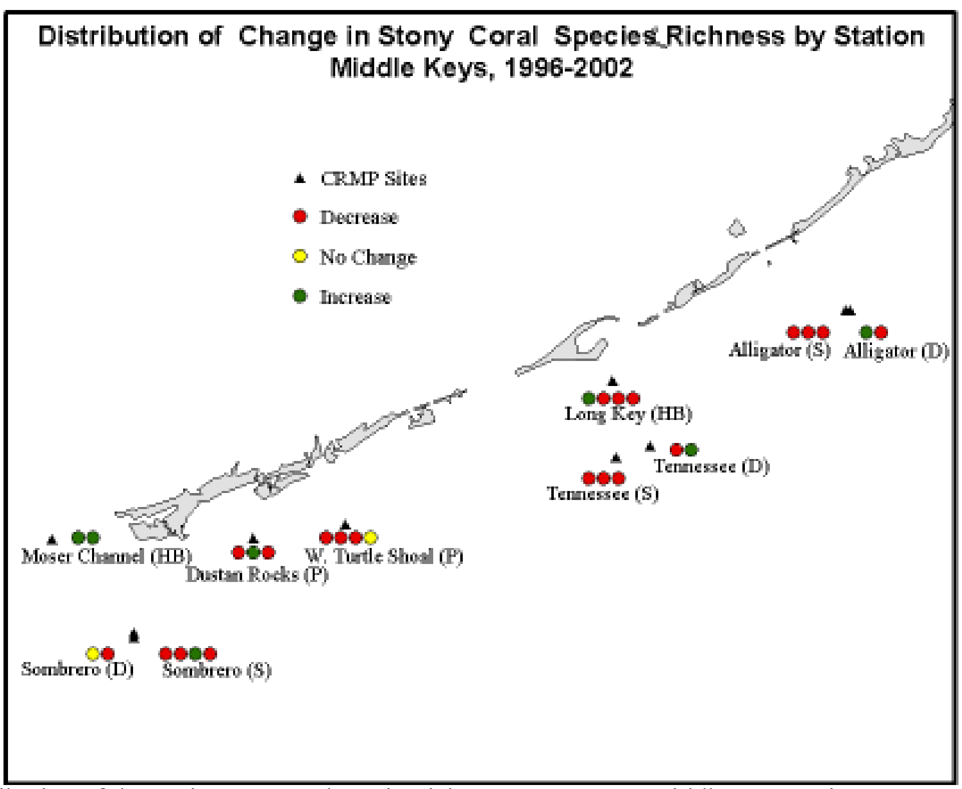


Figure 5. Distribution of change in stony coral species richness 1996-2002, Middle Keys stations.

In the Lower Keys, the number of stony coral species decreased at 31 of 46 stations (67%), increased at 12 stations, and remained unchanged at 3 stations (Figure 6).

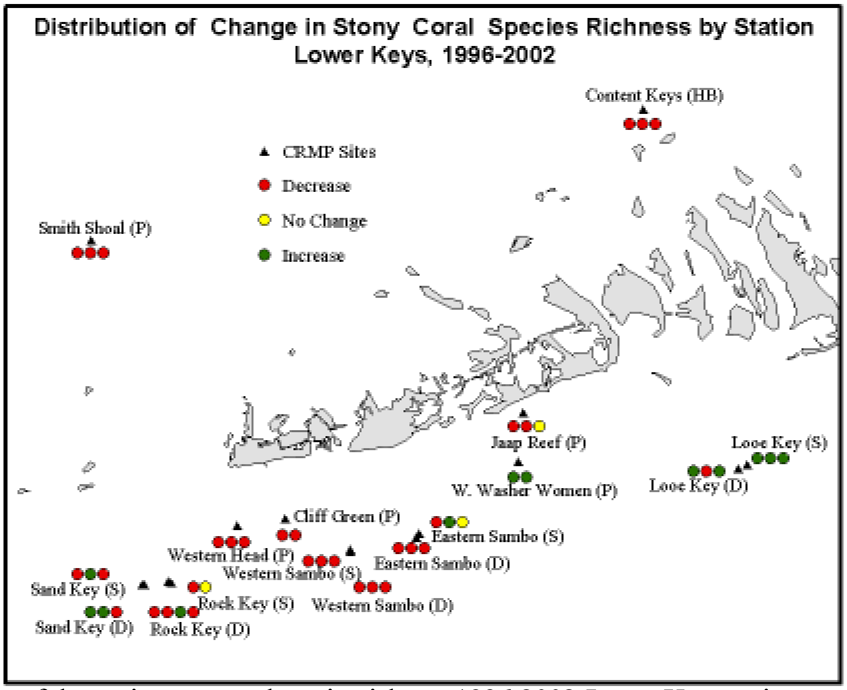


Figure 6. Distribution of change in stony coral species richness 1996-2002, Lower Keys stations.

In the Dry Tortugas from 1999 to 2002, the number of stony coral species decreased at 9 stations and increased at 3 stations (Figure 7).

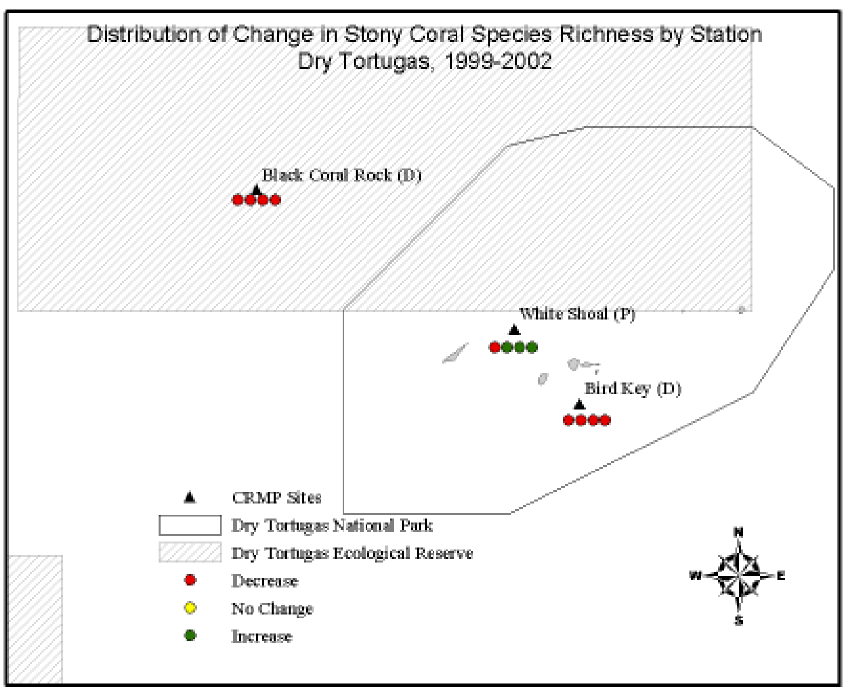


Figure 7. Distribution of change in stony coral species richness 1999-2002, Tortugas stations.

Sanctuary-wide, the number of stations where *Acropora cervicornis* and *Scolymia lacera* were present decreased significantly (α=0.05) while the number of stations with *Copolphyllia natans, Madracis mirabilis, Porites porites, Siderastrea radians, Mycetophyllia ferox* and *M. lamarkiana* decreased at the α=0.1 level. Only *Siderastrea siderea* was found at significantly more stations in 2001-2002 than in previous years.

Stony Coral Condition

Diseases are recorded as either present or absent for each species at a station. In general, the number of stations documented as having diseased corals increased from 1996 to 2002 (Figure 8). Overall, the number of stations containing diseased coral, the number of species with disease, and the different types of diseases observed all increased.

As in previous sampling periods, black band disease was the least common of the disease categories recorded by the project. The number of stations with black band disease was highest in 1998 (19 of 105 stations). In all other years, black band disease was recorded at less than ten stations. The species most commonly affected by black band disease were *Colpophyllia natans*, *Montastraea annularis*, *M. cavernosa*, and *Siderastrea siderea*.

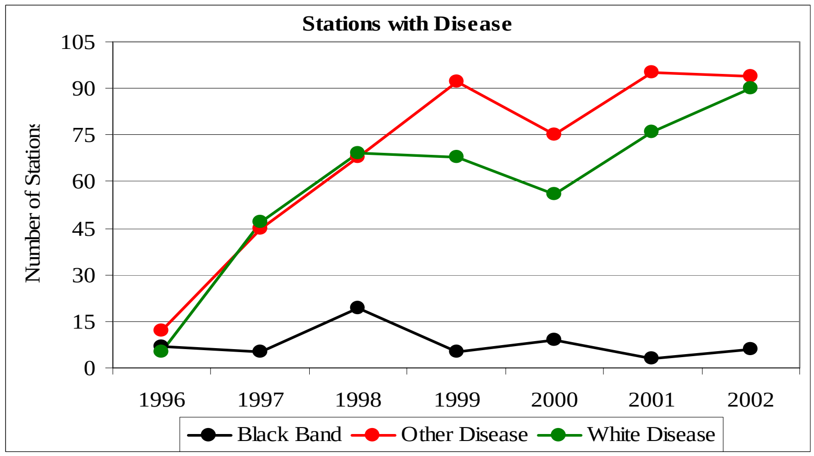


Figure 8. Incidence of coral disease at CREMP stations 1996-2002.

The occurrence of white disease increased from five stations in 1996 to 90 stations in 2002. This increase was primarily driven by increases in white disease in *Montastraea annularis* complex, *Agaricia agaricites* complex, *Porites astreoides*, and *Siderastrea siderea* colonies. In 1996, *M. annularis* complex at all CREMP sites were free from white disease. By 2001, *M. annularis* complex at 32 stations were affected.

White disease was not found to have affected any *A. agaricites* colonies during 1996, but by 2001 white disease was observed on *A. agaricites* at 33 sites. This number had decreased to 27 stations in 2002. Incidence of white disease also increased in *P. astreoides* from zero stations in 1996, to six stations in 2001, and then 12 in 2002. The maximum value previously reported was 11 stations observed in 1997. Incidence of white disease in *S. siderea* increased from four stations in 2001 to 21 stations in 2002. The previous maximum occurrence for this species was 12 stations in 1997.

For adequate data for statistical testing, 2001 and 2002 disease data was pooled for comparison with 1996-2000 data. For the pooled 2001 and 2002 data, testing indicated that *Agaricia agaricites* complex, *Montastraea annularis* complex, *M. cavernosa, Siderestrea siderea*, and *Stephanocoenia michelinii* were affected by white disease at a significantly greater number of stations than the 1996-2000 data (Figure 9).

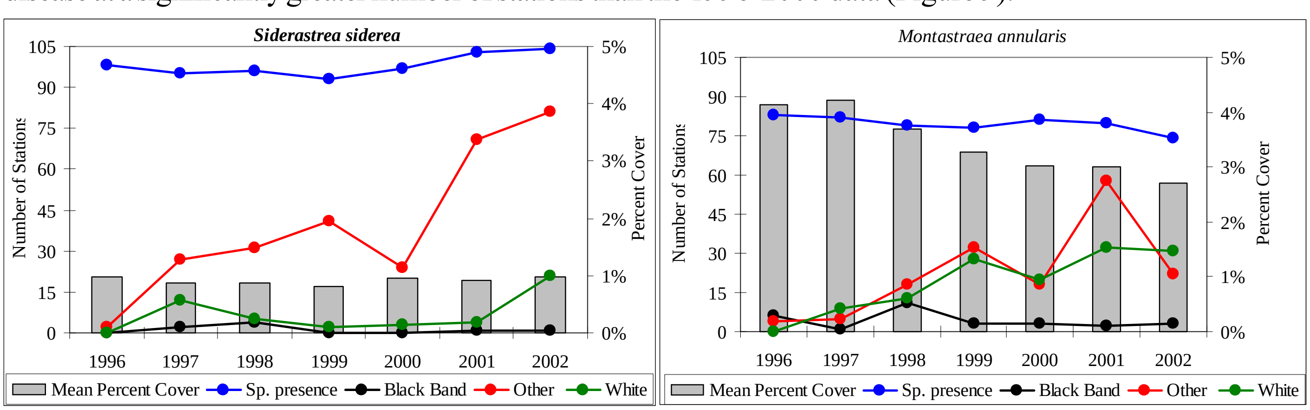


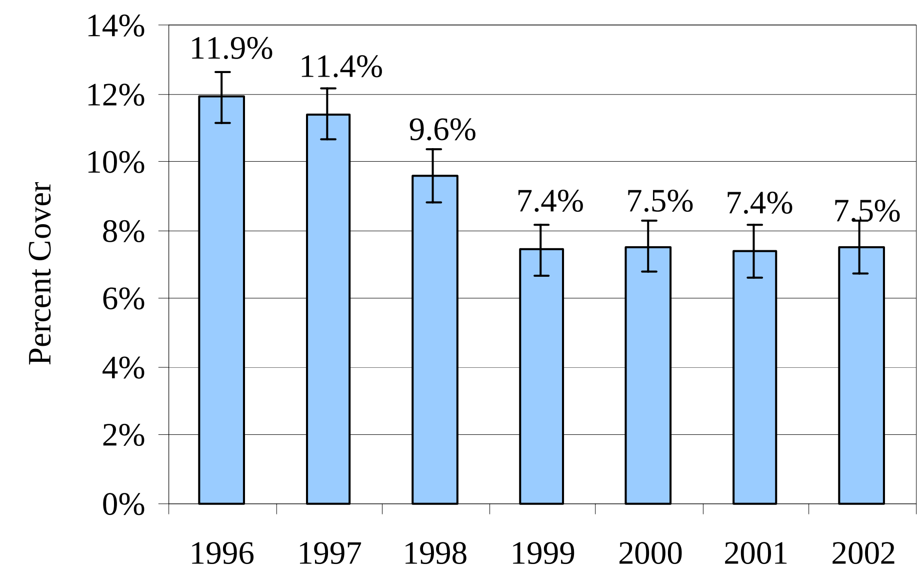
Figure 9. *Siderastrea siderea* and *Montastrea annularis* disease incidence, occurrence and percent cover Sanctuary-wide.

For the purpose of hypothesis testing, the "other disease" data for 2001-2002 were pooled and compared with the data from 1996 - 2000 to determine significant changes in the number of stations where each species was affected by "other disease". Tests indicate that 14 species had significant increases in the number of stations where "other disease" was detected. These species include: *Agaricia agaricites* complex, *Colpophyllia natans*, *Dichocoenia stokesii*, *Eusimilia fastigiata*, *Favia fragum*, *Meandrina meandrites*, *Millepora alcicornis*, *Millepora complanata*, *Montastraea cavernosa*, *Montastraea annularis* complex, *Porites astreoides*, *Porites porites*, *Siderastrea siderea*, and *Stephanocoenia michelinii*.

Pooled data for 2001-2002 was compared with pooled data for 1996-2000 to determine significant differences in the number of sites where bleaching affected each species. Bleaching affected *Agaricia agaricites* complex, *Montastraea annularis* complex, and *Montastraea cavernosa* at an increased number of sites during the 2001-2002 period.

Stony Coral Cover

Between 1996 and 2002, a 38% decline in stony coral cover was observed Sanctuary-wide (Figure 10). This trend was confirmed by non-parametric hypothesis testing at the sanctuary level. The decline in mean percent coral cover from 1997 to 1998 and from 1998 to 1999 was significant with a *p*-value of 0.03 or less for the Wilcoxon rank-sum test. Between 1997 and 1998 coral cover declined from 11.4% to 9.6%. The downward trend continued between 1998 and 1999 when coral cover declined from 9.6% to 7.4%. The changes observed from 1999 to 2002 were determined to be statistically insignificant. Sanctuary-wide coral cover has not changed significantly since 1999.



* Revised to include 105 stations remaining after station reduction.

Figure 10. Mean percent stony coral cover Sanctuary-wide, 1996-2002.*

At the regional and habitat levels, hypothesis testing compared 2002 coral cover data to pooled 1998-2001 data as well as pooled 1999-2001 data. Regionally stony coral cover reflected the patterns observed Sanctuary-wide. In all three geographical areas, a significant decrease in stony coral cover was observed between 1996 and 1998. Comparisons between 1998-2001 pooled data and 2002 data indicate significant decreases in stony coral cover within the Upper and Lower Keys regions. Comparisons between 1999-2001 pooled data and 2002 data detected no significant differences in stony coral cover for any region (Table 2).

Table 2. Results of hypothesis testing for significant change in mean stony coral cover by region.

Time Period	Upper Keys		Middle keys		Lower Keys		Sanctuary-Wide	
	p-value	ά=0.05	p-value	ά=0.05	p-value	ά=0.05	p-value	ά=0.05
96-98	0	Yes	0	Yes	0	Yes	0	Yes
98-02	0.01	Yes	0.11	No	0	Yes	0	Yes
99-02	0.96	No	0.94	No	0.46	No	0.85	No

Hypothesis testing of stony coral cover by habitat type for the periods 1996-1998 vs. 2002 and 1998-2001 vs. 2002 indicate a significant loss of stony coral cover for patch reef, shallow reef and deep reef habitats. Hardbottom habitats were not included in regional analysis of stony coral cover due to insufficient sample size. There was no indication of significant loss in stony coral cover for the period 1999-2001 vs. 2002.

Stony coral cover by habitat type is provided in Figure 11. The greatest mean percent of stony coral cover was consistently observed at patch reef stations. Though deep sites had the greatest number of species present, the percent stony coral cover was consistently lower there than at their shallow counterparts. At patch reef sites, coral cover increased significantly at 10 (34%) stations, increased at 4 (14%) stations and remained unchanged at 15 (52%) stations. For offshore shallow sites, coral cover has decreased significantly at 33 (85%) stations, and was statistically unchanged at 6 (15%) stations, while no stations had a significant gain in coral cover. In the offshore deep habitat, coral cover has decreased significantly at 13 (50%) stations, was statistically unchanged at 13 (50%) stations, and no stations showed a significant gain in coral cover (Table 3). Overall, there were significant losses in stony coral cover at 71% of offshore reef stations, both shallow and deep.

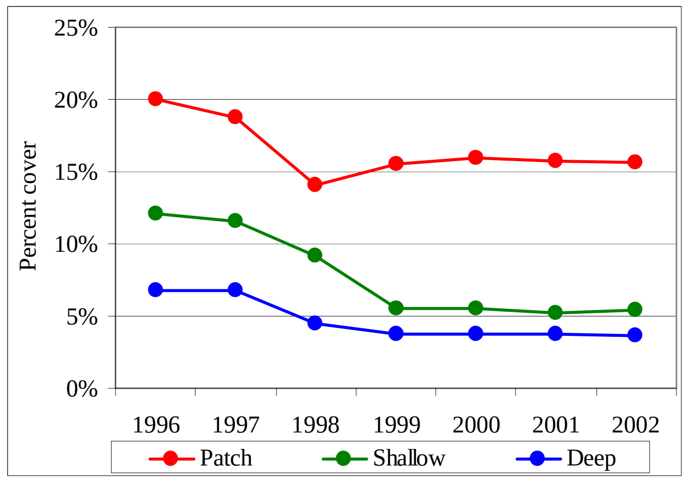


Figure 11. Mean percent stony coral cover by habitat type Sanctuary-wide, 1996-2002.

Table 3. Number of stations with statistically significant change in coral cover by habitat type, 1996-2001 versus 2002.

Habitat	**Patch Reefs**			**Shallow Reefs**			**Deep Reefs**			**Hardbottom**			**Total**		
Status	Loss	Gain	NC	Loss	Gain	NC	Loss	Gain	NC	Loss	Gain	NC	Loss	Gain	NC
Upper Keys	3	2	4	11	0	2	4	0	2	-	-	-	18	2	8
Middle Keys	1	1	5	7	0	3	1	0	5	1	0	5	10	1	18
Lower Keys	6	1	6	15	0	1	8	0	6	0	3	0	29	4	13
Total	10	4	15	33	0	6	13	0	13	1	3	5	57	7	39
Percent	34.48	13.79	51.72	84.61	0.00	15.39	50.00	0.00	50.00	11.11	33.33	55.56	55.34	6.80	37.86

Station-level hypothesis testing compared 2002 stony coral cover data to pooled 1996-2001 data. For the 103 stations with sufficient stony coral cover for analysis, 57 (55%) stations had a significant decrease in stony coral cover, 39 (38%) stations showed no significant change, and only seven (7%) stations had significant gains.

In the Upper Keys, 18 stations (64%) lost significant coral cover while two stations (7.1%) gained coral and eight stations (28.5%) remained unchanged.(Figure 12, Table 3).

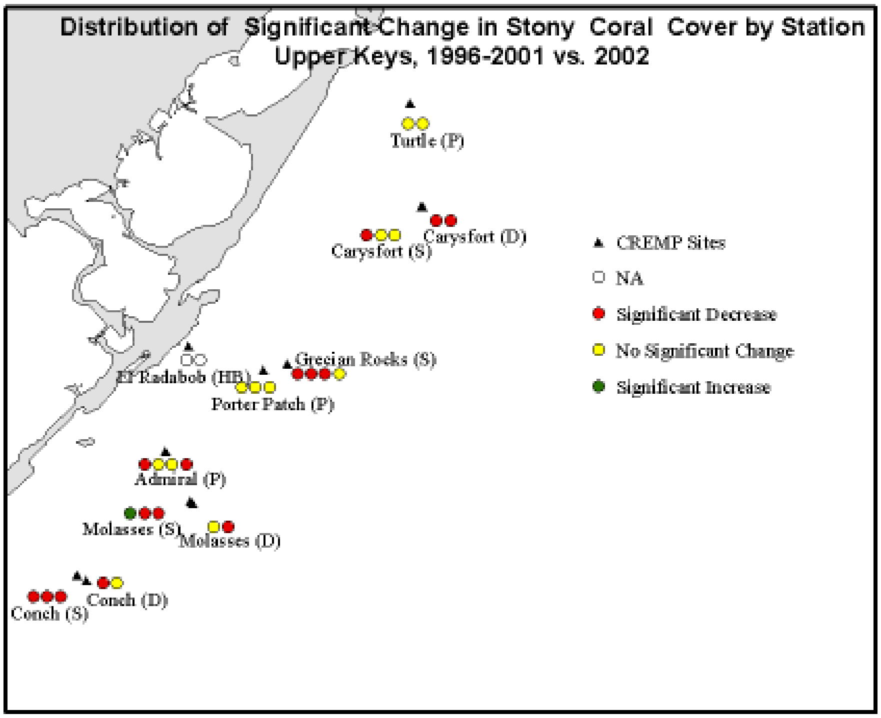


Figure 12. Distribution of significant change in stony coral cover at Upper Keys stations, 1996-2001 vs. 2002.

In the Middle Keys, a significant amount of coral cover was lost at 10 (34%) stations, no significant change was seen at 18 (62%) stations, and a significant amount of coral cover was gained at 1 station (Figure 13, Table 3).

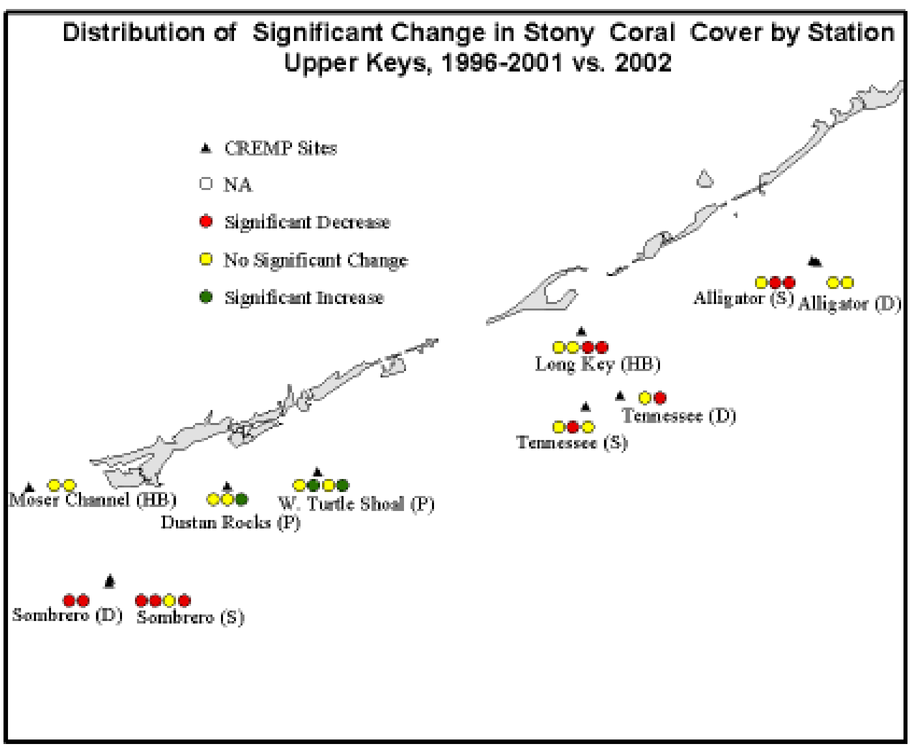


Figure 13. Distribution of significant change in stony coral cover at Middle Keys stations, 1996-2001 vs. 2002.

In the Lower Keys, a significant amount of coral cover was lost at 29 (63%) stations, no significant change was seen at 13 (28%) stations, and a significant amount of coral cover was gained at 4 stations (Figure 14, Table 3).

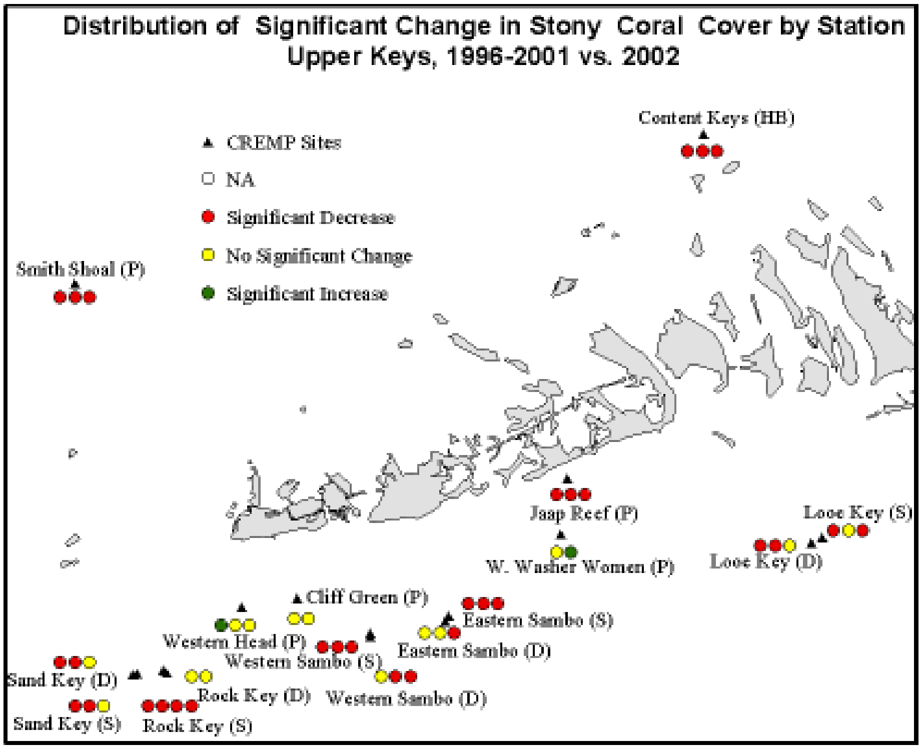


Figure 14. Distribution of significant change in stony coral cover at Lower Keys stations, 1996-2001 vs. 2002.

In the Dry Tortugas in 2002, a significant amount of coral cover was lost at 8 stations, while no significant change was seen at 4 stations. (Figure 15).

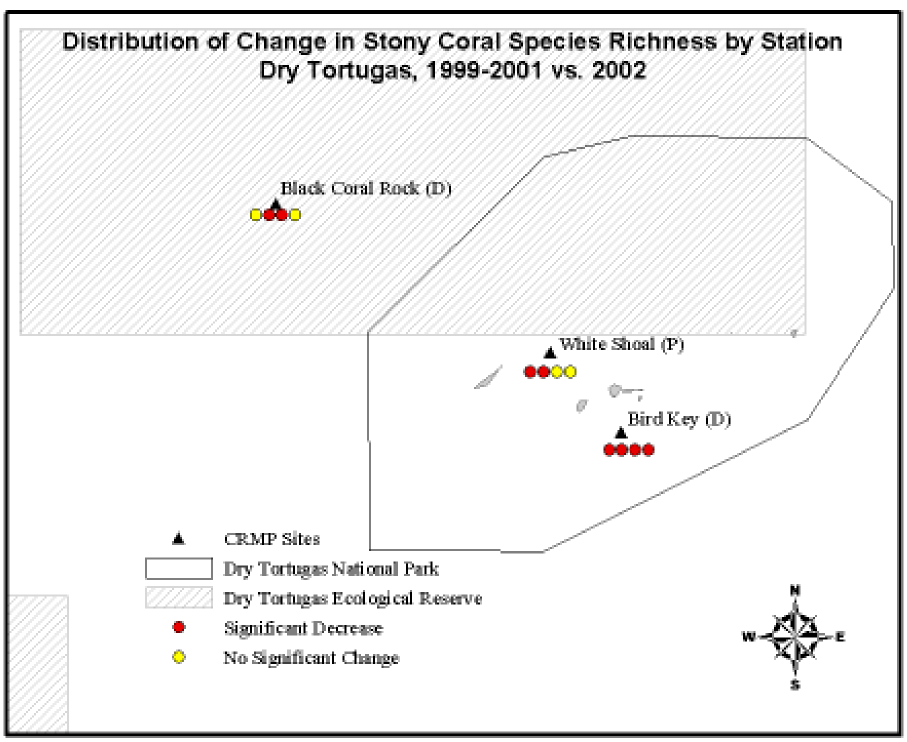


Figure 15. Distribution of significant change in stony coral cover at Dry Tortugas stations, 1999-2001 vs. 2002.

Functional Group Cover

Percent cover data for functional groups in the geographic regions studied from 1996 to 2002 were analyzed (Figure 16). Functional groups included: stony corals, octocorals, zoanthids, sponges, macroalgae, seagrass, and substrate (rock, rubble and sediments). In the Upper Keys from 2001-2002, macroalgae and octocoral cover increased slightly, while stony coral and sponge cover remained unchanged. The Lower Keys had a decrease in macroalgal cover and a slight increase in octocoral cover. Stony coral and sponge cover remained unchanged. The Middle Keys had a significant decrease in macroalgal cover and a significant increase in octocoral cover. All other components of the Middle Keys benthic community remained unchanged. Sanctuary-wide, in 2002, the benthic community within CREMP sites was composed of 66.8% substrate, 11.0% octocoral, 9.3% macroalgae, 7.5% stony coral, 2.5% sponge, 2.2% zooanthids, and 0.6% seagrass.

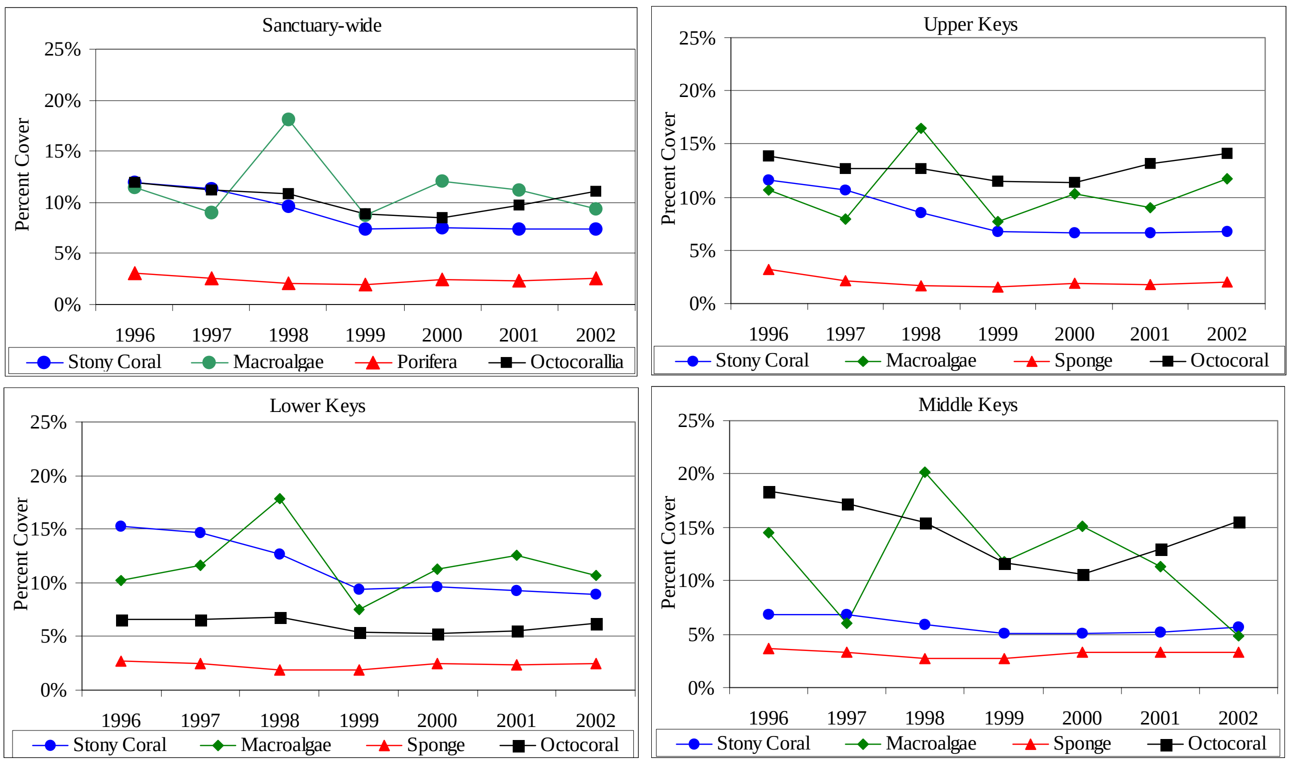


Figure 16. Mean percent cover of functional groups by region, 1996-2002.

Stony Coral Species Cover

An understanding of the overall trend in stony coral cover can be gained by analyzing the changes in percent cover of the most common species. In Figure 17, the six coral species with the greatest mean percent cover sanctury-wide in 1996 were *Montastraea annularis* (4.1%), *M. cavernosa* (1.4%), *Acropora palmata* (1.1%), *Siderastrea siderea* (1.0%), *Millepora complanata* (1.0%), and *Porites astreoides* (0.6%). *M. annularis* represented approximately 35% of the coral cover at CREMP stations in 1996. *M. annularis* decreased from 4.1% in 1996 to 2.7% in 2002 (a 34% reduction). *M. cavernosa* decreased from 1.4% in 1996 to 1.3% in 2002.

Although *Acropora palmata* (elkhorn coral) only occurs in offshore reef habitats sampled, and comprised only 1.1% of the mean coral cover in 1996, it is well recognized as a primary framework species. Striking changes were documented for this species as well as, *A. cervicornis* (staghorn coral), and *Millepora complanata* the once dominant shallow reef bladed fire coral. The mean percent cover of *A. palmata* decreased 91% from 1.1 in 1996 to 0.1 in 2002. Between 1996 and 2002 percent cover of *A. cervicornis* decreased 94%, from 0.20 to a barely detectable 0.01. Also between 1996 and 2002, percent cover of *M. complanata* declined from 1% to 0.03% (Figure 17).

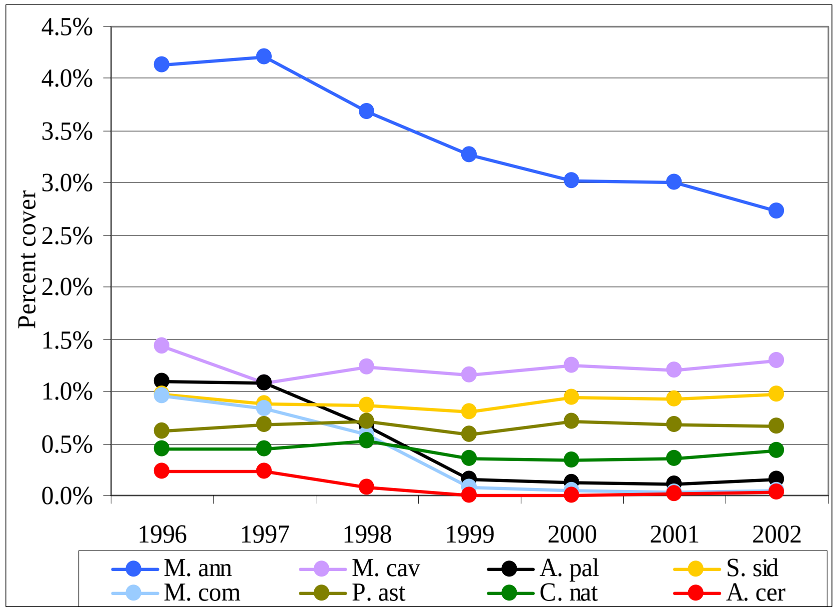


Figure 17. Mean percent cover of selected stony coral species, Sanctuary-wide, 1996-2002.

Bio-eroding Sponge Data

In the Upper Keys, the number of clionids colonies decreased at all stations except the deep stations. All except Upper Keys deep stations displayed a decrease in the number of clionid colonies. In 2002, the mean area of clionid sponge cover was greatest at patch reef stations in the Lower Keys (Table 4). The greatest average number of colonies was seen at Upper Keys deep stations (109) followed by Lower Keys deep stations (53), and then the Lower Keys patch (44). Two stations had significant decreases in the number of colonies present. At Content Keys stations, the mean number of clionid colonies decreased from 35 in 2001 to zero in 2002. Likewise, at Smith Shoal stations the average number of clionid colonies decreased from 46 in 2001 to zero in 2002.

Table 4. Clionid sponge abundance and cover by habitat type and region, 2001-2002.

Site Type	Number of Stations	Avg. Area (cm^2) per Station 2001	2002	Avg. # of Colonies per Station 2001	2002	Avg. Colony Size (cm^2) 2001	2002
Dry Tortugas							
Patch	4	59.4	3.1	3.5	0.3	17.0	72.6
Deep	8	1,185.9	717.2	16.6	9.9	71.3	12.5
Total	**12**	**810.4**	**479.2**	**12.3**	**6.7**	**66.2**	**71.9**
Lower Keys							
Patch	13	1,422.1	1,234.6	7.5	3.4	188.6	364.8
HB	3	2,300.0	0.0	11.7	0.0	197.1	0.0
Shallow	16	28.1	8.6	2.3	0.7	12.5	12.5
Deep	14	189.3	78.6	5.1	3.8	36.8	20.8
Total	**46**	**619.3**	**375.8**	**5.2**	**2.3**	**118.2**	**160.1**
Middle Keys							
Patch	7	292.9	191.1	2.6	2.0	113.9	95.5
HB	6	206.3	0.0	0.2	0.0	1,237.5	0.0
Shallow	10	1,078.8	461.3	0.3	0.5	3,595.8	922.5
Deep	6	552.1	504.2	8.0	2.8	69.0	177.9
Total	**29**	**599.6**	**309.5**	**2.4**	**1.2**	**248.4**	**249.3**
Upper Keys							
Patch	9	19.4	13.9	1.0	0.7	19.4	20.8
HB	2	0.0	0.0	0.0	0.0	0.0	0.0
Shallow	13	44.2	27.9	1.8	0.9	24.0	30.2
Deep	6	343.8	474.2	16.7	18.2	20.6	26.1
Total	**30**	**93.8**	**111.1**	**4.4**	**4.2**	**21.1**	**26.2**

Human Enterovirus Screening

Over 100 types of viruses can be found in human sewage. These pathogens are spread through the fecal-oral route, such that ingestion of contaminated material results in infection. This can occur by drinking contaminated water, recreational exposure (incidental ingestion during swimming) or by eating contaminated foods such as shellfish. Many cause infection with a very low dose (~10 viruses). Furthermore, enteric viruses can cause acute diseases from severe gastroenteritis to paralysis, diabetes and hepatitis. Viruses can also be used as markers of human sewage in the environment because humans are the sole host. Fecal coliform and other indicator bacteria in the environment may have non-human sources.

This study targets two enteric viral groups. Enteroviruses are a wide group of single stranded RNA viruses which include polioviruses, coxcakieviruses and echoviruses. Approximately 75 enterovirus types are currently known. These viruses are well studied and have been used more than any other viral group for environmental surveillance for wastewater contamination. The study also targets the double stranded DNA adenoviruses. While adenoviruses commonly cause upper respiratory infections they are also the most common viruses found in human sewage. They have been used as contamination proxies only recently but many researchers suggest that they are an excellent tool in environmental work. Furthermore, double stranded DNA viruses are suspected to survive in the environment longer than enteroviruses (RNA). Assaying for both virus types in water column and coral mucus samples allows a better assessment of potential contamination. Replicate coral mucous samples were collected from each of the 40 sites. Genetic screening for human enteroviruses is ongoing through collaboration with the U.S.Geological Survey Center for Coastal Studies.

Value Added Station Sampling

Disease Coral Survey (DCS)

Disease Coral Surveys were successfully completed at 18 Value Added Stations at 9 CREMP sites. Only half of the transect area was surveyed at West Turtle Shoal station 4 due to underwater time limitations to sample this heavily populated station.

Overall 323 diseased coral colonies of 22 different species were recorded at 18 stations. A total of 12 different known coral diseases and bleaching affected coral colonies at CREMP Value Added Sites (Figure 18).

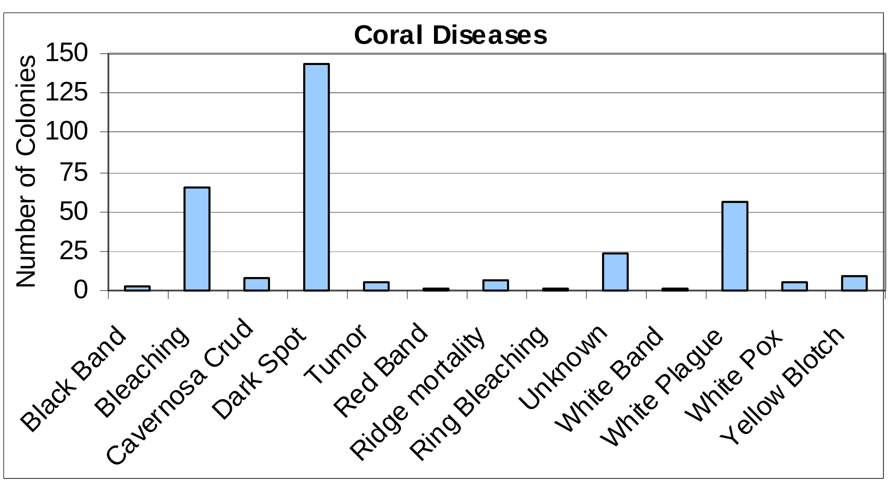


Figure 18. Number of stony coral colonies affected by specific diseases within CREMP Value Added Sites during 2002.

Figure 19 shows the 11 species that were most commonly affected by coral disease. *Siderastrea siderea*, and *Montastraea annularis* were both affected with 4 diseases, while both *Stephanocoenia michelinii,* and *M. cavernosa* were affected by 3 diseases each. All others were affected by 2 or fewer diseases. *Siderastrea siderea* was most commonly affected by what has been termed "Dark Spot" disease. It should be noted that although this malady was very common during the 2002 sampling period, "Dark Spot" disease had virtually disappeared from Middle Keys Value Added Stations by June of 2003. Black Band, White Plague, Bleaching and an unknown malady affected *M. annularis* complex colonies. In addition to *M. annularis* colonies, bleaching affected *M. cavernosa, S. siderea, S. radians, Copolphyllia natans, Porites astreoides*, and *Favia fragum*.

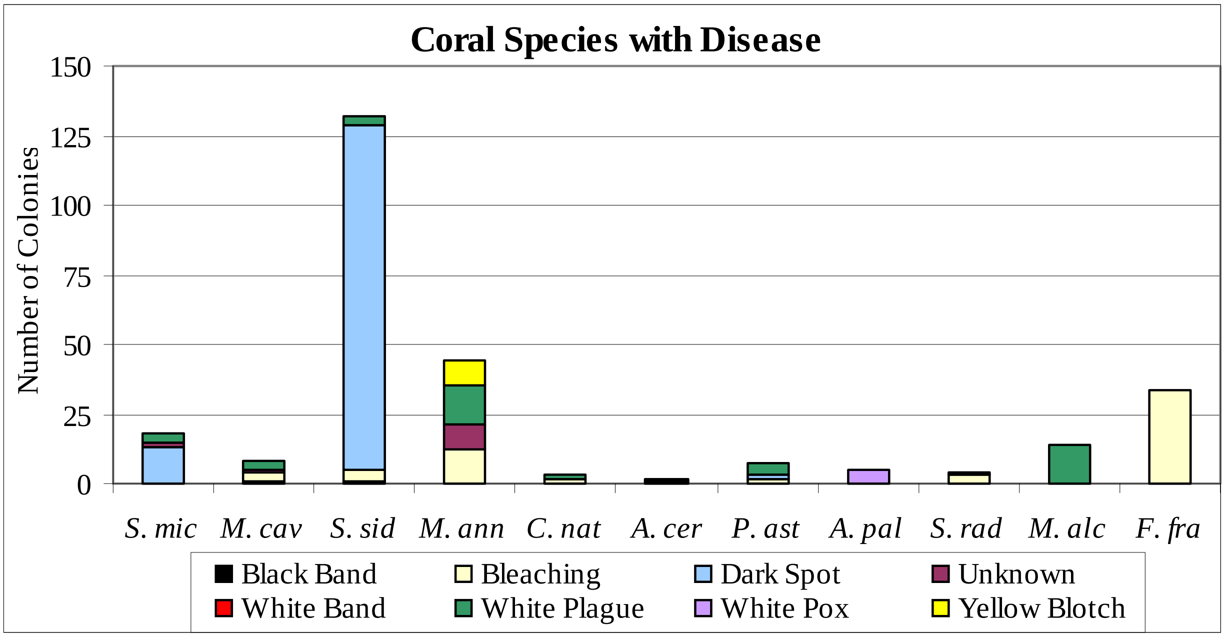


Figure 19. Number of colonies of selected species affected by diseases within CREMP Value Added Sites during 2002.

Diseased surface area tracings have been completed for all diseased colonies at 9 of the 18 stations (50% of the survey image analysis is complete as of March 2003). These data will be integrated with the colony count data from the Value Added Stations, as well as with the projected stony coral cover data obtained from underwater videos (PointCount), to estimate the percent projected surface area of all species present in a transect that is affected by disease.

Preliminary review of the data indicate widespread existence of coral disease among nearly all coral species recorded at CREMP Value Added Stations. Cases of infection by all of the Caribbean coral diseases that can be distinguished underwater were identified.

Coral abundance was assessed at all 18 Value Added Stations (VAS). A wide range of community indices were calculated from VAS species date. Species Richness ranged from 7 to 26 while species diversity (H') ranged from 0.82 to 2.51. Abundance values also varied greatly ranging from 18 colonies at Grecian Rocks station 2 to over 500 colonies at Cliff Green station 4. Table 5 presents calculated community values and indices for all stations.

Table 5. Coral community values and indices for all CREMP Value Added Stations.

Station	Number of Species	Number of Colonies	Density	D	H' log base2	J'	1-Lambda
ER 2	8	56.75	2.84	1.73	0.82	0.39	0.35
ER 4	7	61.5	3.08	1.46	0.9	0.46	0.42
PP 1	10	115	5.75	1.9	1.88	0.81	0.82
PP 2	13	128	6.4	2.47	1.99	0.78	0.83
GR 1	7	27.5	1.38	1.81	1.66	0.85	0.79
GR 2	8	18.33	0.92	2.41	1.91	0.92	0.88
LK 1	14	108	5.4	2.77	1.62	0.61	0.69
LK 2	14	92	4.6	2.87	1.65	0.62	0.65
WT 3	26	399.33	19.97	4.17	2.51	0.77	0.88
WT 4	22	222.33	11.12	3.89	2.22	0.72	0.85
TN 2	12	109.33	5.47	2.34	1.68	0.68	0.73
TN 3	10	136.5	6.83	1.83	1.58	0.69	0.75
JR 1	7	49.5	2.48	1.54	1.41	0.73	0.71
JR 2	9	36	1.8	2.23	1.74	0.79	0.8
CG 3	23	261	13.05	3.95	2.16	0.7	0.81
CG 4	26	502.5	25.13	4.02	2.21	0.68	0.81
WS 1	9	89	4.45	1.78	1.68	0.77	0.75
WS 2	12	136.5	6.83	2.24	1.63	0.66	0.72

The typical coral community at a CREMP Value Added Station contained 176 colonies representing thirteen coral species (Figure 20). Size classes for colonies were 0-3cm, 3-10cm, 10-50cm and greater that 50cm. Twenty-two percent of coral colonies were in the 0-3cm size class while 46% of colonies were 3-10cm, 26% of colonies were 10-50cm and 10% were over 50cm.

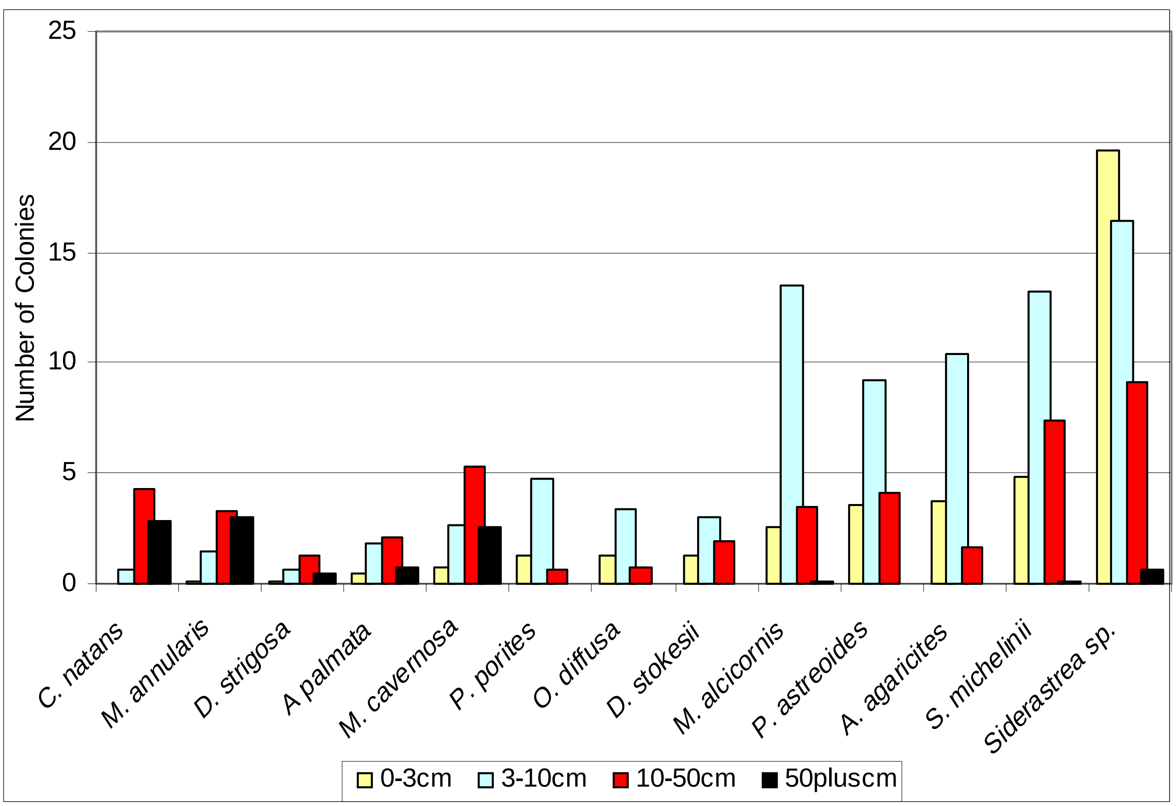


Figure 20. Mean coral community composition and size class distribution at CREMP Value Added Stations 2002.

Sidereatrea sp. had the greatest mean number of colonies in the 0-3cm, 3-10cm, and 10-50cm size classes with 19.6, 16.4 and 9.1 colonies per station respectively. Other common corals in the 3-10cm size class include *M. alcicornis* (mean 13.52 colonies/station), *Stephanocoenia michelinii* (mean 13.27 colonies/station), and *Agaricia agaricites* (mean 3.27 colonies/station). In addition to *Siderastraea sp*., common corals in the 10-50cm size class included *S. michelinii* (mean 7.35 colonies/station), *Porites astreoides* (mean 4.15 colonies/station) and *M. alcicornis* (mean 3.48 colonies/station). The most common coral species over 50cm include *Montastraea annularis* (mean 3.04 colonies/station) *Copolphyllia natans* (mean 2.83 colonies/station) and M. *cavernosa* (mean 2.52 colonies/station) (Table 6).

Table 6. Mean number of colonies per station for each size class for selected coral species from CREMP Value Added Stations during 2002.

Species	0-3cm	3-10cm	10-50cm	50pluscm
C. natans	0	0.67	4.33	2.83
M. annularis	0.07	1.44	3.33	3.04
D. strigosa	0.13	0.63	1.31	0.5
A palmata	0.43	1.86	2.14	0.71
M. cavernosa	0.74	2.61	5.29	2.52
P. porites	1.3	4.73	0.61	0
O. diffusa	1.31	3.38	0.75	0
D. stokesii	1.32	3	1.95	0
M. alcicornis	2.52	13.52	3.48	0.06
P. astreoides	3.58	9.23	4.15	0
A. agaricites	3.72	10.44	1.67	0
S. michelinii	4.81	13.27	7.35	0.08
Siderastrea sp.	19.6	16.43	9.1	0.64

DISCUSSION & CONCLUSIONS

From its inception in 1996, the Coral Reef Evaluation Monitoring Project (CREMP) has documented long-term changes in the status and trends of coral reefs throughout the 2,800 square nautical mile FKNMS. The data set produced from this monitoring effort has been, and will continue to be, an indispensable asset for sound resource management decisions. Between 1996 and 2002, the project reported a 38% reduction in stony coral cover sanctuary-wide. A steep decline in percent cover of stony corals was documented between 1997 and 1999. From 1999 to 2002, the percent cover of stony corals has remained essentially unchanged.

Hypothesis testing documented a significant loss in stony coral cover at 55% of project stations and a significant increase at only 7%. By region, the Upper Keys experienced the greatest decline with significant losses in coral cover at 64% of stations; the Lower Keys lost cover at 63% of stations; and the Middle Keys lost cover at 34% of stations. The greatest declines in coral cover occurred between 1996-1999. Coral cover declined from 11.9% in 1996 to 7.4% in 1999. Since 1999, percent cover at CREMP sites varied less than 0.1% per year. Statistical analysis has determined no significant difference in percent coral cover between 1999 and 2002 suggesting a halt in the decline of coral cover. This halt in coral cover decline has been recognized elsewhere as well. Wilkinson (2002) suggests that some Australian reefs that showed severe declines in coral cover during the 1997-1998 bleaching event are currently showing slow to moderate signs of recovery. Loss of stony corals, increased abundance of algae, and a dramatic increase in bleaching episodes and disease outbreaks are indications that coral reefs are deteriorating worldwide. The U.S. Coral Reef Task Force (http://coralreef.gov/threats.cfm) cites population increases, shoreline development, increased sediments in the water, trampling by tourists and divers, ship groundings, pollution, overfishing and fishing with poisons and explosives that destroy coral habitat as some of the major anthropogenic threats to corals worldwide. Increased water temperatures due to increased concentrations of greenhouse gases in the atmosphere may also have a deleterious effect on the stability of the reef ecosystem. These stressors act separately and in combination with natural factors such as hurricanes and disease to degrade reefs. Further, recent research supports a link between coral disease and anthropogenic stressors (Harvell et al., 1999; Porter et al., 1999; Shinn et al., 2000; Harvell et al., 2001; Porter et al., 2001; Patterson et al., 2002). These threats and others have contributed to an estimated 21% loss of coral reefs worldwide as of 2000 (http://www.aims.gov.au/pages/research/coral-bleaching/scr2002/scr-00.html). The major emphasis of coral reef research worldwide is to identify the causes of coral decline and assess the synergistic impact of these causes on global, regional, and local scales.

On a regional scale, the 117 CREMP stations are downstream of much of the Caribbean basin, the Gulf of Mexico, the Everglades, and Florida Bay. The interaction between these upstream regimes and the Florida Keys varies in magnitude and on many time scales. On a local scale, the 117 CREMP stations are subdivided into four habitat types based on depth, distance from shore, and biotic character. Hardbottom, patch, shallow offshore, and deep offshore reefs each have characteristic sets of stony coral species and relative percent cover. As such, we expect coral reefs in the Florida Keys to respond to stress on multiple scales of space and time.

Since the beginning of the CREMP in 1996, a series of stress events, occurring in quick succession, appear to be responsible for the most recent declines in coral cover and species diversity. Global bleaching events in 1997 and 1998 were severe to moderate and resulted in increased stress, instigating morbidity and mortality in some Cnidarian species. Elevated water temperatures were thought to be the cause of high mortality in *Millepora complanata* in Lower and Middle Keys offshore shallow reefs during this period. Although short lived, hurricanes can cause significant adverse affects to the coral reef community on regional and local scales. Gardner (2002) claims that Florida reefs historically exhibited an average 6.5% loss in coral cover within one year of the occurrence of a hurricane. Hurricane Georges, which hit the Keys in 1998, resulted in coral losses of up to 44% at some locations (J. Dotten Pers. Comm.).

The decline in coral cover observed on Florida reefs is similar to declines reported for reefs elsewhere in the Caribbean and Gulf of Mexico. Linton et al. (2002) report that coral cover in the Bahamas has declined from 9.6% in 1994 to 4.0% in 2001. Bermuda reefs have displayed less precipitous declines, with coral cover decreasing from 23% in 1993 to 18% in 2001. Coral cover in the Cayman Islands has also declined in recent years. Department of Environmental Protection and Conservation Unit data show that Little Cayman reef coral cover declined from 23% in 1997 to 16% in 2001. On Grand Cayman, coral cover declined from 25% in 1997 to 15% in 2001 (Linton et al., 2002).

Reefs of the western Caribbean and the southern Gulf of Mexico have exhibited some of the greatest losses in coral cover in recent years. Major disturbances such as hurricanes Mitch in 1998, Keith in 2000, Iris in 2001, and Isidore in 2002 have had major impacts on reefs along Belize, Honduras, and the Mexican Yucatan. Belize alone reportedly lost up to 75% coral cover on some reefs (Almanda-Villela et al. 2002). This series of hurricanes and the resultant flooding and sedimentation, and an increase in coral disease and bleaching, are expected to have long-term ecological consequences (Almanda-Villela et al., 2002)

The recovery of damaged corals appears to have slowed significantly in recent years. The impact of hurricanes on coral reefs is largely separate from the suite of other anthropogenic stressors, but these anthropogenic stressors affect the recovery of reefs following physical disturbance events. The absence of post-hurricane recovery on CREMP stations is one of dozens of such observations in the Western Atlantic. A synthesis of coral monitoring data (Connell 1997) found no clear examples of reef recovery following disturbances of any kind. Connell (1997) did find 17 clear examples of coral decline in the Western Atlantic with no subsequent recovery. This sharply contrasts with the 19 clear examples of coral decline with recovery and 10 examples of decline with no recovery, that Connell (1997) found on the reefs of the Indo-Pacific.

Declines in coral cover and numbers of species are not necessarily a recent phenomenon and are likely the result of multiple, chronic and acute stressors acting at local, regional, and global scales over long periods of time. The shifting baseline phenomenon emphasizes the importance of viewing recent CREMP results in the context of long-term dynamics in the Florida Keys.

For example, during the 1960s and 1970s, *Acropora* populations exhibited boom and bust dynamics. The populations would expand and occupy virtually all of the potential space on a reef such as Western Sambo. Spur and groove areas were densely populated with large and moderate colonies of *Acropora palmata,* while the fore reef and back reef supported dense thickets of *Acropora cervicornis*. Populations that suffered extensive destruction from hurricanes Donna and Betsy appeared to have recovered within five years.

In 1975, there were acres of *A. cervicornis* within Dry Tortugas National Park. *A. cervicornis* had grown upward to near sea level in the area west of Loggerhead Key actually causing a hinderence to navigation. In late 1977 and early 1978, a severe winter cold front reduced the temperature to about 14°C and virtually all of the *A. cervicornis* was extirpated due to hypothermia. In 1981, a disease epidemic further reduced *A. cervicornis* populations to a minor component on Florida Reef Tract.

With reduced coral cover, high temperatures, and perhaps increased nutrients, marine algae expanded rapidly in the mid 1990's. Ideally, algal control occurs as the result of grazing by herbivores and storm events. However, throughout much of the Caribbean, herbivore populations have been reduced by disease and overfishing. The long-spined sea urchin *Diadema antillarum* is known to be an important algal grazer but populations of this species have yet to recover from a Caribbean-wide die-off that occurred in 1983. CREMP data show that macroalgae percent cover is more variable than other benthic biota (Figure 16). Despite the substantial reductions in herbivore populations, percent cover of macroalgae in CREMP stations has fluctuated between 1996 to 2001 with no net increase (Figure 16) and is probably not limiting coral recovery on these reefs.

FUTURE DIRECTION

The health of the coral reefs of the Florida Keys is dependent on the quality of water along the reef tract. Because of the sensitive nature of corals, even slight changes in water quality can prove stressful for the reef. The Florida Reef Tract is under constant threat from terrestrial impacts far from the reef proper. Extensive agricultural areas, and channelization in central and southern Florida may adversely affect the quality and quantity of water delivered to the Florida Everglades and Florida Bay. As water quality is impacted by changes in the volume of water delivered to Florida Bay, reefs may decline adjacent to channel areas based on similar experiences in other locations (Tomascik and Sanders, 1985; Richmond, 1993; Furnas and Mitchell, 2001; Geister, 2001).

The Comprehensive Everglades Restoration Plan (CERP) aims to re-establish the historical flow of water through south Florida and Florida Bay. This massive project will inevitably alter biological communities and water quality in Florida Bay. Downstream of Florida Bay, the Florida Keys reef tract provides the last opportunity to quantify CERP induced changes. Therefore, continued monitoring is crucial in order to document the status and trends of coral reefs in FKNMS. In addition to the ongoing monitoring, the CREMP will expand its sampling strategy to better understand causes of coral decline and effects of multiple stressors.

The CREMP will continue non-consumptive sampling at established sites from Key Largo to Tortugas Banks to document status and trends of the coral reef ecosystem. We will continue to collect a comprehensive suite of indicators at 9 of the established 40 sites. These additional indicators will consist of a Disease Coral Survey (DCS), stony coral abundance survey, temperature measurements, rugosity measurements, and human enterovirus study. The CREMP will also reference existing data sources, such as remote sensing data and data from *in-situ* data loggers, to examine possible cause and affect relationships within the Florida Reef Tract.

RavenView™ image processing software produces video transcect mosaics that have provided time series comparison of stations for the project. A newly developed tool for this software is an automated system that selects abutting frames using all 9,000 images that provides increased accuracy in representing a station. We are testing the use of these mosaics for quantitative analyses.

The comprehensive monitoring data set on stony coral cover, species richness, bleaching, disease, bioeroders, temperature, fate tracking, human enteroviruses, and abundance will assist those developing landscape-seascape program models designed to characterize physical, chemical and biological stressors. Not only will these data assist managers in determining if the fully protected Tortugas Ecological Reserve and other Sanctuary Preservation Areas (SPA) are functioning to protect sensitive resources, it will also provide definitive feedback on the downstream effects of CERP.

ACKNOWLEDGMENTS

Laurie MacLaughlin, John Halas, Steve Baumgartner, Ben Haskall (FKNMS), Phil Murphy, Mel Parsons, Gary Collins, Fred McManus, William Kruczynski (EPA), G.P. Schmahl (FGBNMS), Lonny Anderson (KML), Captain and Crew of OSV Peter W. Anderson, Dry Tortugas National Park Staff.

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A report of FMRI pursuant to USEPA grant award number X-97468002-0, and NOAA grant award number NA16OP2554.

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