One-year Response of Florida Keys Patch Reef Communities to Translocation of Long-spined Sea Urchins (*Diadema antillarum*)

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Abstract
A one-year experiment was conducted to determine the efficacy of urchin translocations and resulting benthic community effects on Florida Keys patch reefs. Small (1-1.5 cm test diameter) long-spined sea urchins (*Diadema antillarum*) were collected from back reef rubble zones and transported to two experimental patch reefs during September-December 2001. Changes to community structure were assessed on two experimental and two control patch reefs prior to and one year after the urchin translocation, including percent cover, sponge and cnidarian species richness, and juvenile coral density. Urchin densities on the experimental patch reefs one year after the translocation averaged nearly 1 individual/m^2, similar to urchin density estimates in the Florida Keys prior to the 1983-84 mass mortality event. The coverage of stony corals and crustose coralline algae increased, while the coverage of brown foliose algae declined on experimental patch reefs. In contrast, stony coral and crustose coralline algal cover declined on control patch reefs, but increased for brown foliose algae. Juvenile coral densities increased at all sites, but density increases were markedly greater on both experimental sites, reflecting greater densities of smaller juveniles (< 1.5 cm diameter), especially *Porites astreoides* and *Siderastrea siderea*. Greater juvenile densities on experimental reefs may have resulted from more available space for settlement, lower post-settlement mortality from algal overgrowth, or enhanced settlement sites due to increased coverage of crustose coralline algae compared to control reefs. These results are similar to previous investigations of the effects of artificially enhanced or naturally recovering urchin densities on coral reef benthos, especially as they pertain to changes in algal composition and juvenile coral densities. However, other factors, such as storms that frequented the area during the study, are also possible contributors to the temporal patterns documented. Future surveys will monitor the survivorship of the resident adult urchins on experimental reefs and additional changes to benthic community structure that may occur.

Introduction

Understanding the factors responsible for ecosystem change in coral reef ecosystems remains a challenge (Hughes and Connell 1999). This is especially true in the Florida Keys (Dustan and Halas 1987; Porter and Meier 1992; Chiappone and Sullivan 1997), where reefs are subtropical and subjected to substantial continental influence and densely populated shorelines (Marszalek et al. 1977; Jaap 1984). Evidence of coral reef decline is associated with diseases (Dustan 1977; Richardson et al. 1998; Santavy et al. 2001); physical impacts from storm events, but also human-related impacts such as vessel groundings and anchoring (Dustan and Halas 1987); thermal stress, especially large-scale coral mortality after winter cold fronts (Roberts et al. 1982); and coral bleaching during hyperthermic events (Jaap et al. 1988). Decreased herbivory, principally due to the 1983-84 mortality of the long-spined sea urchin *Diadema antillarum* (Lessios et al. 1984), is widely thought to be a major factor explaining increased macroalgal growth on reefs throughout the Caribbean (Hughes et al. 1985; Carpenter 1990), including the Florida Keys (Lapointe 1989; Hallock et al. 1993; Chiappone et al. 1997), but questions about the relative importance of top-down (e.g., predator control) versus bottom-up control (e.g., nutrient availability) remain (Lapointe 1997; Hughes et al. 1999).

Prior to the mass mortality of *Diadema antillarum* in 1983-84, sea urchins attained high (> 20 individuals/m^2) densities in many locations throughout the Caribbean (Sammarco et al. 1974; Hay 1984; Hunte et al. 1986). For example, *D. antillarum* densities on the north coast of Jamaica ranged from 5 to 70 individuals/m^2 in particular habitats (Sammarco 1980; Hughes et al. 1985). In the Florida Keys, however, the few historical data available indicate that sea urchin densities were lower (up to 4-5 individuals/m^2) (Kier and Grant 1965; Bauer 1976, 1980). The effects of the sea urchin mass mortality were evident and widespread, manifested in dramatic increases in algal cover and species composition and decreased coral cover and recruitment (Liddell and Ohlhorst 1986; Hughes et al. 1987). Other sea urchin species did not compensate for the loss of *D. antillarum* (Hughes et al. 1987), but recent observations in Jamaica indicate that other sea urchin species may move to habitats formerly dominated by *D. antillarum*, such as *Tripneustes ventricosus* (Woodley 1999b; Moses and Bonem 2001). Despite lower historical sea urchin densities in the Florida Keys, a general trend of increased algal cover was noted qualitatively after the mass mortality in 1983 at several upper Florida Keys bank reefs (Jaap et al. 1988) and in photo-monitoring stations at six locations from Biscayne National Park to Looe Key (Porter and Meier 1992). Seven years after the mass mortality affected *D. antillarum* in the Florida Keys, a second disease event, after modest recovery to 0.30 to 0.58 individuals/m^2, once again attacked the Florida Keys population, resulting in declines to < 0.01 individuals/m^2 (Forcucci 1994). Since the second Florida Keys mortality event, large-scale surveys during 1999-2001 confirm the poor recovery of sea urchins in multiple habitat types (Chiappone et al. 2002a, b), with notable exceptions in selected shallow-water patch reefs and hard-bottom areas in the Dry Tortugas (Chiappone et al. 2001). Anecdotal surveys indicate that there is continued (over the last 10 years) pulse recruitment events of sea urchins during June through September, and numerous smaller individuals (< 1.5 cm test diameter [TD]) can be observed in rubble zones on the shoreward side of bank reefs such as Pickles Reef and Conch Reef (K. Nedimyer, personal observation). The recruitment and survival of juvenile sea urchins in these areas may be a function of adequate habitat (e.g., loose rocks and crevices) that effectively minimizes post-settlement mortality from predators that probably affects survivorship in other habitat types. However, the juvenile sea urchins that settle in these rubble zones do not survive though the winter, probably due to scouring and over-toppling during storm events. At this time, juvenile sea urchins do not appear to recruit in substantial numbers to other reef habitats in the Florida Keys.

A multi-faceted project was undertaken during September 2001 to explore the efficacy of translocating juvenile *Diadema antillarum* that recruited to rubble zones to nearby patch reefs, to track the survivorship of translocated sea urchins, and to ascertain the effects of increased sea urchin densities on patch reef community structure (see previous chapter). There is interest in this previously ubiquitous element of the Florida Keys reef ecosystem, because there is expectation that sea urchin recovery will help to reverse the trend in macroalgal expansion at the expense of reef-building corals observed on particular reefs (Porter and Meier 1992; Edmunds and Carpenter 2001). This study describes a one-year assessment of the effects of urchin translocation on patch reef community structure, focusing on changes in benthic cover, species richness, juvenile coral density, and urchin density and test diameter. The null hypothesis tested in this study is that there will be no difference in community structure between reefs with and without translocated *D. antillarum*.

Materials and methods

Study Sites

Four patch reefs roughly similar in size, shape, depth, and location were selected for study inshore of Pickles Reef in the upper Florida Keys, offshore of Plantation Key (Tavernier). Patch reefs were chosen as the areas for sea urchin translocation because of their relatively small size and abundance of microhabitats (e.g., large coral heads, crevices) to place translocated sea urchins from nearby back reef rubble habitats. The study sites are characterized as dome-shaped patch reefs at 7.5-9 m (25-30 feet) depth in Hawk Channel, a V-shaped basin separating the Pleistocene islands of the Florida Keys from the offshore bank-barrier reef tract. Initial benthic sampling was conducted during August 31 to September 1, 2001, followed by three months of urchin translocation expeditions from September through December. Re-surveys of patch reef community structure were conducted during September 18, 2002, approximately one year after the initial urchin translocation.

Experimental patch reef #1 (ER #1; 24^o 59.177'N, 80^o 26.099'W) is roughly circular in shape and 10-11 m in diameter. Several large coral heads (0.5-1 m diameter), mostly represented by *Montastraea cavernosa*, flank the southern end of the reef (Fig. 1). The site is bounded by dense seagrass and is immediately adjacent to ER #2 to the west. The second experimental patch reef had fewer large coral heads, but there were some large *Siderastrea siderea* colonies on the southern side of the reef (Fig. 1). ER #2 is approximately 11 m x 9 m along the N-S and E-W axes, respectively. One of the two control sites, control patch reef #3 (CR #3; 24^o 59.182'N, 80^o 26.119'W), is separated from ER #2 by a moderately dense seagrass bed. This site is 7.5-8.0 m deep with some moderate-sized *Montastraea faveolata* colonies, but has less vertical relief than the experimental sites (Fig. 2). The second control patch reef (CR #4; 24^o 59.101'N, 80^o 26.128'W) is west of the first three patch reefs and has a less consolidated reef framework, with the interior of the patch reef largely comprised of rubble, sand overlying hard-bottom, and deeper pockets of sediment (Fig. 2). Large colonies of *Diploria labyrinthiformis* and *M. cavernosa* occur on the southern side of the reef.

Urchin Translocation

During September to December 2001, several translocations of juvenile *Diadema antillarum* were made from the rubble zone near Pickles Reef to the two experimental patch reefs (see previous chapter). Maps were constructed of the two experimental sites to facilitate re-surveys of sea urchins to assess survivorship after translocation. A total of 455 juvenile sea urchins were moved to ER #1 and 238 individuals moved to ER #2. The numbers of sea urchins translocated to the experimental reefs were based upon the area of the reef, availability of sea urchins at the time of translocation, and the number of crevices available to place individuals. During September to December 2001, each site was visited six to eight times to release new sea urchins and/or to survey survivorship. From May to October 2002, each experimental site was re-visited an additional three times to assess the number of surviving sea urchins.

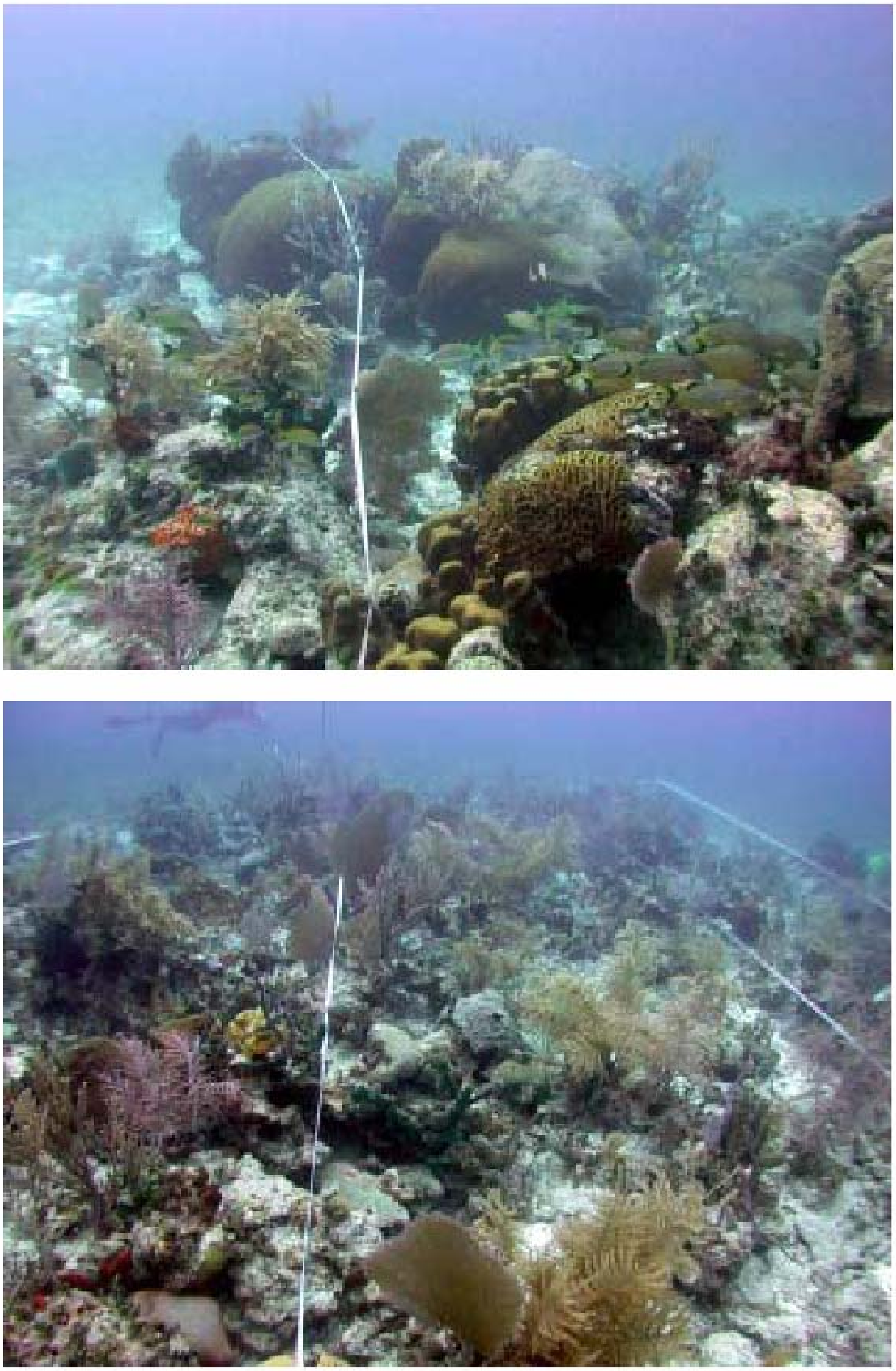

Figure 1. Underwater photographs of sea urchin experimental sites #1 (top) and #2 (bottom), taken during September 2002.

Figure 2. Underwater photographs of sea urchin control sites #3 (top) and #4 (bottom), taken during September 2002.

Benthic Surveys
A suite of variables was measured to evaluate the possible responses of the experimental patch reefs to the translocation of sea urchins, following procedures summarized in Miller et al. (2002). Before and one year following the urchin translocation, percent cover, species richness, topography, juvenile coral density, urchin density and size, gorgonian density and size, and coral density, size, and condition were assessed. At each patch reef, four 10-m transects were haphazardly placed along the long axis of each site (Fig. 1). Transects served as the basis for measuring coverage, species richness, and the densities and sizes of macro-invertebrates. Percent coverage was assessed using the linear point-intercept method, in which 100 points per transect, spaced at 10-cm intervals, were sampled to determine the type of benthos underlying each point. The presence and total numbers of sponges, stony corals, and gorgonians were surveyed 0.4 m out on each side of the four transects, yielding a transect area of 8 m^2 and a total sampling area of 32 m^2 for each patch reef. Sea urchins were surveyed in a similar fashion to determine the density of particular species and the test diameter (cm) of individuals found. Gorgonian and coral density were surveyed on two of the four transects per site in 0.4 m swaths on one transect side (4 m^2 transect area). Gorgonians were surveyed for the species, colony number, and maximum height using four size classes (< 20 cm, 20-50 cm, 50-100 cm, and > 100 cm). Juvenile corals (< 4 cm maximum diameter) were assessed on two transects per site by randomly placing ten 0.65 m x 0.48 m quadrats (total area of 3.12 m^2 per transect) along two of the four transects. Topographic complexity was assessed along all four transects by measuring the maximum and minimum depth of each transect using a digital depth gauge and recording the maximum vertical relief in 0.4 m x 10 m areas. Within each 0.4 m x 10 m transect, an estimate of the percentage of the transect area with a given topographic profile was assessed using five relief categories: < 0.2 m, 0.2-0.5 m, 0.5-1.0 m, 1.0-1.5 m, and > 1.5 m. All surveys, with the exception of video, were completed using pencils and plastic slates, and typically one site could be completed in 90 minutes of underwater bottom time with three trained personnel.

Results
Patch Reef Characteristics
The four patch reefs selected for study were at a similar depth and had similar maximum relief (Table 1). However, both experimental sites tended to have a greater percentage of the patch reef areas with 0.2-0.5 m of vertical relief (Fig. 1) compared to control sites (Fig. 2). The experimental sites had areas of higher relief represented by 1+ m diameter coral heads that were the principal areas used to translocate juvenile urchins from rubble zones. No other significant differences in topography were noted between experimental and control sites from year to year during the course of the study.

Benthic coverage at both experimental sites was dominated by algal turf, brown foliose algae (*Dictyota*), and scleractinian corals, especially *Montastraea cavernosa* and *Siderastrea siderea*. At ER #1, corals (20 species) and sponges (35 species) were represented by many more species compared to gorgonians (8 species). Gorgonian density was relatively low (3.88 colonies/m^2) and mostly dominated by small (< 20 cm) and medium-size (20-50 cm) sea fans (*Gorgonia ventalina*) and sea plumes (*Pseudopterogorgia* spp.). At ER #2, a larger percentage of the patch reef was comprised of sand and sand overlying hard-bottom compared to ER #1. Corals and gorgonians were represented by 15 and 18 species, respectively, while sponges were the most speciose (35 taxa). Gorgonian density on ER #2 was twice as high (8.50 colonies/m^2) compared to the first experimental patch, but was similarly dominated by sea plumes and sea fans. The primary difference in gorgonian densities between the two experimental sites was attributed to more *Eunicea* species at ER #2. Like ER #1, gorgonians were represented by mostly small (< 20 cm height) to intermediate-sized (20-50 cm) colonies at ER #2.

Table 1. Physical characteristics of experimental (top) and control (bottom) patch reefs, expressed in terms of the mean (1 SE) minimum and maximum depth of surveyed transects, mean (1 SE) maximum vertical relief, and estimated mean (1 SE) percentage of site with given topographic relief. Data are based upon surveys of four 10 m x 0.4 m transects per site each year.

Experimental patch reefs

Physical variable	Experimental site #1		Experimental site #2		Combined experimental	
	2001	2002	2001	2002	2001	2002
Minimum depth (m)	7.5 (0.0)	7.7 (0.1)	7.4 (0.1)	7.6 (0.1)	7.5 (0.1)	7.7 (0.1)
Maximum depth (m)	7.6 (0.1)	8.0 (0.1)	7.5 (0.0)	8.0 (0.1)	7.6 (0.1)	8.0 (0.0)
Maximum relief (cm)	82 (16)	79 (13)	41 (7)	45 (4)	62 (21)	62 (17)
Relief area (%)						
< 0.2 m	72.5 (4.3)	61.3 (8.3)	63.8 (7.2)	70.0 (7.4)	68.2 (4.4)	65.7 (4.4)
0.2-0.5 m	25.0 (4.6)	23.8 (5.5)	35.0 (7.1)	28.8 (7.5)	30.0 (5.0)	26.3 (2.5)
0.5-1.0 m	1.3 (1.3)	15.0 (6.1)	1.3 (1.3)	1.3 (1.3)	1.3 (0.0)	8.2 (6.9)
1.0-1.5 m	1.3 (1.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.7 (0.7)	0.0 (0.0)
> 1.5 m	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Control patch reefs

Physical variable	Control site #3		Control site #4		Combined control	
	2001	2002	2001	2002	2001	2002
Minimum depth (m)	7.4 (0.1)	7.5 (0.0)	8.0 (0.1)	7.7 (0.1)	7.7 (0.2)	7.6 (0.1)
Maximum depth (m)	7.5 (0.0)	7.5 (0.0)	8.1 (0.0)	7.8 (0.0)	7.8 (0.2)	7.7 (0.1)
Maximum relief (cm)	42 (6)	44 (7)	63 (17)	61 (19)	53 (11)	53 (9)
Relief area (%)						
< 0.2 m	77.5 (3.2)	78.8 (4.7)	76.3 (7.2)	83.8 (5.5)	76.9 (0.6)	81.3 (2.5)
0.2-0.5 m	21.3 (2.4)	18.8 (2.4)	17.5 (6.0)	10.0 (2.0)	19.4 (1.9)	14.4 (4.4)
0.5-1.0 m	1.3 (1.3)	2.5 (2.5)	5.0 (2.0)	6.3 (3.8)	3.2 (1.9)	4.4 (1.9)
1.0-1.5 m	0.0 (0.0)	0.0 (0.0)	1.3 (1.3)	0.0 (0.0)	0.7 (0.7)	0.0 (0.0)
> 1.5 m	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Both control sites were similarly dominated by algal turf, brown foliose algae, especially *Dictyota*, crustose coralline algae, stony corals, and sponges. CR #3 had large areas of sand and sand overlying hard-bottom and was patchier than the experimental sites. The species richness of corals, gorgonians, and sponges was relatively similar to the experimental sites. Gorgonian density at CR #3 was similar to ER #2 (about 7.1 colonies/m^2), mostly represented by small (< 20 cm) to intermediate-sized (20-50 cm) colonies. CR #4 had greater topographic relief than the first control site. Vertical relief at this site was up to nearly 1 m due to the presence of large coral heads on the southern end of the reef. Brown foliose algae and green calcareous algae (*Halimeda*) comprised less coverage that at the other sites. While coral cover was relatively high, there was considerable variability due to the localized occurrence of large coral heads on one end of the patch reef and large areas of sand and rubble in the interior of the site. Species richness of corals, gorgonians, and sponges was similar or slightly lower at CR #4 compared to the other three patch reefs. Gorgonian density was low (4.3 colonies/m^2) and similar to ER #1, and was almost exclusively comprised of sea plumes and sea fans, most of which were < 20 cm in height.

Tables 2 through 5 list the stony coral, gorgonian, and sponge species recorded within transects during the two sampling periods. Stony coral species richness was slightly lower on control patch reefs, usually by two to three species (Table 2). *Diploria strigosa*, *Leptoseris cucullata*, *Madracis decactis*, and *Montastraea annularis* were observed on one or both experimental sites, but not on control sites, while *Meandrina meandrites* was observed on control sites, but not on experimental sites. Gorgonian species richness was slightly greater at the experimental sites (Table 3). *Erythropodium caribaeorum*, *Plexaura homomalla*, and *Eunicea succinea* were recorded on experimental sites, but not control sites. Sponge species richness was relatively similar among both experimental and control sites (Tables 4-5), but there was a larger discrepancy between control sites during 2001 to 2002. However, many of the species not recorded at the control sites during 2002 were predominately cryptic sponges. Few changes were noted in species richness from year to year for these species groups.

Sea Urchin Translocation Effects

Not surprisingly, experimental sites showed an increase in the density (Table 6) and mean test diameter (Table 7) of *Diadema antillarum* between 2001 and 2002, principally due to the effects of translocation (Fig. 3). Urchin densities at the control sites either exhibited no change or a slight density decrease. The densities of other sea urchin species at both experimental and control sites did not change markedly during the year of study. Although the change in mean size and size distribution of *D. antillarum* at the experimental sites largely reflected the growth of translocated urchins during the year (Fig. 4), sea urchin recruits in the 1.0-1.5 cm TD size class were also evident at both experimental sites.

Changes in the coverage of different benthic components exhibited some marked differences between experimental (Table 8) and control sites (Table 9). Percent coral cover increased on both experimental patch reefs, while both control patch reefs showed declines (Fig. 5). The magnitude of change in percent coral cover on the experimental sites (9.8% to 15.3%) was +5.5% absolute and +56% relative. Coral cover on the control patch reefs declined from 9.1% to 6.8%, representing a –2.4% absolute change and –26% relative change during the study. The temporal patterns in coral cover may be partially due to the random location of transects from year to year and is not considered significant, especially since we did not see evidence of substantial coral growth or mortality. Sponge cover decreased on experimental patch reefs from a mean of 7.4% to 5.3%, but exhibited a slight increase on control patch reefs from 5.3% to 6.0%.

Different algal functional groups by far exhibited the most notable changes in benthic community structure between experimental and control patch reefs. Algal turf exhibited a slight decrease on both experimental sites from 28.6% to 24%, representing a -4.6% absolute change and -16.2% relative change. In contrast, control sites exhibited a slight increase from 23.4% to 27.8%, representing a +4.4% absolute change and +18.7% relative change. The coverage of crustose coralline algae (CCA) exhibited the most significant difference between experimental and control patch reefs during the study (Fig. 5). Large increases (7.5% to 19%) were documented on both experimental sites, representing a +11.5% absolute change and +153% relative change. In contrast, control sites exhibited no discernible temporal pattern in CCA cover,

Table 2. Species richness (numbers of species) of stony corals (Milleporina and Scleractinia) observed within four 15 m x 0.8 m (12 m^2) transects on experimental (top) and control (bottom) patch reefs before and one year after urchin translocation.

Experimental patch reefs

Coral species	**Experimental site #1**		**Experimental site #2**		**Combined experimental**	
	2001	**2002**	**2001**	**2002**	**2001**	**2002**
A. agaricites	1	1	1	1	1	1
A. fragilis			1	1	1	1
A. humilis	1	1	1	1	1	1
C. natans	1	1			1	1
D. stokesi	1	1	1	1	1	1
D. clivosa			1			
D. labyrinthiformis	1	1		1	1	1
D. strigosa	1	1		1	1	1
E. fastigiata	1				1	
L. cucullata			1	1	1	1
M. decactis	1				1	
M. alcicornis	1	1	1	1	1	1
M. annularis	1	1		1	1	1
M. faveolata	1	1	1	1	1	1
M. cavernosa	1	1	1	1	1	1
P. astreoides	1	1	1	1	1	1
P. branneri		1		1		1
P. porites divaricata	1	1	1		1	1
P. porites furcata	1	1	1	1	1	1
P. porites porites	1			1	1	1
S. radians	1	1	1	1	1	1
S. siderea	1	1	1	1	1	1
S. bournoni	1	1	1		1	1
S. michelini	1	1		1	1	1
Total species	20	18	15	18	22	21

Control patch reefs

Coral species	**Control site #3**		**Control site #4**		**Combined control**	
	2001	**2002**	**2001**	**2002**	**2001**	**2002**
A. agaricites	1	1	1	1	1	1
A. fragilis	1				1	
A. humilis	1			1	1	1
C. natans			1		1	
D. stokesi	1	1	1	1	1	1
D. clivosa				1		1
D. labyrinthiformis	1		1	1	1	1
E. fastigiata		1		1		1
F. fragum			1		1	
L. cucullata		1				1
M. meandrites	1				1	
M. alcicornis	1	1	1	1	1	1
M. faveolata	1	1	1	1	1	1
M. cavernosa	1	1	1	1	1	1
P. astreoides	1	1	1	1	1	1
P. branneri	1	1	1		1	1
P. porites divaricata	1	1	1		1	1
P. porites furcata	1	1	1	1	1	1
P. porites porites		1				1
S. radians	1	1	1	1	1	1
S. siderea	1	1	1	1	1	1
S. bournoni	1	1	1	1	1	1
S. michelini	1	1		1	1	1
Total species	17	16	15	15	19	19

Table 3. Species richness (numbers of species) of gorgonians (Octocorallia) observed within four 15 m x 0.8 m (12 m^2) transects on experimental (top) and control (bottom) patch reefs before and one year after urchin translocation.

Experimental patch reefs

Gorgonian species	**Experimental site #1**		**Experimental site #2**		**Combined experimental**	
	2001	**2002**	**2001**	**2002**	**2001**	**2002**
E. caribaeorum			1	1	1	1
E. calyculata		1	1		1	1
E. fusca			1	1	1	1
E. laciniata		1	1	1	1	1
E. mammosa	1	1	1	1	1	1
E. succinea	1		1		1	
E. tourneforti		1	1	1	1	1
G. ventalina	1	1	1	1	1	1
M. elongata		1		1		1
M. muricata			1	1	1	1
M. flavida	1	1	1	1	1	1
P. flexuosa		1	1	1	1	1
P. homomalla	1		1	1	1	1
P. dichotoma			1	1	1	1
Pseudoplexaura sp.	1	1	1	1	1	1
P. flagellosa		1	1	1	1	1
P. acerosa	1	1	1	1	1	1
P. americana	1	1	1	1	1	1
P. rigida		1				1
P. citrina			1		1	
Total species	8	13	18	16	18	18

Control patch reefs

Gorgonian species	**Control site #3**		**Control site #4**		**Combined control**	
	2001	**2002**	**2001**	**2002**	**2001**	**2002**
B. asbestinum	1				1	
E. calyculata	1	1	1		1	1
E. fusca	1	1			1	1
E. laciniata	1		1		1	
E. mammosa	1	1	1	1	1	1
E. tourneforti	1	1			1	1
G. ventalina	1	1	1	1	1	1
M. elongata		1				1
M. muricata	1	1			1	1
M. flavida	1	1	1		1	1
P. flexuosa	1	1	1	1	1	1
P. dichotoma	1	1	1	1	1	1
Pseudoplexaura sp.	1	1	1	1	1	1
P. flagellosa	1	1			1	1
P. acerosa	1	1	1	1	1	1
P. americana	1	1	1	1	1	1
P. rigida		1				1
P. citrina		1				1
Total species	15	16	10	7	15	16

where coverage actually decreased at CR #3 and only slightly increased at CR #4 (Table 9). The overall change in CCA cover on control sites was from 7.8% in 2001 to 8.3% in 2002, representing a +0.5% absolute change and +6.5% relative change.

Table 4. Species richness (numbers of species) of sponges observed within four 15 m x 0.8 m (12 m^2) transects on experimental patch reefs before and one year after urchin translocation.

Sponge species	**Experimental site #1**		**Experimental site #2**		**Combined experimental**	
	2001	**2002**	**2001**	**2002**	**2001**	**2002**
A. clathrodes		1				1
A. wiedenmayaari	1	1	1	1	1	1
A. compressa	1	1	1	1	1	1
A. viridis	1	1	1	1	1	1
A. varians		1		1		1
A. cauliformis	1	1	1	1	1	1
A. fistularis			1	1	1	1
A. lacunosa	1	1			1	1
C. vaginalis	1	1	1	1	1	1
C. nucula	1	1	1	1	1	1
C. deletrix	1	1	1	1	1	1
Cliona sp.	1	1	1		1	1
D. etheria	1	1	1	1	1	1
D. janiae	1	1	1	1	1	1
Halisarca sp.	1	1	1	1	1	1
I. birotulata	1	1	1	1	1	1
I. campana	1	1	1	1	1	1
I. felix	1	1	1	1	1	1
I. strobilina	1	1	1	1	1	1
M. barbadensis	1	1	1	1	1	1
M. unguifera	1	1	1	1	1	1
M. laevis	1	1			1	1
N. digitalis	1	1	1	1	1	1
N. erecta	1	1	1	1	1	1
P. acanthifolium	1	1	1	1	1	1
P. lunaecharta	1	1	1	1	1	1
P. crassa	1	1	1	1	1	1
Ptilocaulis sp.		1	1	1	1	1
R. venosa		1	1	1	1	1
S. coralliphagum	1	1	1	1	1	1
S. vesparium	1		1		1	
S. tenerrima	1	1	1	1	1	1
T. ignis	1	1	1	1	1	1
U. ruetzleri	1				1	
V. rigida	1	1	1	1	1	1
X. muta				1		1
Unknown blue tube	1		1		1	
Unknown carmine	1		1		1	
Unknown mauve		1				1
Unknown orange		1	1		1	1
Unknown encrusting	1		1		1	
Unknown red sponge	1	1	1	1	1	1
Total species	35	35	35	31	38	37

Green foliose algae, primarily represented by *Ventricaria ventricosa* and *Caulerpa verticillata*, showed little change on experimental sites (from 0.9% in 2001 to 0.4% in 2002) (Table 8), but mixed patterns were evident on control sites (Table 9). The coverage of green calcareous algae, primarily represented by *Halimeda* spp., showed little change on experimental sites (3.8% to 3.1%) compared to control sites, where mean coverage increased from 1.8% to 3.8%, representing a +2% absolute change and +114% relative change. The coverage of brown foliose algae (BFA), primarily represented by *Dictyota* spp., greatly declined on experimental patch reefs (Fig. 5), especially at ER #1, where coverage decreased from 11% to 1.8%. Overall, the coverage of BFA on experimental sites decreased from 10% to 5.1%, representing a –4.9% absolute decline and –48.7% relative decline. In contrast, control sites either exhibited no change or an increase in coverage of BFA (Table 9).

Table 5. Species richness (numbers of species) of sponges observed within four 15 m x 0.8 m (12 m^2) transects on control patch reefs before and one year after urchin translocation.

Sponge species	**Control site #3**		**Control site #4**		**Combined control**	
	2001	**2002**	**2001**	**2002**	**2001**	**2002**
A. clathrodes	1				1	
A. wiedenmayaari	1	1	1	1	1	1
A. compressa	1	1	1	1	1	1
A. viridis	1	1			1	1
A. varians		1	1	1	1	1
A. archeri	1				1	
A. cauliformis	1	1	1	1	1	1
A. fistularis	1	1			1	1
A. lcaunosa		1				1
C. plicifera				1		
C. vaginalis	1	1	1		1	1
C. nucula	1	1	1	1	1	1
C. deletrix	1	1	1	1	1	1
Cliona sp.	1	1	1	1	1	1
C. vasculum	1				1	
D. etheria	1	1	1	1	1	1
D. janiae	1	1	1	1	1	1
Halisarca sp.	1		1		1	
I. birotulata	1	1	1	1	1	1
I. campana	1	1	1	1	1	1
I. felix	1	1	1	1	1	1
I. strobilina	1	1	1	1	1	1
M. barbadensis	1		1	1	1	1
M. unguifera		1	1	1	1	1
M. laevis	1	1			1	1
N. digitalis	1	1	1	1	1	1
N. erecta	1	1	1	1	1	1
P. acanthifolium	1	1	1	1	1	1
P. lunaecharta	1	1	1	1	1	1
P. crassa	1	1	1	1	1	1
Ptilocaulis sp.		1				1
R. venosa		1		1		1
S. coralliphagum	1	1	1	1	1	1
S. vesparium	1		1		1	
S. tenerrima	1	1			1	1
T. ignis	1	1	1		1	1
V. rigida	1	1			1	1
X. muta	1				1	
Unknown blue tube				1		
Unknown carmine			1		1	
Unknown orange	1	1			1	1
Unknown encrusting	1		1		1	
Unknown red sponge	1	1	1	1	1	1
Total species	35	32	28	25	38	33

Table 6. Mean (1 SE) density (no. individuals per m^2) of urchins observed within four 15 m x 0.8 m (12 m^2) transects on experimental and control patch reefs before and one year after urchin translocation.

Treatment	*Diadema antillarum*		*Echinometra viridis*		*Eucidaris tribuloides*	
	2001	2002	2001	2002	2001	2002
Experimental site #1	0	0.719 (0.219)	0.031 (0.031)	0	0.031 (0.031)	0.125 (0.051)
Experimental site #2	0	0.781 (0.299)	0.031 (0.031)	0	0.031 (0.031)	0.031 (0.031)
Pooled experimental	0	0.750 (0.172)	0.031 (0.020)	0	0.031 (0.020)	0.078 (0.033)
Control #3	0	0	0	0	0.031 (0.031)	0.063 (0.036)
Control #4	0.156 (0.079)	0.094 (0.060)	0	0	0.031 (0.031)	0.031 (0.031)
Pooled control	0.078 (0.047)	0.047 (0.033)	0	0	0.031 (0.020)	0.047 (0.023)

Table 7. Size frequency and mean (1 SE) test diameter (cm) of *Diadema antillarum* observed within four 15 m x 0.8 m (12 m^2) transects on experimental and control patch reefs before and one year after urchin translocation.

Treatment	No. surveyed		Size range (cm)		Mean diameter (cm)	
	2001	2002	2001	2002	2001	2002
Experimental site #1	0	23	0	1.3-5.3	0	4.2 (0.2)
Experimental site #2	0	25	0	1.1-5.2	0	4.1 (0.1)
Pooled experimental	0	48	0	1.1-5.3	0	4.2 (0.1)
Control #3	0	0	0	0	0	0
Control #4	5	3	1.8-6.7	3.4-5.3	3.6 (0.8)	4.5 (0.6)
Pooled control	5	3	1.8-6.7	3.4-5.3	3.6 (0.8)	4.5 (0.6)

Changes in the density and species composition of juvenile corals documented for the experimental and control sites are summarized in Table 10. A total of seven scleractinian coral species were observed as juveniles on the experimental sites in 2001 compared to nine species on the control sites. More species were found (11) on experimental sites in 2002, but one less species was recorded on control sites. Species recorded as juveniles on the experimental sites in 2002, but not in 2001, included *Agaricia fragilis*, *Eusmilia fastigiata*, and *Leptoseris cucullata*. Mean juvenile densities increased significantly on the experimental sites, from an average of 6.2 juveniles/m^2 to 15.3 juveniles/m^2, representing a +147% relative increase (Fig. 6). Mean densities also increased on the control sites, but not to the same degree, from 6.6 juveniles/m^2 to 9.9 juveniles/m^2 or a +51% relative increase. Notable increases in the densities of *Porites astreoides*, *P. porites*, and *Siderastrea siderea* were noted for both experimental and control sites from 2001 to 2002. The mean size (maximum diameter) of juvenile scleractinian corals for experimental and control sites is summarized in Table 11. For the most abundant species on experimental patch reefs, mean juvenile size decreased (e.g., *P. astreoides* and *S. siderea*) or showed no substantial change (e.g., *S. radians*). On control patch reefs, except for many smaller juveniles of *S. siderea* observed in 2002, most species exhibited no change or increases in mean juvenile size.

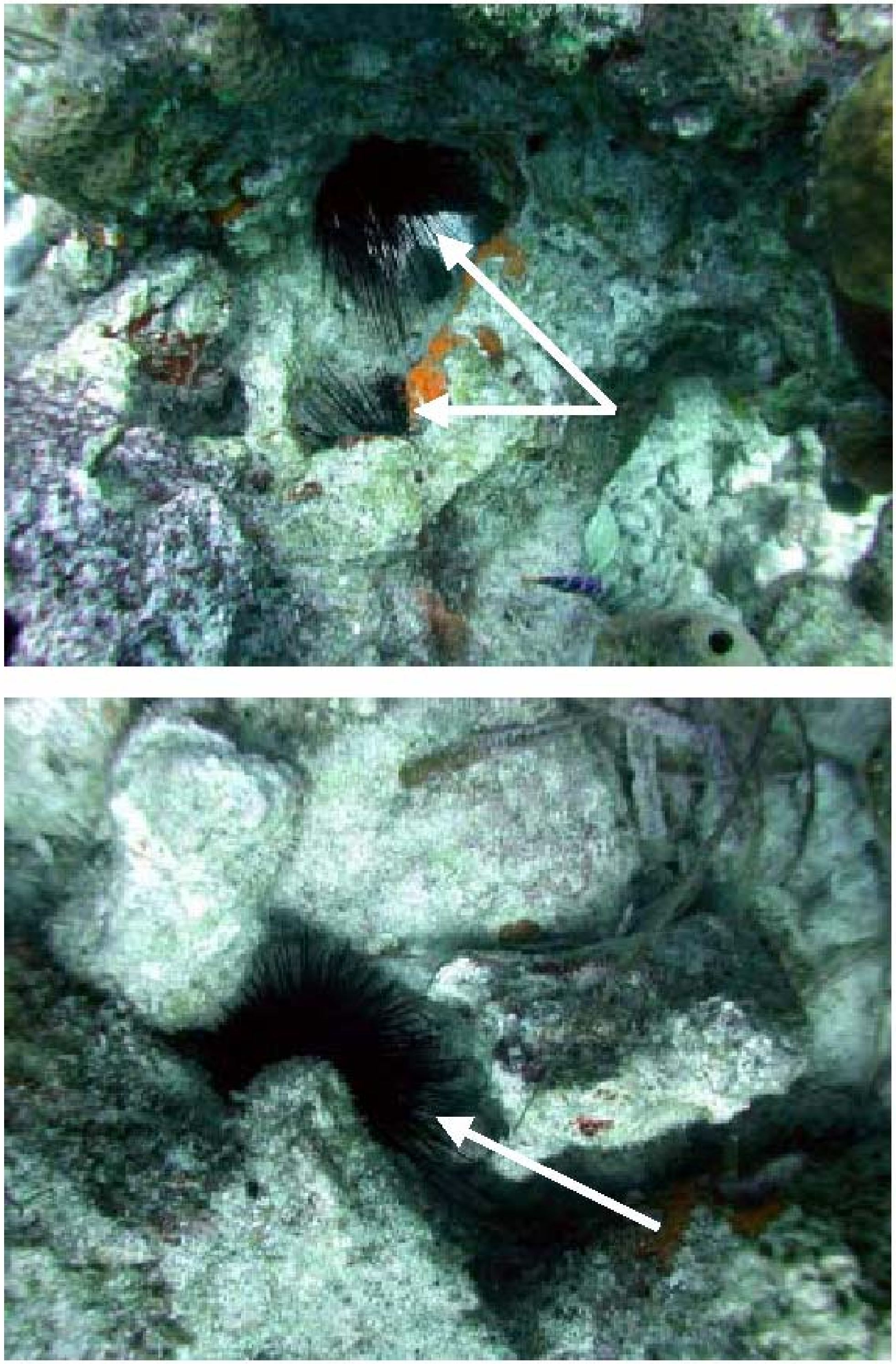

Figure 3. Individual *Diadema antillarum* at ER #1, one year after translocation.

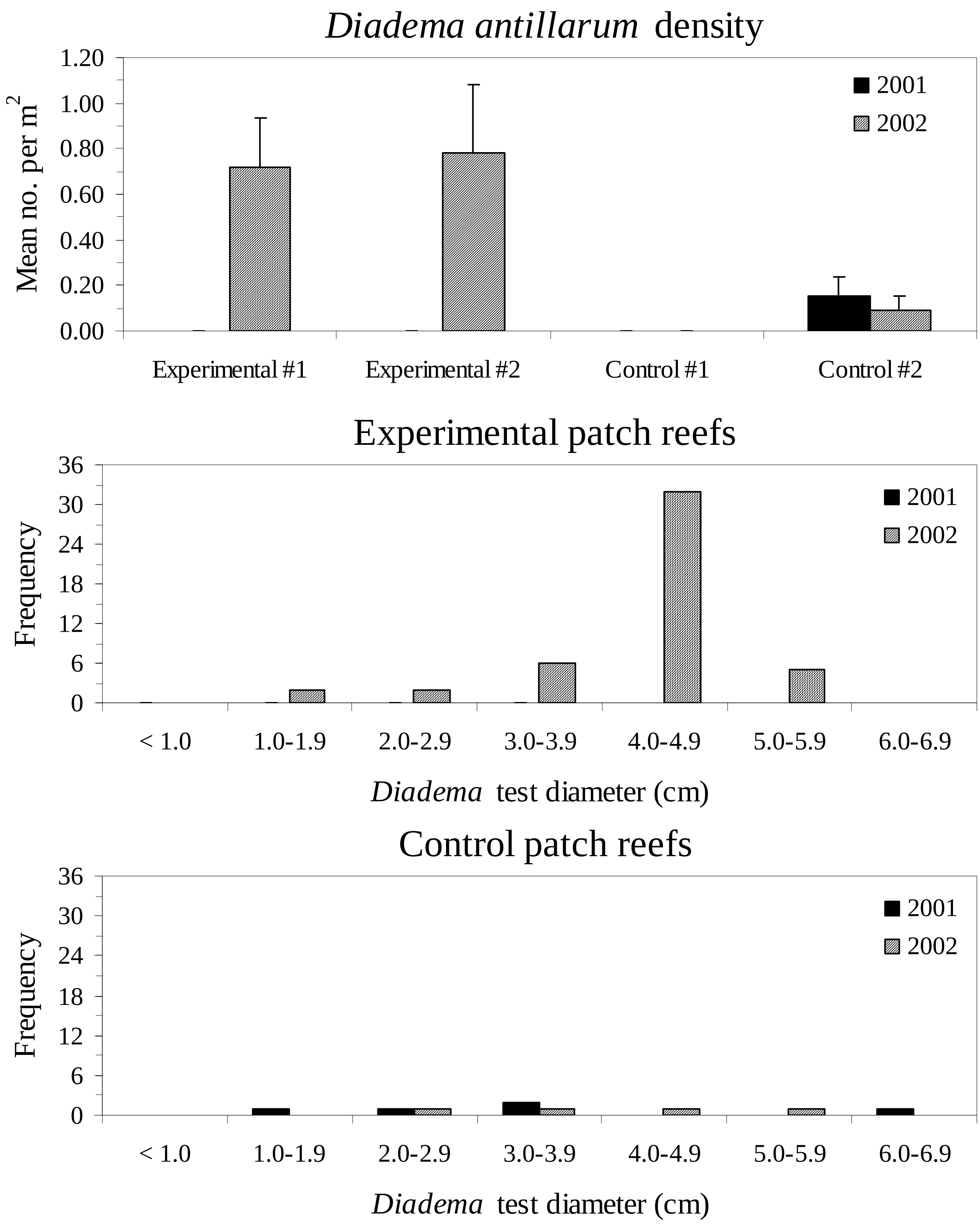

Figure 4. Changes in mean density (no. individuals per m^2) and test size distribution of *Diadema antillarum* before and one year after urchin translocation on Florida Keys patch reefs. Error bars represent one standard error. “Control #1 and #2” = CR #3 and CR #4.

Table 8. Mean (1 SE) percent cover of major benthic groups on experimental patch reefs before and one year after urchin translocation. Sample size = 4 transects per site per year and 100 points per transect.

Bottom type	Experimental site #1		Experimental site #2		Combined experimental	
	2001	2002	2001	2002	2001	2002
A. agaricites	0.25 (0.25)		0.25 (0.25)		0.25 (0.00)	
C. natans	1.00 (1.00)				0.50 (0.50)	
D. stokesi			0.25 (0.25)	0.50 (0.29)	0.13 (0.13)	0.25 (0.25)
D. labyrinthiformis		0.25 (0.25)		0.50 (0.50)		0.38 (0.13)
D. strigosa		1.75 (1.03)				0.88 (0.88)
M. alcicornis		0.50 (0.29)	0.25 (0.25)		0.13 (0.13)	0.25 (0.25)
M. annularis	1.00 (1.00)	0.25 (0.25)			0.50 (0.50)	0.13 (0.13)
M. cavernosa	6.50 (4.57)	14.50 (3.59)	1.00 (0.71)	0.75 (0.75)	3.75 (2.75)	7.63 (6.88)
M. faveolata		1.00 (0.58)	0.25 (0.25)	1.00 (1.00)	0.13 (0.13)	1.00 (0.00)
P. astreoides	1.00 (0.41)	1.25 (0.63)	0.25 (0.25)	1.50 (0.96)	0.63 (0.38)	1.38 (0.13)
P. porites furcata	0.50 (0.29)			0.25 (0.25)	0.25 (0.25)	0.13 (0.13)
P. porites porites			0.25 (0.25)	0.25 (0.25)	0.13 (0.13)	0.13 (0.13)
S. radians	0.75 (0.25)	0.75 (0.25)		0.50 (0.29)	0.38 (0.38)	0.63 (0.13)
S. siderea	3.00 (0.91)	1.25 (0.48)	3.00 (2.04)	3.25 (2.93)	3.00 (0.00)	2.25 (1.00)
S. bournoni				0.50 (0.50)		0.25 (0.25)
Total coral cover	14.00 (4.56)	21.50 (4.63)	5.50 (2.10)	9.00 (2.27)	9.75 (4.25)	15.25 (6.25)
Branching gorgonians	0.25 (0.25)	1.25 (0.48)	0.50 (0.29)	0.50 (0.29)	0.38 (0.13)	0.88 (0.38)
Sponges	6.50 (1.04)	4.25 (0.75)	8.25 (2.39)	6.25 (1.03)	4.13 (2.71)	5.25 (1.00)
Algal turf	30.75 (2.14)	28.50 (2.40)	26.50 (2.40)	19.50 (1.55)	28.63 (2.13)	24.00 (4.50)
Coralline algae	6.25 (1.70)	18.50 (3.43)	8.75 (1.55)	19.50 (2.78)	7.50 (1.25)	19.00 (0.50)
Green foliose algae	0.75 (0.48)	0.25 (0.25)	1.00 (0.71)	0.50 (0.29)	0.88 (0.13)	0.38 (0.13)
Halimeda spp.	4.25 (0.63)	2.75 (0.48)	3.25 (1.03)	3.50 (0.50)	3.75 (0.50)	3.13 (0.38)
Brown foliose algae	11.00 (2.45)	1.75 (0.63)	9.00 (2.27)	8.50 (3.28)	10.00 (1.00)	5.13 (3.38)
Red foliose algae	0.50 (0.29)		0.25 (0.25)		0.38 (0.13)	
Red calcareous algae	0.50 (0.29)			2.00 (0.82)	0.25 (0.25)	1.00 (1.00)
Cyanobacteria	1.75 (0.48)		2.50 (1.66)	0.25 (0.25)	2.13 (0.38)	0.13 (0.13)
Total algal cover	56.75 (1.31)	51.75 (4.33)	51.75 (6.12)	53.75 (5.01)	54.25 (2.50)	52.75 (1.00)
Sand	12.75 (2.63)	15.00 (2.35)	14.00 (2.80)	16.25 (6.07)	13.38 (0.63)	15.63 (0.63)
Sand on hard-bottom	10.25 (3.12)	4.00 (1.47)	19.50 (4.99)	5.50 (1.19)	14.88 (4.63)	4.75 (0.75)

The three most abundant juveniles on experimental and control patch reefs were *Porites astreoides*, *Siderastrea radians*, and *S. siderea*. The size distribution of juvenile *P. astreoides* indicated increases in most size classes, especially colonies < 2.5 cm in maximum diameter (Fig. 7). In contrast, the size distribution of *S. radians* showed little change from year to year or between experimental and control sites (Fig. 8). For *S. siderea*, the decrease in mean juvenile size for both experimental patch reefs was principally due to the greater abundance of smaller juveniles (< 1.5 cm) observed during 2002 (Fig. 9). A similar pattern was observed on CR #3 for this species, but not CR #4. For some of the more common species observed as juveniles, while greater numbers of smaller size classes were observed in 2002 compared to 2001, these changes were magnified on the experimental patch reefs.

Table 9. Mean (1 SE) percent cover of major benthic groups on control patch reefs before and one year after urchin translocation. Sample size = 4 transects per site per year and 100 points per transect.

Bottom type	Control site #3		Control site #4		Combined control	
	2001	2002	2001	2002	2001	2002
A. agaricites	0.50 (0.29)		0.25 (0.25)	0.25 (0.25)	0.38 (0.13)	0.13 (0.13)
A. fragilis				0.25 (0.25)		0.13 (0.13)
C. natans			1.00 (1.00)		0.50 (0.50)	
D. stokesi	0.50 (0.29)	0.50 (0.29)			0.25 (0.18)	0.25 (0.25)
D. labyrinthiformis				1.75 (1.44)		0.88 (0.88)
M. alcicornis	0.50 (0.29)	0.25 (0.25)	0.25 (0.25)	0.25 (0.25)	0.38 (0.13)	0.25 (0.00)
M. cavernosa			6.75 (3.90)	3.25 (3.25)	3.38 (3.38)	1.63 (1.63)
M. faveolata	1.00 (1.00)	1.50 (1.50)			0.50 (0.50)	0.75 (0.75)
M. frankski				0.25 (0.25)		0.13 (0.13)
P. astreoides	1.50 (0.96)	0.75 (0.48)	1.50 (0.50)	0.75 (0.25)	1.50 (0.00)	0.75 (0.00)
P. porites furcata	0.50 (0.29)	0.50 (0.29)	0.25 (0.25)	0.25 (0.25)	0.38 (0.13)	0.38 (0.13)
S. radians		0.50 (0.50)		0.50 (0.29)		0.50 (0.50)
S. siderea	0.25 (0.25)		2.00 (0.71)	1.00 (0.41)	1.13 (0.88)	0.50 (0.50)
S. bournoni	1.25 (1.25)	1.00 (1.00)			0.63 (0.63)	0.50 (0.50)
S. michelini	0.25 (0.25)				0.13 (0.13)	
Total coral cover	6.25 (2.21)	5.00 (2.74)	12.00 (4.45)	8.50 (3.20)	9.13 (2.88)	6.75 (1.75)
Branching gorgonians		1.25 (0.63)	0.25 (0.25)	0.75 (0.25)	0.13 (0.13)	1.00 (0.25)
Sponges	6.75 (1.31)	7.00 (2.12)	3.75 (1.49)	5.00 (0.58)	5.25 (1.50)	6.00 (1.00)
Algal turf	21.50 (4.77)	25.00 (4.22)	25.25 (4.97)	30.50 (2.72)	23.38 (1.88)	27.75 (2.75)
Coralline algae	6.25 (1.65)	9.75 (2.59)	9.25 (2.59)	6.75 (1.31)	7.75 (1.50)	8.25 (1.50)
Green foliose algae	0.25 (0.25)	1.00 (0.41)	1.25 (0.75)		0.13 (0.13)	0.50 (0.50)
Halimeda spp.	2.75 (0.63)	4.75 (1.89)	0.75 (0.48)	2.75 (1.31)	1.75 (1.00)	3.75 (1.00)
Brown foliose algae	6.00 (2.04)	10.75 (2.63)	3.00 (1.78)	1.00 (0.41)	4.50 (1.50)	5.88 (4.88)
Red foliose algae						
Red calcareous algae		2.25 (0.95)				1.13 (1.13)
Cyanobacteria	15.25 (4.66)		5.75 (1.11)	1.00 (0.41)	10.50 (4.75)	0.50 (0.50)
Total algal cover	52.00 (5.99)	53.50 (8.05)	45.25 (5.19)	42.00 (3.49)	48.63 (3.38)	47.75 (5.75)
Sand	21.00 (9.16)	21.25 (9.34)	21.50 (5.52)	29.50 (7.01)	21.25 (0.25)	25.38 (4.13)
Sand on hard-bottom	14.00 (4.34)	7.50 (2.33)	0.50 (0.29)	3.75 (1.80)	7.25 (6.75)	5.63 (1.88)

Discussion

The community structure of coral reefs throughout the Caribbean and in Florida has changed in dramatic ways over the last two decades. The epizootic die-off of the keystone grazer *Diadema antillarum* in the 1980s (Lessios 1988), whiteband disease that killed *Acropora* corals to the point of ecological extinction (Aronson and Precht 2001), possibly nutrification (Lapointe 1997), and overfishing (Hughes et al. 1999), have all contributed to a shift from coral reefs dominated by stony corals to dominance by macroalgae. Because grazing by *D. antillarum* previously had such a profound effect in reducing macroalgae on coral reefs, and because juvenile sea urchins are apparently readily available in select rubble zone habitats in the Florida Keys, we decided to test the efficacy of translocating sea urchins to evaluate survival after translocation and the potential effects of increased grazing on benthic community structure. Two of the experimental patch reefs received over six hundred transplanted urchins during 2001, and despite 70% mortality after one year, densities still averaged approximately 1 urchin/m^2, similar to historical densities reported for the Florida Keys (Kier and Grant 1965; Bauer 1976, 1980). Sources of sea urchin mortality identified during the one-year study included storms (primarily in rubble zone habitats; see previous chapter) and fish predation.

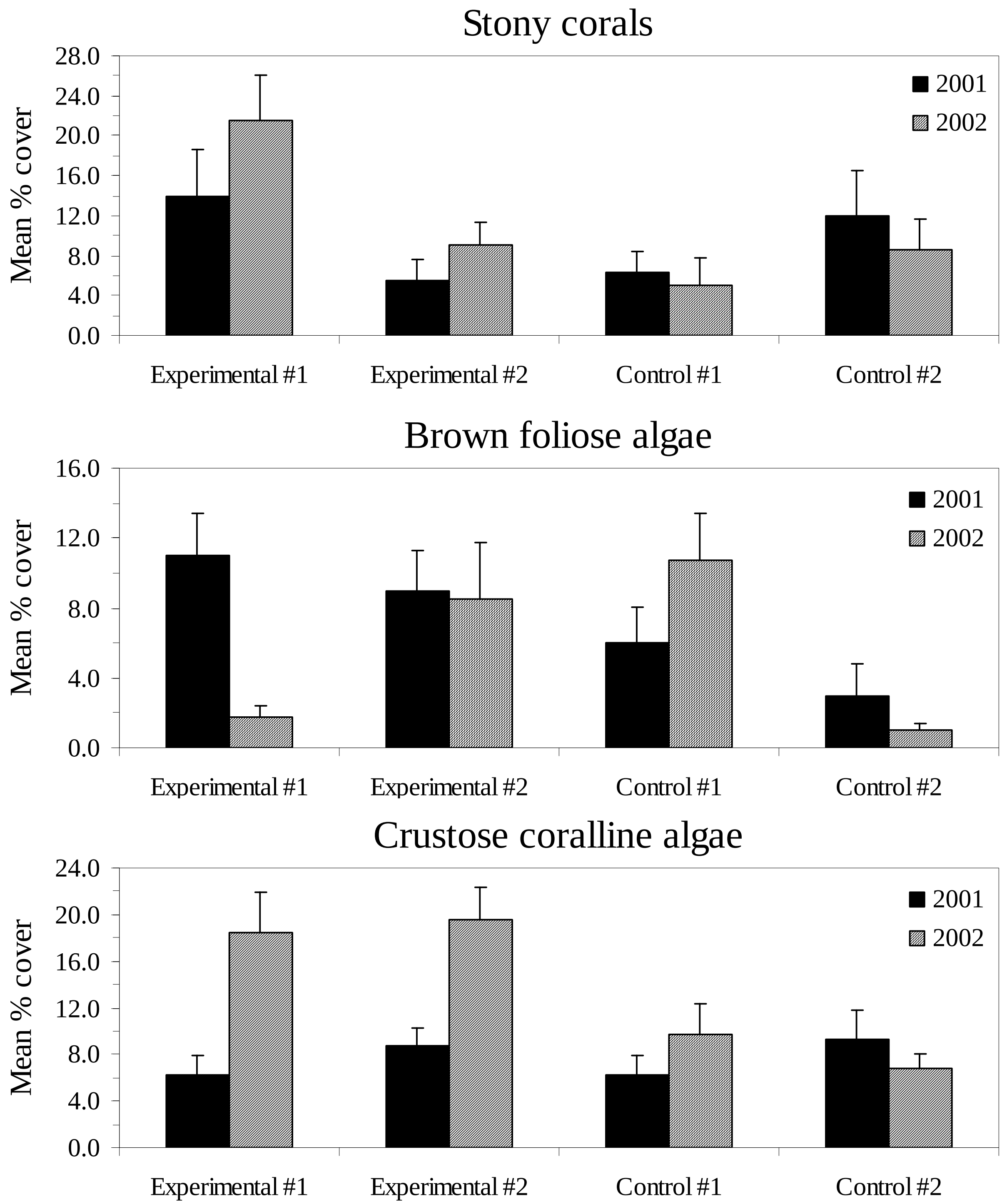

Figure 5. Changes in mean percent cover of stony corals, crustose coralline algae, and brown foliose algae before and one year after urchin translocation on Florida Keys patch reefs. Error bars represent one standard error. “Control #1 and #2” = CR #3 and CR #4.

Table 10. Mean (1 SE) density (no. per m^2) of juvenile scleractinian corals on experimental (top) and control (bottom) patch reefs before and one year after urchin translocation. Sample size = ten 0.65 m x 0.48 m quadrats along each of two transects per site (total area per transect = 3.12 m^2).

Experimental patch reefs

Coral species	Experimental site #1		Experimental site #2		Combined experimental	
	2001	2002	2001	2002	2001	2002
A. agaricites	0.77 (0.24)	0.32 (0.32)		0.32 (0.32)	0.39 (0.39)	0.32 (0.00)
A. fragilis				0.48 (0.48)		0.24 (0.24)
E. fastigiata				0.16 (0.16)		0.08 (0.08)
L. cucullata				0.16 (0.16)		0.08 (0.08)
M. cavernosa			0.32 (0.32)		0.16 (0.16)	
P. astreoides	1.28 (0.32)	2.72 (1.12)	1.76 (0.48)	6.89 (2.08)	1.52 (0.24)	4.81 (2.09)
P. branneri				0.16 (0.16)		0.08 (0.08)
P. porites	0.80 (0.48)	0.32 (0.32)	0.32 (0.00)	1.60 (0.00)	0.56 (0.24)	0.96 (0.64)
S. radians	3.85 (0.96)	4.97 (4.01)	3.04 (0.80)	4.01 (1.44)	3.45 (0.41)	4.49 (0.48)
S. siderea	0.16 (0.16)	4.17 (4.17)	0.32 (0.32)	3.53 (2.88)	0.24 (0.08)	3.85 (0.32)
S. bournoni	0.16 (0.16)	0.32 (0.32)			0.08 (0.08)	0.16 (0.16)
S. michelini		0.16 (0.00)		0.16 (0.16)		0.16 (0.00)
Total density	6.57 (0.80)	13.14 (1.28)	5.77 (0.64)	17.47 (4.01)	6.17 (0.40)	15.31 (2.17)
Total species	6	7	5	10	7	11

Control patch reefs

Coral species	Control site #3		Control site #4		Combined control	
	2001	2002	2001	2002	2001	2002
A. agaricites		0.48 (0.16)	1.92 (0.00)	1.12 (0.80)	0.96 (0.96)	0.80 (0.32)
D. stokesi	0.16 (0.16)			0.16 (0.16)	0.08 (0.08)	0.08 (0.08)
M. cavernosa	0.32 (0.32)	0.16 (0.16)		0.32 (0.00)	0.16 (0.16)	0.24 (0.08)
P. astreoides	2.08 (1.76)	4.17 (0.32)	2.72 (0.48)	3.04 (0.16)	2.40 (0.32)	3.61 (0.57)
P. branneri			0.16 (0.16)		0.08 (0.08)	
P. porites	0.16 (0.16)	0.48 (0.48)		0.64 (0.64)	0.08 (0.08)	0.56 (0.08)
S. radians	2.40 (1.44)	1.92 (0.32)	1.60 (0.32)	1.76 (1.76)	2.00 (0.40)	1.84 (0.08)
S. siderea	0.48 (0.16)	3.53 (0.32)	0.48 (0.16)	1.60 (0.96)	0.48 (0.00)	2.57 (0.97)
S. michelini	0.32 (0.32)	0.32 (0.00)	0.32 (0.32)	0.16 (0.16)	0.32 (0.00)	0.24 (0.08)
Total density	5.93 (0.16)	11.06 (0.48)	7.21 (0.80)	8.81 (2.72)	6.57 (0.64)	9.94 (1.13)
Total species	7	7	6	8	9	8

Previous studies have clearly shown the effects of enhanced or depressed sea urchin densities on coral reef community structure. Experimental reductions of sea urchins on patch reefs on the north coast of Jamaica caused substantial changes in algal biomass, species composition, and coral recruitment (Sammarco 1980), while the mass mortality of *Diadema antillarum* in 1983-84 resulted in marked increases in algal cover, changes in algal species composition, and declines in coral cover and recruitment, especially in shallower reef habitats (Liddell and Ohlhorst 1986; Hughes et al. 1987). Conversely, artificially enhanced or naturally recovering sea urchin populations can cause marked declines in macroalgal abundance and increases in juvenile coral densities (Edmunds and Carpenter 2001; Haley and Solandt 2001; Solandt and Campbell 2001). Not surprisingly, results from our translocation indicate that enhanced sea urchin densities are probably responsible for the changes in algal species composition and abundance and juvenile coral densities recorded, even over the course of only one year. These results are not unexpected, as a number of studies have demonstrated the effects of increased urchin densities on coral reef benthos (Edmunds and Carpenter 2001), or conversely, the effects of the 1983-84 mass mortality of sea urchins on benthic community structure (Hughes et al. 1985; Carpenter 1990). Without sea urchins, fleshy and filamentous algae are abundant and corals are scarce, but with *D. antillarum*, opposing patterns emerge (Woodley 1999a).

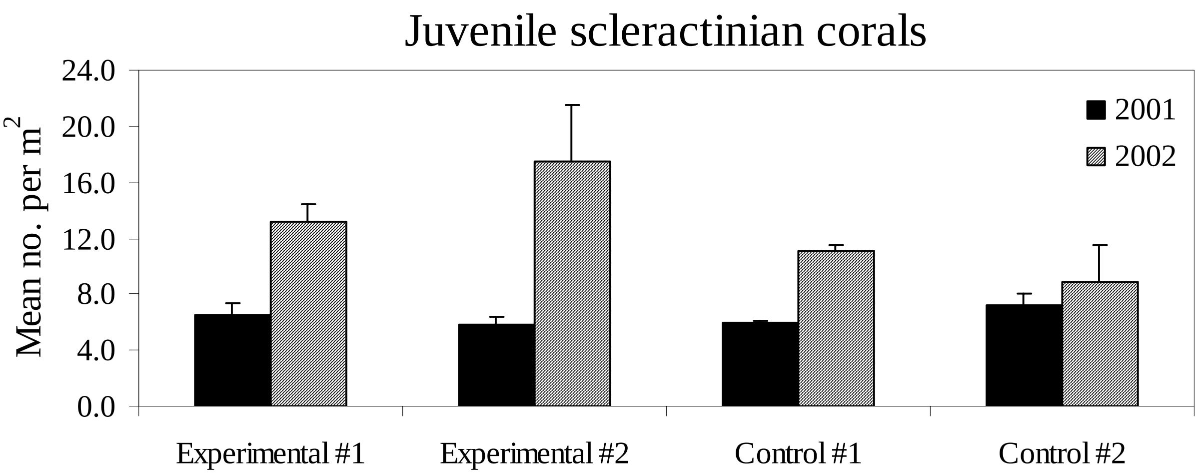

Figure 6. Changes in mean density (no. colonies per m^2) of juvenile scleractinian corals before and one year after urchin translocation on Florida Keys patch reefs. Error bars represent one standard error. “Control #1 and #2” = CR #3 and CR #4.

Table 11. Mean (1 SE) diameter (cm) of juvenile scleractinian corals on experimental (top) and control (bottom) patch reefs before and one year after urchin translocation. N = number of juveniles sampled.

Experimental patch reefs

Coral species	Experimental site #1				Experimental site #2			
	2001		2002		2001		2002	
	N	Mean	N	Mean	N	Mean	N	Mean
A. agaricites	2	2.1 (0.9)	2	2.4 (1.5)			2	2.3 (1.3)
A. fragilis							3	2.8 (0.2)
E. fastigiata							1	0.8 (---)
L. cucullata							1	0.9 (---)
M. cavernosa					2	1.8 (0.9)		
P. astreoides	8	2.2 (0.4)	18	2.0 (0.3)	11	1.8 (0.3)	28	1.4 (0.2)
P. branneri							1	2.7 (---)
P. porites	5	2.7 (0.3)	2	1.5 (0.0)	2	1.5 (0.6)	4	1.8 (0.4)
S. radians	24	2.0 (0.2)	31	1.7 (0.1)	19	1.3 (0.2)	8	1.8 (0.4)
S. siderea	1	2.4 (---)	25	0.8 (0.2)	2	2.1 (0.7)	20	0.8 (0.2)
S. bournoni	1	3.2 (---)	2	2.4 (0.1)				
S. michelini			2	1.0 (0.4)			1	1.3 (---)

Control patch reefs

Coral species	Control site #1				Control site #2			
	2001		2002		2001		2002	
	N	Mean	N	Mean	N	Mean	N	Mean
A. agaricites			3	3.0 (0.4)	12	1.4 (0.3)	7	2.3 (0.2)
D. stokesi	1	2.4 (---)					1	2.4 (---)
M. cavernosa	2	1.0 (0.2)	1	1.7 (---)			2	2.9 (0.7)
P. astreoides	13	2.0 (0.3)	27	1.5 (0.2)	16	1.6 (0.2)	18	1.7 (0.3)
P. branneri					1	1.1 (---)		
P. porites	1	2.4 (---)	3	2.4 (0.9)			4	1.8 (0.7)
S. radians	15	1.8 (0.2)	12	2.4 (0.3)	10	1.5 (0.2)	11	1.7 (0.2)
S. siderea	3	2.7 (0.5)	22	1.1 (0.2)	3	1.8 (0.3)	10	1.2 (0.2)
S. michelini	2	2.5 (0.3)	2	2.7 (1.2)	2	1.7 (0.5)	1	2.9 (---)

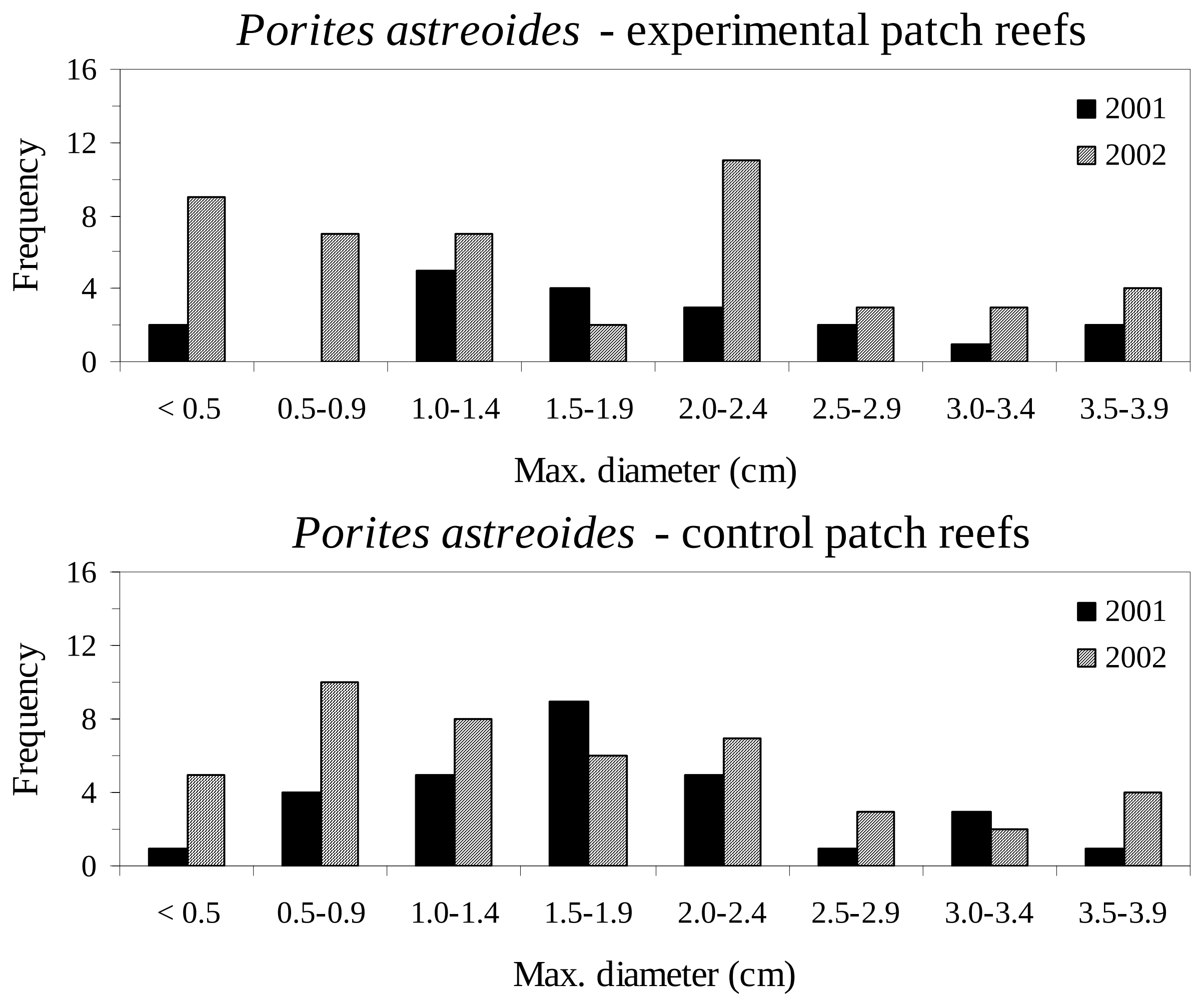

Figure 7. Size frequency distributions of juvenile *Porites astreoides* before and one year after urchin translocation on Florida Keys patch reefs.

Recent studies on the north coast of Jamaica have shown that urchin densities within particular zones are 10 times higher than in adjacent areas and may initiate a phase shift reversal from algal to coral dominance (Edmunds and Carpenter 2001). Within these urchin zones, juvenile coral densities are 2 to 11 times greater than in seaward zones dominated by macroalgae. At low sea urchin densities, macroalgal abundance is high and settlement of coral spat may be high, but survivorship is low due to algal overgrowth. In contrast, at high sea urchin densities, intense grazing may damage juvenile corals and coral survivorship may be reduced (Sammarco 1980). In our translocation study, the increase in the number of species and densities of juvenile corals may be due to two causal mechanisms. First, increased sea urchin grazing and hence a reduction in fleshy macroalgae may facilitate the identification of smaller (< 4 cm) corals within quadrats during 2002, particularly on the experimental sites. Second, increased grazing by urchins could have led to increased coverage by crustose coralline algae, which may enhance coral settlement. For example, lettuce coral larvae of the genus *Agaricia* are induced to metamorphose by crustose coralline algae (Morse et al. 1988) and experimental studies have shown that *A. humilis* settle and metamorphose in response to chemosensory recognition of a morphogen on the surface of the alga *Hydrolithon boergesenii* (Morse et al. 1994). Although juvenile *Agaricia* were not the

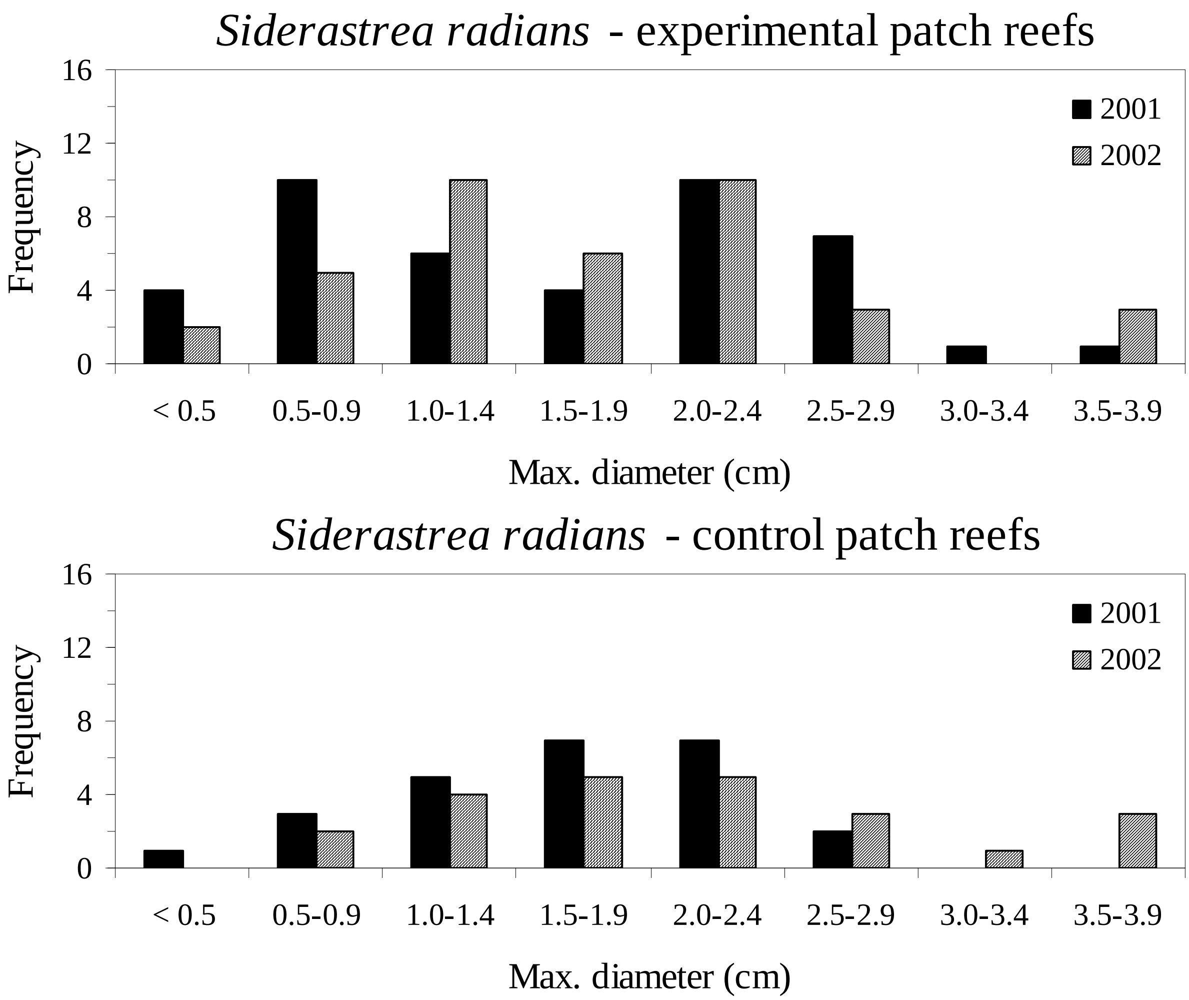

Figure 8. Size frequency distributions of juvenile *Siderastrea radians* before and one year after urchin translocation on Florida Keys patch reefs.

most abundant juveniles on the experimental patch reefs, it was clear that coverage of crustose coralline algae increased on the experimental reefs. However, without knowing the settlement preferences of the most abundant juvenile corals, it is impossible to discern whether increased grazing facilitated our ability to detect small juvenile corals or settlement was enhanced because of reduced algal cover. It is also plausible that a pulse recruitment event or greater post-settlement survivorship occurred for several coral species during the study period, as increases in juvenile densities, especially smaller size classes, were also recorded on the control patch reefs.

It will remain important to monitor these patch reefs during the next one to two years, in order to ascertain the fate of the remaining translocated urchins. If these sea urchins remain for the time being, will changes to the benthos continue, or if they suffer mortality, if and how quickly will the patch reefs return to their previous state? It appears that sea urchin densities of about 1 individual per m^2 were sufficient to cause detectable changes on these patch reefs, even over a relatively short period. While more substantial changes have been recently reported for Jamaican reefs (Edmunds and Carpenter 2001), especially in terms of juvenile coral densities, sea urchin densities are significantly greater than the experimental patch reefs used in our study. Other issues to address concern how much translocation, if any, will be required in other habitat types

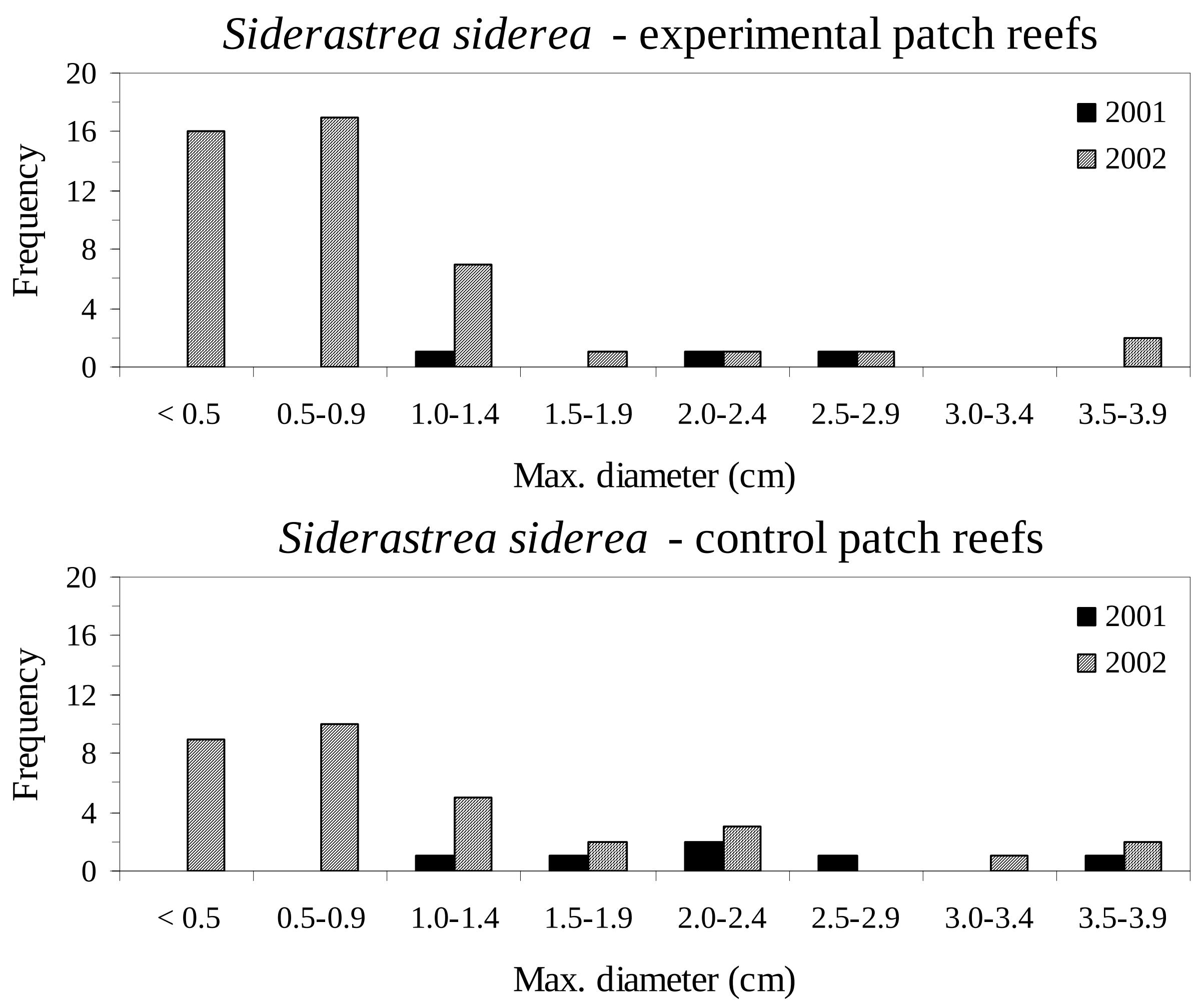

Figure 9. Size frequency distributions of juvenile *Siderastrea siderea* before and one year after urchin translocation on Florida Keys patch reefs.

to maintain densities of approximately one sea urchin per m^2, as well as the principal causes of sea urchin mortality after translocation. It is also possible that juvenile sea urchin settlement may eventually be enhanced by the presence of adult sea urchins on the experimental reefs.

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