Benthic Cover on Coral Reefs of Isla de Culebra (Puerto Rico) 1991-1998 and a Comparison of Assessment Techniques

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U.S. Department of the Interior
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Abstract

Fringing, barrier and patch reefs of Isla de Culebra, Puerto Rico damaged by Hurricane Hugo (September 1989) were surveyed in 1991 and 1994 to quantify benthic cover and assess recovery of coral on the reefs. In July 1998 (three years after Hurricane Marilyn, September 1995), the same sites were resurveyed. Digital video was used to quantify benthic cover in 1998 on the four permanent transects installed at each site in 1991. In addition, photoquadrats taken in 1991 and 1994 surveys were repeated in 1998 in order to compare findings over the three survey periods and calibrate the photoquadrat datasets with the more robust digital camera dataset. As expected, results from the three surveys showed that stony coral and octocoral cover data clustered by site and not year. Scleractinian coral cover varied from 8.9% (sd=10.7) at Dewey Reef in 1991 to a mean high of 37.0% (sd=15.9) at Punta Tamarindo Grande Reef in 1998.   Mean scleractinian coral cover was consistently highest at Punta Tamarindo Grande Reef and lowest at Dewey Reef. Punta Tamarindo Grande and Dewey reefs showed an apparent increase in stony coral cover between 1991 and 1998. Windward Reef showed an increase between 1991 and 1994, but a decrease between 1994 and 1998. Recovery of damaged coral was difficult to determine due to the difficulty of analyzing the 35-mm photoquadrats.

Introduction

The coral reefs of Puerto Rico, along with those of most other northeastern Caribbean islands, are in the highest risk category worldwide for being directly threatened with degradation from multiple human activities (Burke and Maidens, 2004). The fringing, barrier, and patch reefs of Isla de Culebra, Puerto Rico have sustained acute damage from coral diseases, hurricanes [Vicente, 1989; Shinn and Halley, unpub. data (1992)], explosives, anchors, and ship groundings, as well as chronic damage from sediment runoff, sewage influx (Environmental Quality Board, 1970), and overfishing. Areas of Culebra were used for military exercises between 1902 and July 1975. Due to these activities, some land and water may be contaminated with mercury, lead, copper, magnesium, lithium, perchlorate, TNT, napalm, depleted uranium, PCBs, solvents and pesticides. In the late 1970s and early 1980s, an unknown pathogen caused white-band disease and killed an estimated 90-95% of the *Acropora palmata* in the nearby Virgin Islands (Gladfelter, 1982). In 1979, powerful ground swells from Hurricanes David and Frederic toppled most of the *A. palmata* on Culebra (Vicente, 1989) and nearby St. Croix reefs (Rogers and others, 1982). In 1983, another unknown pathogen caused a Caribbean-wide epizootic that killed nearly 97% of the sea urchins, *Diadema antillarum*, an important grazer on Western Atlantic coral reefs (Lessios and others, 1984). On 18 September 1989, Hurricane Hugo, a Category 4 hurricane on the Saffir-Simpson scale, stalled over Culebra, producing widespread damage on land and to the reefs and seagrass beds (Vicente, 1989). In September 1995, Category 3 Hurricane Marilyn inflicted damage to the terrestrial and marine environments of the northeastern Caribbean, including Culebra.

As of 1998, only a few studies had documented the status of Culebra's coral reefs and seagrass beds (Environmental Quality Board, 1970), assessed damage from specific events (Vicente, 1989), or initiated long-term studies to detect trends [Shinn and Halley, unpub. data (1992)]. Vicente (1989) reported extensive damage from Hurricane Hugo on Culebra's reefs, especially the exposed reefs east of the island, where most colonies of *A. palmata* were dead, toppled, and fragmented. *Porites porites* and *Acropora cervicornis* rubble formed piles up to 3 m deep. Little regeneration was observed nearly two years later [Shinn and Halley, unpub. data (1992)], even though these three species colonize primarily via fragmentation (e.g., Shinn, 1976; Highsmith and others, 1980). However, successful coral recruitment on the dead coral rubble was documented by Shinn and Halley [unpub. data (1992)]. Vicente (1989) reported large bare areas (termed "blow outs") in *Thalassia testudinum* and *Syringodium filiforme* seagrass beds at Tamarindo Grande, as well as burial of a *T. testudinum* bed beneath 2 ft of sand (the buried sea grass survived).

Hurricanes damage coral reefs on many levels, from simple physical destruction of reef organisms to initiating complex changes in reef structure and function. Storm-generated swells break up coral colonies and flatten the physical structure of the reef, reducing the amount of shelter available for numerous reef organisms, including fishes. Species diversity may be affected by changes in relative abundance and/or loss of species; competition between organisms may shift if there is high mortality of a dominant species or newly opened space for colonization. To understand the processes shaping coral reef communities, long-term studies are essential. Yet in 1991, there were few long-term studies documenting changes on Caribbean coral reefs (Connell, 1997).

In 1991, Shinn and Halley established long-term monitoring stations to follow the recovery of three Culebra coral reefs over time: an exposed windward reef; a relatively protected reef west of Culebra; and a reef exposed to nutrient influx from a canal running through the town of Dewey. At each station, permanent markers were installed, still photos and analogue video were taken, and selected coral colonies were cored or measured. In addition, deep cores from the windward and relatively protected reefs were drilled to elucidate the history of the reefs. All sites were sampled again in 1994, using still photos and analogue video.

Building on the work of Shinn and Halley, a team of scientists led by Shinn revisited the Culebra sites in July 1998. We resampled the three permanent stations using still

photography and analogue video as in the first surveys and included quantitative digital video. This study presents a summary of scleractinian coral and octocoral cover data obtained from 35-mm photoquadrats on the three long-term reef sites in 1991, 1994 and 1998, and presents baseline benthic cover data from the same transects in 1998 using digital video images.

Study site

Isla de Culebra (18º 18' N; 65º 18' W) is located near the northeastern edge of the Caribbean Plate and the eastern limit of the Greater Antilles. The prevailing ocean currents, driven by the trade winds, flow to the west-northwest. Seawater temperatures vary annually from approximately 24º to 31º C, and water quality closely approaches Sargasso Sea values for most variables [V.H. Garrison, unpub. data (2000)]. Tropical storms and hurricanes periodically damage the fringing coral reefs (Environmental Quality Board Report, 1970; Vicente, 1989) and seagrass beds (Vicente, 1989). The 28 km² island rises from a shelf with average depths of 20-30 m. Vieques lies 14 km to the south; the Virgin Passage cuts between Culebra and

St. Thomas, approximately 35 km to the east. Twenty-three km to the north, the shelf slopes to over 100 m and the abyssal depths of the Puerto Rican Trench, the deepest in the Atlantic Ocean.

Three permanent stations were established by Shinn and Halley in 1991 (fig. 1). Each station consists of 13 uniquely numbered 1.9-cm-diameter stainless steel stakes driven into and cemented in the substrate. Four transects consisting of three pins placed 10 m apart radiate from a central pin to the north, east, south, and west, forming a cross configuration (fig. 2).

- Punta Tamarindo Grande Reef (Site C) (figs. 3, 4a and 4b): 6 m depth; north of Punta Tamarindo, on the lee (west) side of the island. The location of central pin was determined using a military GPS: 18º 19.604' N, 65º 19.895' W. In 1998, the reef was dominated by the *Montastraea annularis* complex and showed relatively high spatial complexity and scleractinian coral cover. Cored to 6.5 m, the reef consisted of an uncemented accumulation of the same coral species present on the reef today [Shinn and Halley, unpub. data (1992)].
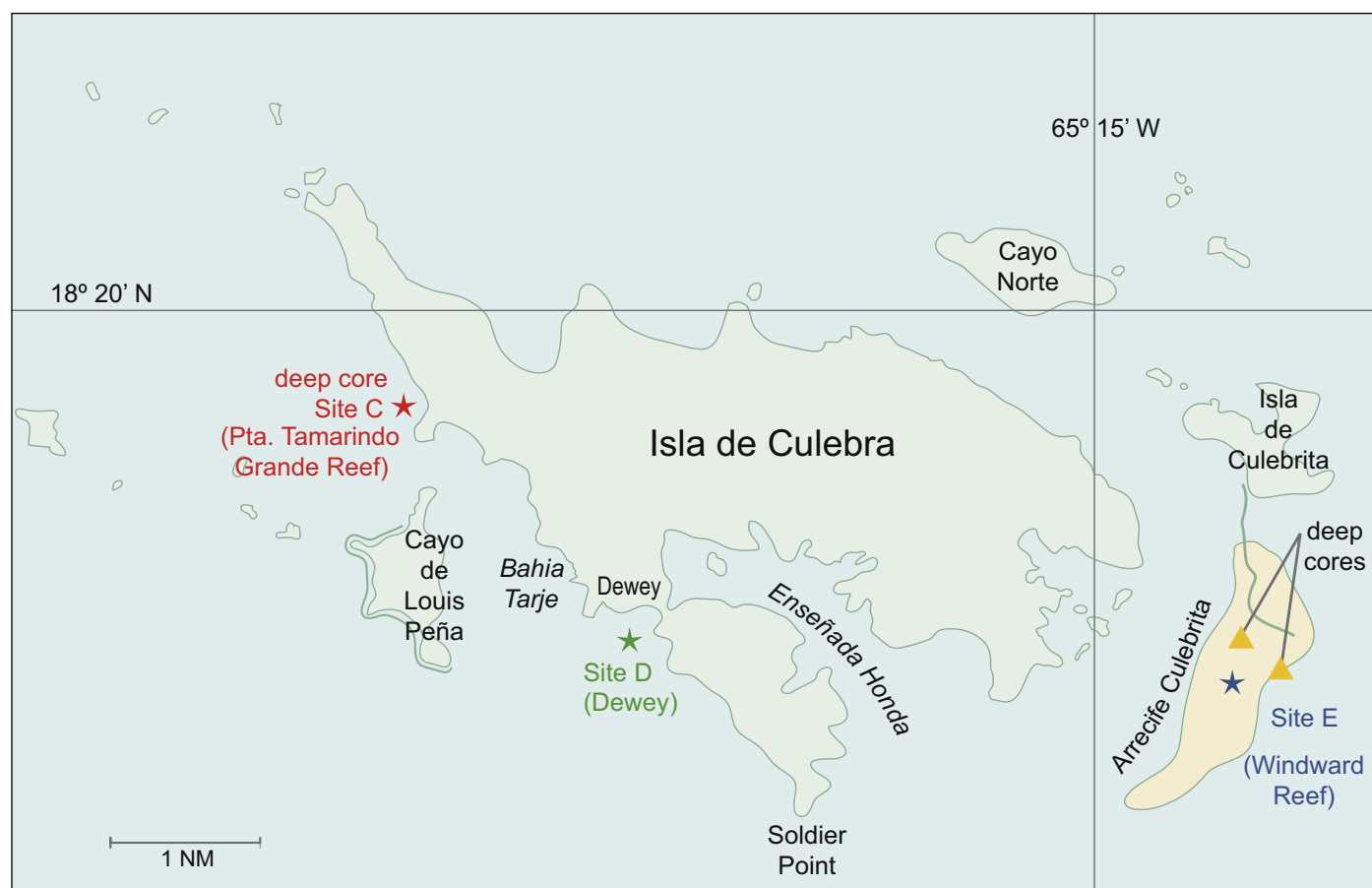

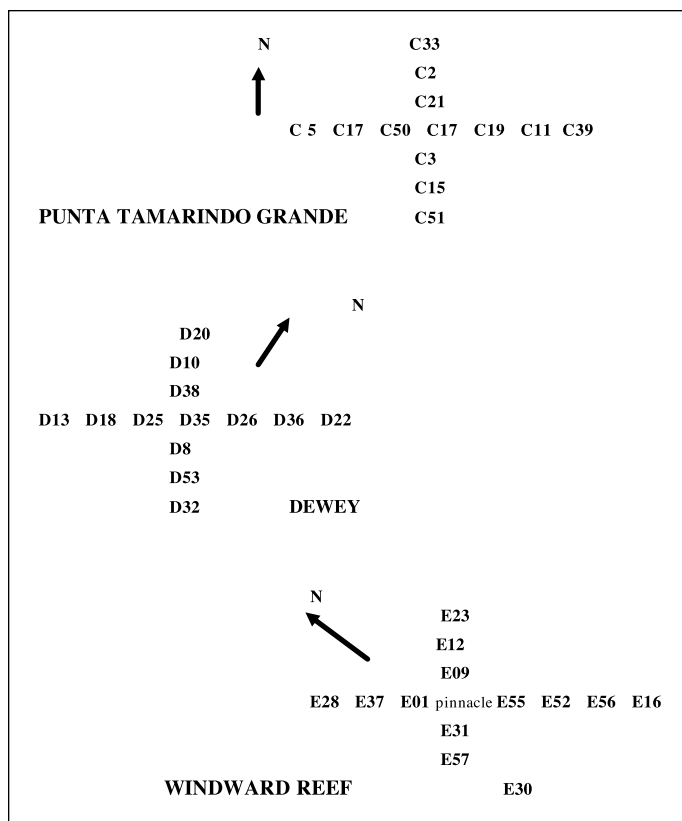Figure 1. Map of Isla de Culebra with study sites C, D, and E indicated.

Figure 2. Diagrams of the long-term study sites at Punta Tamarindo Grande (Site C), Dewey (Site D), and Windward Reef (Site E), Culebra showing pin numbers and orientation. Distance between adjacent pins is 10 m, with the exception of Windward Reef pins E01, E09, E55, and E31, which are > 10 m apart.

Figure 3. Aerial photograph of northwest Culebra. Study site C, indicated with circle, is northwest of Punta Tamarindo Grande.
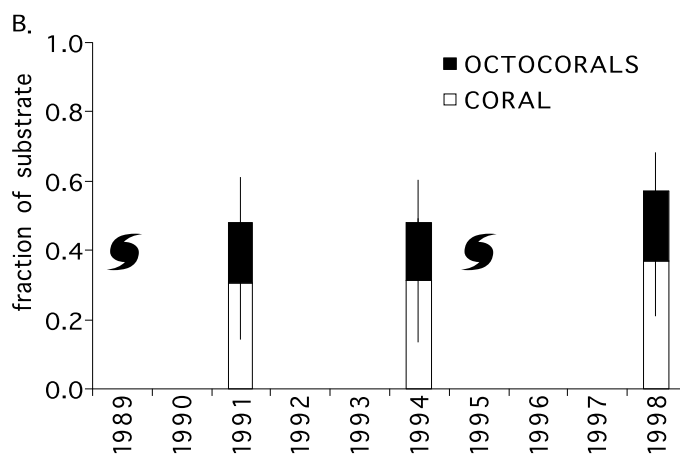
Figure 4a. Reef at study site C, Punta Tamarindo Grande (anchor is from boat anchored for a few hours at the site and not on the transect); b. fraction of substrate covered by live scleractinian corals and octocorals, site C. Analysis from 35-mm still images in 1991, 1994 and 1998. Error bars indicate standard deviation. Hurricanes Hugo (September 1989) and Marilyn (September 1995) are indicated.

- Dewey Reef (Site D) (figs. 5, 6a and 6b): approximately 6 m depth; reef southwest of the western opening of the canal that runs through the town of Dewey and into Ensenada Honda. The location of the central pin was determined using a military GPS: 18° 19.590' N, 65° 19.290' W. Bearings to land: Soldier Point bears 148°; western entrance of Culebra canal bears 050°. This reef had the lowest spatial complexity and hard coral cover of the three sites, with extensive evidence of bioerosion. Macroalgae dominated.

- Windward Reef (Site E) (figs. 7, 8a and 8b): from 2 – 11m in depth; the center is a pinnacle (top at 1.5m depth) that lies seaward of an exposed reef off Puerto del Manglar on the eastern (windward) shore of Culebra. The location of

Figure 5. Aerial photograph of west-central Culebra. The town of Dewey and canal are visible in the upper right. Study site D, Dewey Reef, is indicated by the circle.

a site on the lee side of the reef leeward of the pinnacle was determined using a military GPS as 18º 17.646' N, 65º 14.225' W. Bearings to land from the pinnacle: lighthouse on Culebrita bears 030º; eastern tip of Culebra bears 341º; Soldier Point bears 242º. Site E had the greatest spatial complexity and relief of the three sites: dominated by *M. annularis* complex; *Millepora alcicornis* abundant; numerous *P. porites* mounds; extensive *A. palmata* and *A. cervicornis* rubble. Cored to a depth of 5.5 m, bedrock was not reached; 1-2 m of uncemented *A. palmata* covered a hard limestone composed of *P. porites* cemented by gray mud-textured Mg-calcite [Shinn and Halley, unpub. data (1992)].

Methods

Photoquadrats

Still images (underwater camera with 20-mm lens) were taken at each pin (three sites), from 3m above the substrate, with the numbered pin at the center of the photograph, and the view oriented north-south (top-bottom of photograph) (Fig. 2). The 35-mm slides from all years were scanned and electronic files created. Image quality was adjusted using image-processing software to enhance identification of benthic organisms and substrate type. Only the substrates around pins photographed in all sampling periods were analyzed: 13 pins from Punta Tamarindo Grande; 13 pins from Dewey Reef; and nine pins from the Windward Reef. Using commercially available spreadsheet software, 50 dots were randomly generated and plotted on a two-dimensional grid that was then superimposed over a scanned image. The substrate at each dot was identified

and entered into the database for that image. All identifications were by one person. A new dot pattern was randomly generated for each of the 105 images analyzed. Each image (50 substrate identifications) was treated as one sample at that site for that year, with 13 samples/period for Punta Tamarindo Grande and Dewey reefs and nine samples/period at Windward Reef. The smaller sample size at Windward Reef was due to: the lack of an image of the central pin located at the apex of a pinnacle that was awash (breaking waves); a shallow, high-energy reef to the north preventing installation of a fourth pin; and loss of pins between sampling periods. Only two types of bottom cover (live stony coral and octocoral) could be reliably identified in the photoquadrats taken from 3 m above the bottom, resulting in three classification categories: "live stony coral," "octocoral," and "other." Multidimensional scaling and
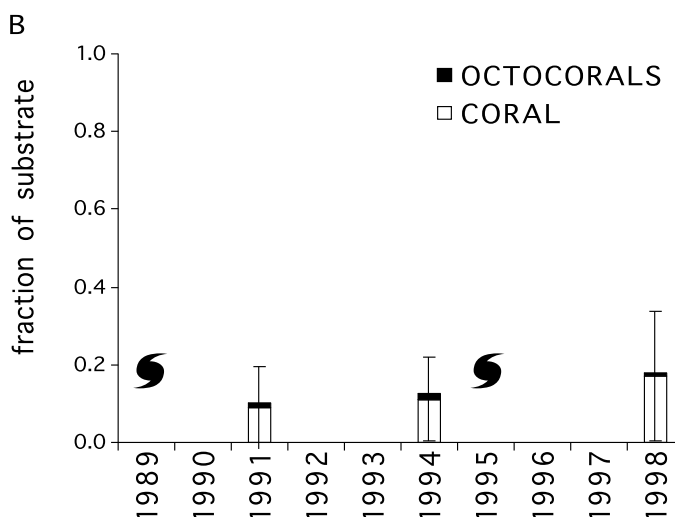

Figure 6a. Reef at study site D, Dewey Reef; b. fraction of substrate covered by live scleractinian corals and octocorals, Site D. Analysis from 35-mm still images in 1991, 1994, and 1998. Error bars indicate standard deviation. Hurricanes Hugo (September 1989) and Marilyn (September 1995) are indicated.

Figure 7. Aerial photograph of mouth of Puerto del Manglar, eastern Culebra, at upper left and windward reefs to the right. Study site E, Windward Reef, is indicated by the circle.

cluster analysis were used to detect similarities among sites and sampling periods.

Video

In 1998, digital videos were taken using a digital video recorder in an underwater housing. The camera was held perpendicular to and 40 cm above the substrate (fig. 8a), while a swimming speed of 5-7 minutes per 10 m was maintained. Surge complicated the process. The swimming rate and distance from substrate were previously optimized (Aronson and others, 1994; Wheaton and others, 1996; Rogers and Miller, 2001). Four transects were video taped at each site; each transect began at the central (or center-most) pin and ended at the most distant pin (usually 30 m from the central pin) in that "arm" of the cross (fig. 2). Each transect constituted a single sample, producing four replicate samples per site.

Digital video images were directly transferred to a PC using a capture board and software specific to the camera. As a digital tape of a transect was viewed on a monitor, unique frames, as non-overlapping as possible, were captured manually and saved in bitmap format. Approximately 30 unique images depicted 10 linear meters of substrate. Transects were usually 30 m in length, or approximately 90 unique images. Due to constraints imposed by terrain and exposure, three transects on Windward Reef were 20 m and one was 30 m (fig. 2). For analysis, the first three unique images of each transect at Punta Tamarindo Grande and Dewey reefs were discarded to eliminate the central pin area which marked the beginning of all four transects at a site. Windward Reef did not have a common central pin from which each transect could begin. From the remaining unique images, 50 were randomly selected per transect. Ten dots were randomly generated, plotted on a two-

dimensional grid (using spreadsheet software), and superimposed over the image. The substrate at each dot was identified to the most specific taxonomic level possible and entered into the database for that image. All identifications were by one person. Video analysis produced many more substrate categories than the analysis of 35-mm images from a distance of 3 m because of the distance from the substrate and superior quality of the digital images. A new dot pattern was randomly generated for each of the 600 video frames analyzed. The optimal number of dots per image was determined in other studies (Aronson and others, 1994; Wheaton and others, 1996; Rogers and Miller, 2001). Furthermore, analogue videos of the transects, taken at an oblique angle to the substrate, recorded the general appearance of the reef at each site for each sampling period.
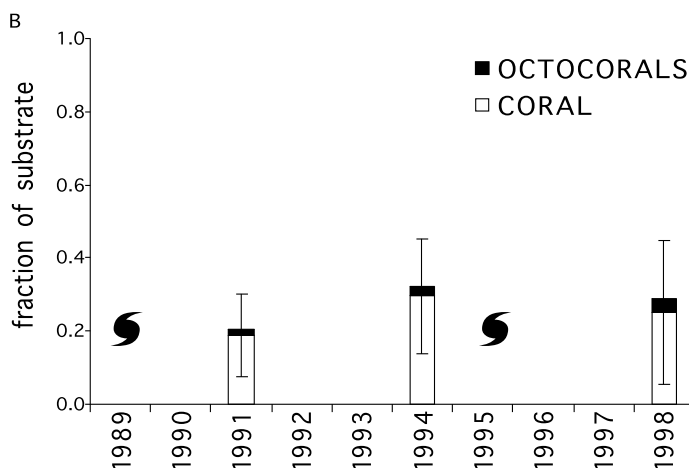

Figure 8a. Reef at study site E, Windward Reef; b. fraction of substrate covered by live scleractinian corals and octocorals, Site E. Analysis from 35-mm still images in 1991, 1994, and 1998. Error bars indicate standard deviation. Hurricanes Hugo (September 1989) and Marilyn (September 1995) are indicated.

Results

Scleractinian and octocoral cover (35-mm photoquadrat analysis)

Scleractinian coral cover ranged from a mean low of 8.9 % (sd=10.7) at Dewey Reef in 1991 to a mean high of 37.0% (sd=15.9) at Punta Tamarindo Grande Reef in 1998 (figs. 4b and 6b). Octocoral cover was highest at Punta Tamarindo Grande Reef, ranging from a 1994 mean=16.7 % (sd =12.2) to a 1998 mean=20.2% (sd=11.1) (table 1 and fig. 4b). Octocoral cover was lowest, at approximately 1%, at Dewey Reef (table 2 and fig. 6b). Patchy distribution of stony coral and octocorals at all sites produced relatively high standard deviations.

Mean scleractinian coral cover was consistently highest at Punta Tamarindo Grande Reef and ranged from a 1991 mean of 30.4% (sd= 16.1) to 37.0 % (sd=15.9) in 1998. At Punta Tamarindo Grande Reef, *M. annularis* complex dominated (table 1), contributing 63 – 80% of the coral cover; *P. porites* was a distant second, accounting for 4-13% of coral at the site. At Dewey Reef, hard coral cover was generally low (fig. 6b), with *M. annularis* complex the most abundant (table 2). Stony coral cover at Windward Reef ranged from a mean low of

19.0 % (sd=11.3) in 1991 to a mean high of 29.6% (sd=15.8) in 1994 (fig. 8b) and was greater than at Dewey and less than at Punta Tamarindo Grande reefs. *Porites porites* was the most abundant coral species (51-63%) (table 3) at the Windward site.

Punta Tamarindo Grande and Dewey reefs showed an apparent increase in stony coral cover between 1991 and 1998 (tables 1 and 2, figs. 4b and 6b). Windward Reef showed an increase between 1991 and 1994, but a decrease between 1994 and 1998 (table 3 and fig. 8b). Variation among samples at each site was high. Multidimensional scaling and cluster analysis clearly indicated stony coral and octocoral cover data clustered by site and not year (figs. 9 and 10).

Benthic cover (digital video image analysis)

Scleractinian and octocoral covers were highest at Punta Tamarindo Grande Reef, intermediate at Windward Reef, and lowest at Dewey Reef (table 4). Macroalgal cover, primarily *Dictyota* spp., was highest at Dewey Reef and lowest at Windward, while sponge cover was highest at Windward and lowest at Dewey (table 4), although the identification of sponges was problematic.

Table 1. Summary of substrate composition at site C, from analysis of 35-mm slides taken in 1991, 1994, and 1998. Shown as fraction of total substrate and standard deviation (sd).

SITE C SUBSTRATE	24-Jul-91 mean	sd	27-Jan-94 mean	sd	9-Jul-98 mean	sd
Acropora cervicornis	0.01	0.01	0.00	0.01	0.00	0.01
Diploria clivosa	0.00	0.00	0.01	0.02	0.00	0.00
Diploria labyrinthiformis	0.00	0.00	0.00	0.00	0.00	0.01
Montastraea annularis	0.24	0.15	0.20	0.17	0.29	0.17
Porites astreoides	0.01	0.02	0.01	0.02	0.00	0.01
Porites porites	0.01	0.01	0.04	0.04	0.02	0.02
unidentified coral	0.03	0.04	0.06	0.05	0.06	0.06
coral lesions (disease?)	0.01	0.01	0.00	0.00	0.00	0.00
octocorals	0.18	0.13	0.17	0.12	0.20	0.11
sponges	0.02	0.06	0.00	0.00	0.01	0.01
macroalgae	0.01	0.01	0.00	0.00	0.00	0.00
dead coral with algae	0.44	0.15	0.39	0.20	0.39	0.21
other live cover (tunicates, crinoids, etc.)	0.00	0.00	0.00	0.07	0.00	0.00
pavement	0.00	0.01	0.00	0.00	0.00	0.00
rubble	0.04	0.05	0.08	0.09	0.02	0.02
sand	0.01	0.04	0.05	0.05	0.02	0.02

Table 2. Summary of substrate composition at site D, from analysis of 35-mm slides taken in 1991, 1994, and 1998. Shown as fraction of total substrate and standard deviation (sd).

SITE D	24-Jul-91		27-Jan-94		9-Jul-98	
SUBSTRATE	mean	sd	mean	sd	mean	sd
Acropora cervicornis	0.00	0.00	0.00	0.00	0.00	0.01
Montastraea annularis	0.07	0.11	0.08	0.09	0.09	0.11
Porites astreoides	0.00	0.01	0.00	0.01	0.00	0.00
Porites porites	0.01	0.02	0.02	0.04	0.04	0.07
Millepora alcicornis	0.00	0.00	0.00	0.00	0.00	0.01
unidentified coral	0.01	0.02	0.02	0.02	0.03	0.03
octocorals	0.01	0.02	0.01	0.02	0.01	0.02
sponges	0.00	0.00	0.01	0.02	0.00	0.01
macroalgae	0.12	0.07	0.12	0.21	0.07	0.12
dead coral with algae	0.55	0.14	0.58	0.24	0.46	0.17

Comparison of 1998 data from 35-mm photoquadrats and digital video images

Both methods showed the similar apparent changes in stony coral and octocoral cover. Analysis of digital video images gave consistently lower estimates (5-8% lower) of scleractinian cover than 35-mm photoquadrats (fig. 11). Octocoral cover data exhibited no consistent difference between the two methods (tables 1-4). Standard deviations of the digital video image data were consistently much lower than in the 35-mm photoquadrat data (tables 1-4 and fig. 11).

Scans of all 35-mm photoquadrats and captured digital video images are available on this website.

Twenty-four species of stony coral were identified at the three sites in July 1998 (table 5). Coral diseases were present on the reefs at Punta Tamarindo Grande and Dewey but not quantified. Gorgonian aspergillosis, a seafan disease caused by the fungus *Aspergillus sydowii* (Smith and others 1996), infected colonies of *Gorgonia ventalina* at all sites. White-plague Type II, caused by *Aurontimonus coralicida* (Denner and others, 2003; Richardson, 1998; Richardson and others, 1998), was observed on *M. annularis* at Punta Tamarindo Grande and Dewey reefs. Black-band disease (Richardson, 1997) was

Table 3. Summary of substrate composition at site E, from analysis of 35-mm slides taken in 1991, 1994, and 1998. Shown as % cover of total substrate and standard deviation (sd)

| SITE E	24-Jul-91		27-Jan-94		9-Jul-98	
SUBSTRATE	mean	sd	mean	sd	mean	sd
Acropora cervicornis	0.00	0.01	0.03	0.05	0.02	0.06
Dendrogyra cylindrus	0.00	0.00	0.01	0.02	0.00	0.00
Montastraea annularis	0.03	0.06	0.05	0.09	0.04	0.07
Porites astreoides	0.03	0.08	0.01	0.02	0.01	0.03
Porites porites	0.12	0.07	0.15	0.10	0.14	0.13
Millepora alcicornis	0.01	0.02	0.03	0.07	0.02	0.06
unidentified coral	0.00	0.01	0.02	0.02	0.02	0.02
octocorals	0.01	0.04	0.03	0.05	0.04	0.06
macroalgae	0.02	0.04	0.01	0.02	0.02	0.03
dead coral with algae	0.23	0.19	0.14	0.12	0.25	0.15
rubble	0.50	0.21	0.49	0.28	0.43	0.26
sand	0.04	0.08	0.04	0.09	0.01	0.04
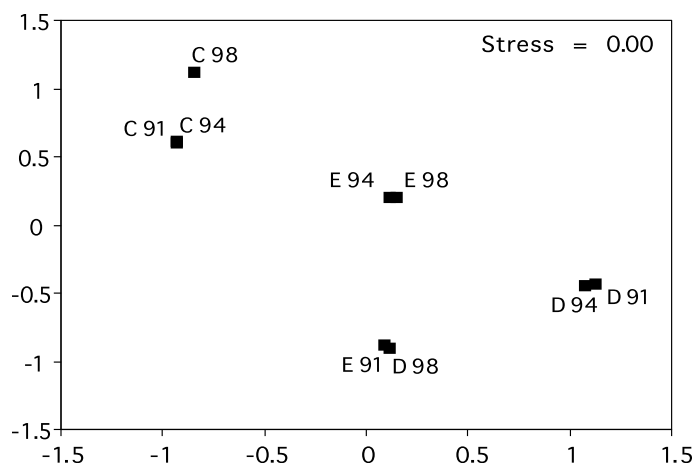
Figure 9. Multidimensional scaling plot of benthic cover data from three Culebra reefs in 1991, 1994, and 1998. C indicates site C at Punta Tamarindo Grande, D indicates site D near Dewey, and E represents site E on the windward reef. Numbers indicate the year the data were collected. Benthic cover data generally grouped by site and not time period.
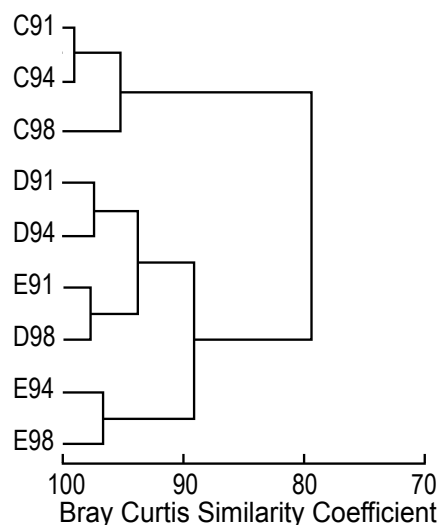

Figure 10. Cluster diagram of the three long-term monitoring stations at Culebra, Puerto Rico, based on mean scleractinian and octocoral cover at a site in a sampling year. Letters represent the three study sites; numbers indicate the year.

present at all three sites. Lesions of tissue loss similar to those produced by infections of white plague III and by focused biting by terminal phase *Sparisoma viride* (stoplight parrotfish) were observed on numerous colonies of *M. annularis* at the Punta Tamarindo Grande site.

Discussion

Twenty-two months before the long-term sites were established in 1991, the eye of Category 4 Hurricane Hugo stalled over Culebra. Based on the condition of new coral recruits, low abundance of macroalgae, abundance of *D. antillarum*, and the growth of coral recruits they measured, Shinn and Halley [unpub. data (1992)] predicted recovery of the damaged Culebra reefs within 5 years, but warned that a disease outbreak could slow or even halt recovery. In 1995, Category 3 Hurricane Marilyn inflicted additional damage. That storm occurred 20 months after the 1994 sampling and 34 months before the 1998 field work reported here. The combination of a second intense hurricane and presence of the four coral diseases identified would have hindered recovery on Culebra's reefs.

Based on 1991, 1994, and 1998 photoquadrats, apparent changes in stony coral cover between 1991 and 1998 were within the large variation in cover at each site (figs. 4b, 6b and 8b). The magnitude of variation was a result of the patchiness of the reefs, the small area sampled at each site, the difficulty in identifying organisms from the 35-mm photoquadrats, and the general inadequacy of the experimental design and methods to detect change. Both multidimensional scaling analysis and cluster analysis showed the reefs to cluster by site

and not time period, indicating that initial differences among sites were greater than changes within each site over time. Macroalgae were most abundant on and clearly dominated the Dewey Reef, which appeared degraded based on the presence of severely bioeroded dead coral heads scattered throughout the site. The reef is close to the raw sewage discharge from the town of Dewey. All diseases (gorgonian aspergillosis, white-plague type II, black-band disease, and possibly white-plague type III) observed in 1998 have been reported on other reefs in the region (Weil, 2004).

The distance from the camera to the substrate (40 cm for digital video, compared to 300 cm for still photographs) accounts for the greater number of organism and substrate types that could be identified in the video images. The digital video images were considerably easier to analyze. Analysis of the 35-mm still images consistently produced higher estimates of stony coral cover than from digital video images, most probably an artifact of the small sample size not being as representative of the site.

Recommendations

Advances in video technology since 1991 made quantitative digital video our method of choice in 1998 for detecting change on reefs and archiving images of an area for future analysis or comparison (Rogers and Miller, 2001). In 1998, quantitative digital video offered high-resolution images, superior light capture, digital-digital transfer to computers, quality control/assurance of substrate identification, and captured a

Table 4. Mean fraction of substrate on three Culebra reefs. Data are from analysis of digital video images taken July 1998. Standard deviation = sd.

	Site C		Site D		Site E	
	mean	sd	mean	sd	mean	sd
Stony corals	0.31	0.07	0.09	0.02	0.19	0.06
Octocorals	0.12	0.02	0.02	0.01	0.06	0.05
Sponges	0.01	0.01	0.01	0.01	0.06	0.07
Zoanthids	0.00	0.001	0.00	0.00	0.00	0.01
Macroalgae	0.08	0.04	0.17	0.08	0.05	0.02
Other Substrate	0.47	0.03	0.72	0.11	0.63	0.10

larger spatial area in less time when compared to still camera photoquadrats. Also, identification of substrate is much easier (possible) at a distance of 40 cm, compared to 3m. Today, we highly recommend the use of still digital cameras at 40 cm distance from the substrate. Images are of much higher resolution (meaning easier identification of substrate and organisms), the cost of the still camera and housing is much more economical, and there is no time-consuming manual capture of unique frames. We suggest that future monitoring of these reefs be along the pins/transects videotaped in this study as well as along haphazardly selected 10 m transects along depth contours. A pilot oversampling study should be used to determine the optimum number of haphazard transects needed for greater statistical power and lower variation. By continuing to monitor the transects along the permanent pins, change on those specific areas of reefs and individual coral heads (e.g., mortality from disease or hurricane damage) can be followed and much learned about the dynamics on coral reefs in Culebra.

In December 1999, the government of Puerto Rico took a significant step in managing and helping sustain Culebra's marine resources. A marine reserve was declared in the waters around Isla Luis Pena and northwestern Culebra. In order to document the effects of the new marine reserve, a new program was initiated to monitor benthic cover and reef fish abundance (Hernández and others, 2004). The program includes at least one of the three permanent sites in this study. Fortunately,

Table 5. Scleractinian coral species and dominant macroalgae species identified while filming and photographing the three Culebra reef sites in July 1998. These are very preliminary lists.

Scleractinian coral species

FAMILY	SCIENTIFIC NAME
Astrocoeniinae	*Stephanocoenia michelinii*
Pocilloporidae	*Madracis decactis*
Acroporidae	*Acropora palmata*
	Acropora cervicornis
Agariciidae	*Agaricia agaricites*
	Agaricia fragilis
	Leptoseris cucullata
Siderastreidae	*Siderastrea siderea*
Poritidae	*Porites astreoides*
	Porites divaricata
	Porites furcata
	Porites porites
Faviidae	*Colpophyllia natans*
	Diploria clivosa
	Diploria labyrinthiformis
	Diploria strigosa
	Favia fragum
	Montastraea annularis
	Montastraea cavernosa
Mussidae	*Dendrogyra cylindrus*
	Mussa angulosa
	Mycetophyllia danaana
	Mycetophyllia ferox
Milleporina	*Millepora alcicornis*

Macroalgae (observed on transects – not an inventory)

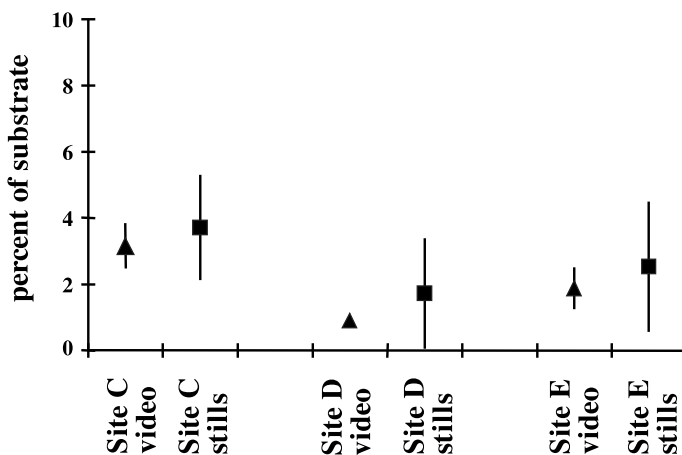| Dictyotaceae	*Dictyota* spp.
Halimedaceae	*Halimeda opuntia*
Oscillatoriaceae	*Schizothrix* sp. (*calcicola*?)

Figure 11. Stony coral cover on three Culebra reefs in July 1998. Data from analysis of digital video images and 35-mm images. Error bars represent standard deviation.

Punta Tamarindo Grande Reef is within the new reserve and baseline data exist. Long-term studies are essential to our understanding of the dynamics and resilience of coral reef ecosystems.

Acknowledgments

References Cited

Aronson, R.B., P.J. Edmunds, W.F. Precht, D.W. Swanson, and D.R. Levitan. 1994. Large-scale, long-term monitoring of Caribbean coral reefs: simple, quick, inexpensive techniques. *Atoll Research Bulletin*, 421, 19 p.

Burke, L. and J. Maidens. 2004. *Reefs at Risk in the Caribbean*. World Resources Institute, Washington, D.C. 80 p.

Connell, J.H. 1997. Disturbance and recovery of coral assemblages. *Proc. 8th Int. Coral Reef Symp.*, v. 1, p. 9-22.

Denner, E.B.M., G. Smith, H.J.Busse, P. Schumann, T. Narzt, S.W. Polson, W. Lubitz, L.L. Richardson. 2003. *Aurantimonas coralicida* gen. nov., sp. nov., the causative agent of white plague type II on Caribbean scleractinian corals. *Int. J. Syst. Evol. Microbiol.*, v. 53, p. 1115-1122.

Environmental Quality Board. 1970. An island in transition, Culebra. *A Staff Report on the Environment to the Governor's Special Committee on Culebra. Office of the Governor, Commonwealth of Puerto Rico*.

Gladfelter, W.B. 1982. White-band disease in *Acropora palmata*: implications for the structure and growth of shallow water reefs. *Bull. Mar. Sci.*, v. 32, p. 639-643.

Hernández-Delgado, E.A., B. J. Delgado, and A. M. Sabat. 2004. Coral decline and lack of compliance threatens fish functional groups recovery patterns in the Luis Peña Channel No-take Natural Reserve, Culebra Island, PR. *Gulf and Caribb. Fish. Inst.*, p. 42.

Highsmith, R.C., A.C. Riggs, and C.M. D'Antonio. 1980. Survival of hurricane generated coral fragments and a disturbance model of reef-calcification/growth rates. *Oecologia*, v.46, p. 322-329.

Lessios, H.A., D.R. Robertson, and J.D. Cubit. 1984. Spread of *Diadema* mass mortalities through the Caribbean. *Science*, v. 226, p. 335-337.

Richardson, L.L. 1997. Occurrence of the Black band disease cyanobacterium on healthy corals of the Florida Keys. *Bull. Mar. Sci.*, v. 61, p. 485-490.

Richardson, L.L. 1998. Coral diseases: what is really known? *TREE*, v. 13, p. 438-443.

Richardson, L.L., W.M. Goldberg, R.G. Carlton, and J.C. Halas. 1998. Coral disease outbreak in the Florida Keys: Plague Type II. *Rev. Biol. Trop.*, v. 46, Suppl. 5, p. 187-198.

Rogers, C.S. and M.J. Miller. 2001. Coral bleaching, hurricane damage, and benthic cover on coral reefs in St. John, U.S. Virgin Islands: a comparison of surveys with the chain transect method and videography. *Bull. Mar. Sci.*, v. 69, p. 459-470.

Rogers, C.S., T.H. Suchanek, and F.A. Pecora. 1982. Effects of Hurricanes David and Frederic (1979) on shallow *Acropora palmata* reef communities: St. Croix, U.S. Virgin Islands. *Bull. Mar. Sci.*, v. 32, p. 532-548.

Shinn, E.A. 1976. Coral reef recovery in Florida and the Persian Gulf. *Environ. Geol.*, v. 1, p. 241-254.

Smith, G.W., L. Ives, I. Nagelkerken, and K.B. Ritchie. 1996. Caribbean Sea Fan Mortalities. *Nature*, v. 383, p. 487.

Vicente, V. 1989. Puerto Rico 1989 Annual Report. NOAA/NMFS.

Weil, E. 2004. Coral reef diseases in the wider Caribbean. In *Coral Disease and Health,* eds. E. Rosenberg and Y. Loya, pp. 35-68, Heidelberg, Springer-Verlag.

Wheaton, J.L., W.C. Jaap, P. Dustan, and J. Porter. 1996. *Florida Keys National Marine Sanctuary, EPA Water Quality Protection Plan, Coral reef and hardbottom monitoring project, 1996 Annual Report*, 30 p.