Recovery of reefs at Discovery Bay, Jamaica and the role of *Diadema antillarum*

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ABSTRACT

The status of the reefs near Discovery Bay was assessed in 1997 to investigate their extent of degradation. Data were collected at 27 reef sites, and 3 depths using point intercept transects. At three previously studied sites, coral cover had increased significantly at all three depths (from <5% to 13.8%) since 1989, due partly to recruitment by opportunistic colonizers such as *Porites astreoides*, and *Agaricia agaricites*, and at 5 m due to grazing by *Diadema antillarum*. Cover by macroalgae had decreased (from 79% to 50.6%), especially at 5 m, where the abundance of *Diadema* and other sea urchins has increased in recent years. The nutrient levels on the fore reef were very low, with infrequent surface pulses of 1.0-1.5 µM of Dissolved Inorganic Nitrogen and 0.1-0.2 µM of Dissolved Inorganic Phosphorus. The substantial increase in coral cover and decrease in macroalgal cover indicate that the reefs of Discovery Bay may be on the road to recovery.

Keywords Coral, Jamaica, Macroalgae, *Diadema*, Nutrients, Recovery.

Introduction

Jamaican reefs are among the most widely studied in the world. Numerous studies in physiology, functional morphology and other aspects of biology and ecology of reef organisms have been carried out at Discovery Bay (e.g. Goreau 1959, Goreau and Goreau 1973, Goreau and Land 1974, Kinzie 1973, Porter et al. (1981), Liddell and Ohlhorst 1986, 1992). These reefs were once thought to be the most diverse Caribbean reefs (Goreau 1959, Goreau and Goreau 1973).

In the past two decades, the reefs have seen a decline in coral diversity and abundance (Huston 1985 , Liddell and Ohlhorst 1987, Andres and Witman 1995). These changes are believed to have been induced by decades of increasing chronic disturbance coupled with acute catastrophic events. The history of decline started in 1980 when hurricane Allen destroyed the shallow reef community at Discovery Bay (Woodley et al. 1981). In 1980, shortly before Allen, *Acropora cervicornis* suffered from white band disease (Tunnicliffe 1983). In 1983 the mass mortality of the grazing echinoid *Diadema antillarum*, an important grazer on the reef (Sammarco et al. 1974, Sammarco 1980), occurred throughout the Caribbean from a water-borne pathogenic disease (Lessios et al. 1984, Hughes et al. 1985). Since other herbivores had already been greatly reduced by overfishing, these disturbances resulted in declines in coral abundance and a major bloom of macroalgae, probably enhanced in some localities by terrestrial runoff from nearby human communities. In 1988, any recovery by corals was further set back by hurricane Gilbert (Woodley 1989). Such extensive disturbance in a relatively short period of time resulted in further decline of reefs, which never had a chance to recover from any one event (Liddell and Ohlhorst 1986, Hughes 1994, Liddell and Ohlhorst 1992, Lapointe 1997, Hughes et al. 1999).

In the 15 years previous to this study, coral abundance above a depth of 30 m had declined on the fore reef from 30-60% in 1977 to <5% in 1992. Coral cover was high (27%) only at 30 m (Andres and Witman 1995). Macroalgal cover above 30 m had increased from 5% to 79%. The community structure of the shallow West Fore Reef at Discovery Bay had changed from coral dominated to alga dominated (Goreau 1992, Liddell and Ohlhorst 1992, Hughes 1994).

The reefs near Discovery Bay were assessed in 1997 to determine their current status. Surveys of benthic community composition were carried out to investigate whether the reefs had seen any recovery. At the same time, levels of dissolved inorganic nutrients and the abundance of *Diadema* were measured. It was found that the reefs have seen recovery since the last decade and that herbivory from increasing populations of *Diadema antillarum* may be partly responsible for the observed increase in coral abundance. In addition, the nutrient levels on the reefs were found to be very low.

Methods

The study area was located on the north coast of Jamaica from Rio Bueno to Pear Tree Bottom, including Discovery Bay and covered 10 km of coastline (Fig 1a,b). Data on community structure were gathered in 1997, using point intercept transects 10 m in length, marked at 20 cm intervals. There were a total of 27 sites, and at each site three depths were surveyed: 5, 10 and 15 m. At each depth, data from 15 transects, 1 m apart, were collected. The substratum beneath each transect point was categorized into one of nine benthic groups: coral, other cnidarians, macroalgae, turf algae, crustose coralline algae, sponges, bare rock, sand, rubble. On each transect, *Diadema antillarum* were counted along a 1 m band.

Nutrient levels were assessed from water samples collected monthly at surface and 10 m, from August

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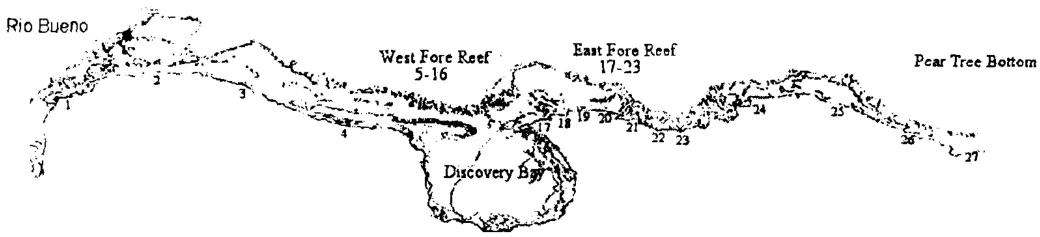

Fig. 1a Map of the study area showing the North Coast of Jamaica from Rio Bueno to Pear Tree Bottom, a distance of approximately 10 km. Note Discovery Bay located in the centre.

to December 1997. Dissolved inorganic nitrogen and dissolved inorganic phosphorus were determined using standard tests (Parsons et al. 1984) on samples from 3 sites on the West Fore Reef and 4 sites on the East Fore Reef, with a known enriched site in the back reef of Discovery Bay as control for high nutrients. The back reef area of Discovery Bay has been shown to possess high nutrient levels at or near areas of freshwater submarine springs, which carry groundwater from the land (D'Elia et al. 1981). Results from previous reef surveys (Liddell and Ohlhorst 1992, Andres and Witman 1995, Edmunds and Bruno 1996) were used for comparisons to determine the changes that have occurred in the last 5 years.

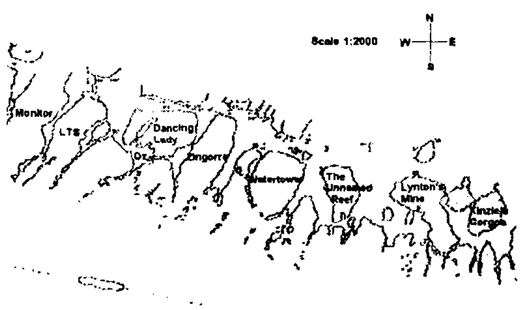

Fig. 1b Map of the West Fore Reef showing the reefs used in the historical comparison: LTS, Zingorro and Kinzie's.

Results

Community structure patterns

There was variation in community structure over the 10 km distance and among the three depths explored. Since corals and macroalgae are the main focus groups in assessing reef condition, only these two will be addressed in this paper. The mean coral cover at 15 m (10.7%) was significantly lower than at 5 and 10 m (using multiple anova tests and Tukey HSD significant difference at 95% C.I). At 5 and 10 m, however, the mean coral cover was approximately the same (14.9% and 15.9%) (Fig. 2a). Mean macroalgal cover increased significantly with depth: at 5 m cover by macroalgae was 34.3%; it increased to 56.5% at 10 m and 61.8% at 15 m (Fig. 2b). Coral cover varied among the 27 sites, from 4% to 40%

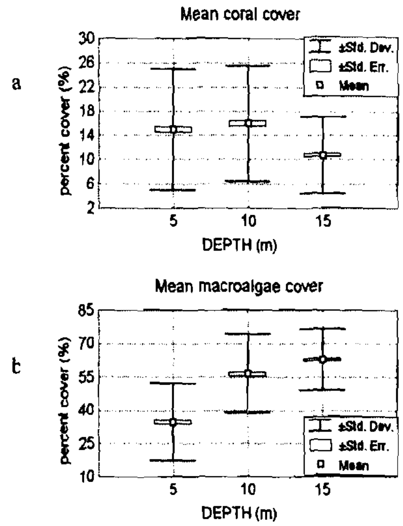

Fig. 2 Mean coral and macroalgae cover at 5, 10 and 15 m on fore reefs near Discovery Bay. The results are a mean of 27 sites surveyed between Rio Bueno and Pear Tree Bottom, a distance of ≈10 km.

and cover by macroalgae from 11% to 84% (Fig. 3).

Diadema abundance and distribution

Diadema abundance varied from site to site at 5 m, with densities ranging from 0.1 m^{-2} to 3.4 m^{-2} (Fig. 4a). *Diadema* distribution was also very patchy at 10 m and the highest density was 0.6 m^{-2} (Fig. 4b). The mean abundance of *Diadema* was 1.54±1.5(SD) m^{-2} at 5 m, 0.1±0.3 m^{-2} at 10 m, and 0 m^{-2} at 15 m depth (Fig. 4c). At 5 m, the abundance of macroalgae was inversely correlated with density of *Diad*ema, while the abundance of corals showed a slightly positive correlation with *Diadema* density (Table 1).

Table 1. Correlation matrix for *Diadema* with corals and macroalgae at 5 m. (Pearson Product Moment Correlation r, $p < 0.05$).

	corals	macroalgae
Diadema	0.14	-0.45

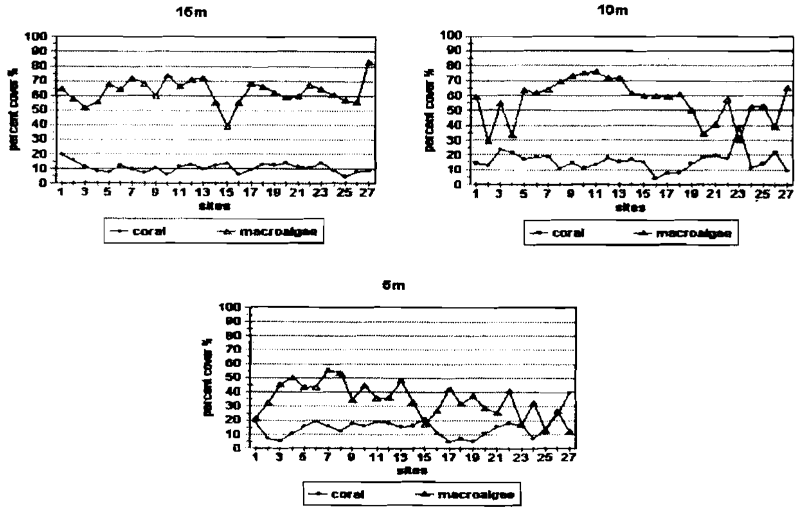

Fig. 3 Coral and macroalga cover found at 27 reef sites along the north coast of Jamaica, at three depths: 5, 10 and 15 m. Sites 1-4 are between Discovery Bay and Rio Bueno, sites 5-23 are located on the West and East Fore reefs of Discovery Bay and sites 24-27 are found between Discovery Bay and Pear Tree Bottom.

Coral species abundance and distribution

The most abundant coral species at all three depths were *Porites astreoides, Porites porites* and *Agaricia agaricites* (Fig. 5). *Acropora cervicornis* and *Acropora palmata*, historically the spatial dominants, were uncommon. *Montastrea annularis* was also very reduced and was no longer a dominant frame builder as in previous decades before (Goreau 1959, Hughes 1994).

Comparisons with the historical data

Comparisons between the present data and those from past studies (Liddell and Ohlhorst 1992, Andres and Witman 1995, Edmunds and Bruno 1996) at three reef sites on the West Fore Reef: Kinzie's, Zingorro, LTS and the East Fore Reef at Dairy Bull, show that coral cover has increased significantly (Student's t-test for difference between two means) at all three depths (from <5% to 13.8%). Liddell and Ohlhorst used point intercept transects (11), Andres and Witman used line transects (4) and Edmunds and Bruno used point intercept transects (5). At 10 m on Kinzie's reef coral cover increased significantly from 2.0% in 1994 (Edmunds and Bruno 1996) to 12.3% in 1997, $p<0.05$ (difference between two means). Macroalgal cover was reduced from 62% to 53% but was not significant (Fig. 6). On Dairy Bull, East Fore Reef at 10 m coral cover increased significantly from 23% in 1994 (Edmunds and Bruno 1996) to 39% in 1997, $p<0.05$. Macroalgal cover decreased from 39% to 30.1% (Fig. 6). On Zingorro reef, at 15 m, coral cover increased significantly from 2.3% in 1989 (Liddell and Ohlhorst 1992) to 11.6% in 1997, $p<0.05$. Macroalgal cover was about the same (Fig. 7). At LTS reef the change in coral and macroalgal cover was compared for 5, 10 and 15 m. Coral cover increased significantly at all three depths from 1992 to 1997, $p<0.05$ (Fig. 8). Macro-algae decreased at all three depths but only at 5 m was the reduction significant, from 70% in 1992 (Andres and Witman 1995) to 34.5% in 1997, $p<0.05$ (Fig. 8).

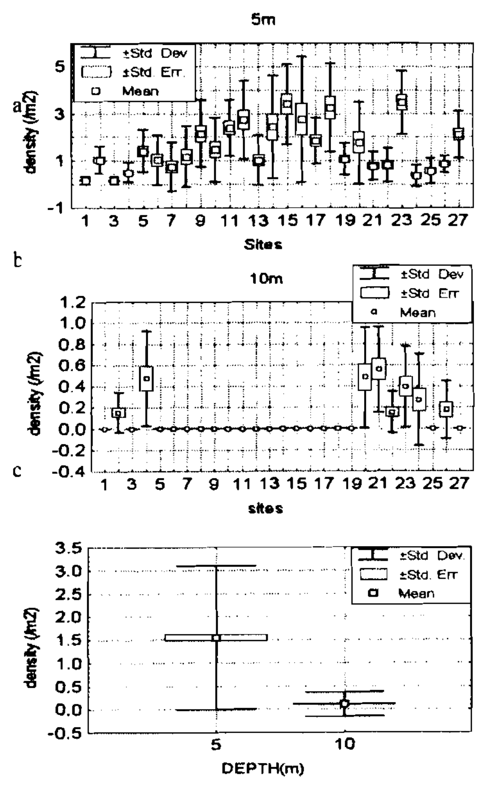

Fig. 4 *Diadema* abundance at 5 and 10 m from 27 fore reef sites (a, b) and the difference in mean density between 5 and 10 m (c) near Discovery Bay, Jamaica.

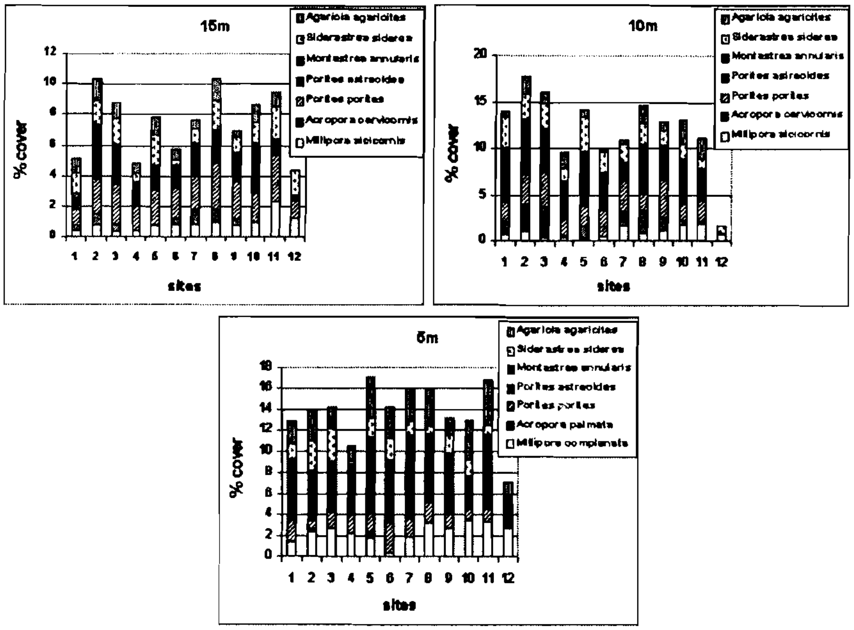

Fig. 5 Abundance of the major coral species found on the West Fore Reef of Discovery Bay at three depths: 5, 10 and 15 m.

Nutrient status of Discovery Bay reefs

Nutrient levels on the fore reefs near Discovery Bay were low, with a few infrequent pulses of 1.0-1.5 μM

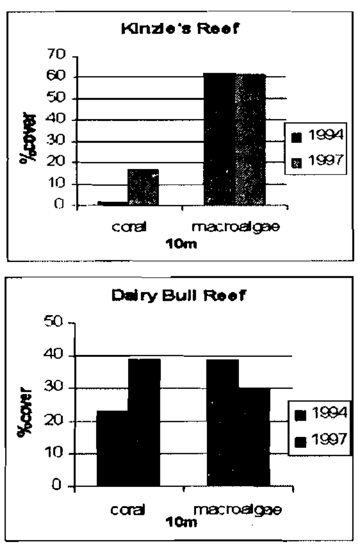

Fig. 6 Change in coral and macroalgae cover at 10 m on Kinzie's and Dairy Bull Reef between 1994 and 1997.

Dissolved Inorganic Nitrogen (DIN) and 0.1-0.2 μM Dissolved Inorganic Phosphorus (DIP) (Table 2).

These slight increases in the DIN and DIP levels were low and not considered as evidence of chronic enrichment, as these results were never replicated in consecutive months and were only slightly above the critical threshold of 1.0 μM DIN and 0.1 μM DIP. Above these levels macroalgal productivity is saturated and a phase shift occurs from coral to macroalgae abundance (Lapointe 1997). The high DIN or DIP generally coincided with rainfall or lowered salinities, on the sampling days.

Discussion

Coral and macroalgal abundance varied significantly over the 27 reef sites and among the three depths. The difference in coral and macroalgal cover among depths and sites is partly a result of sampling variance, fore reef morphology, depth, wave energy and biological factors, particularly herbivory, which govern the distribution and abundance of corals. There was an increase in the *Diadema* populations on the reefs at 5 m, since the last survey in 1993 (Hughes 1994) and movement into deeper waters up to 10 m. At 5 m, wherever *Diadema* was abundant the grazing of this sea urchin had apparently shaped the community reducing macroalgal cover and enabling greater coral cover (Woodley 1999). Very high densities of *Diadema* inhibit coral recruitment and growth, with maximum coral recruitment and growth occurring at intermediate densities (4 m^{-2}) (Sammarco 1980).

Table 2. Dissolved Inorganic Nitrogen and Phosphorus (DIN, DIP) concentrations in µM, from August to December 1997 for eight sites. NA – not analysed, sites 1-3 from West Fore Reef; sites 4-7 from East Fore Reef; site 8 from freshwater spring in back reef.

SITE	Aug 13		Oct 14		Nov 4		Nov 11		Nov 19		Dec 11		Dec 18	
	DIN	**DIP**	**DIN**	**DIP**	**DIN**	**DIP**	**DIN**	**DIP**	**DIN**	**DIP**	**DIN**	**DIP**	**DIN**	**DIP**
1 (surface)	-	0.03	-	0.06	-	0.05	0.06	0.03	0.49	0.04	0.3	0.03	0.2	-
1 (10 m)	-	0.05	-	0.07	-	0.02	1.16	0.08	0.37	0.05	0.2	0.02	0.2	-
2 (surface)	-	-	-	0.06	-	0.03	-	-	0.39	0.06	-	-	0.2	-
2 (10 m)	-	-	-	0.06	-	0.03	0.1	0.03	0.4	0.04	0.2	0.02	0.3	-
3 (surface)	-	0.02	0.65	0.17	-	0.02	-	-	0.85	0.11	-	0.02	0.3	-
3 (10 m)	-	0.02	-	0.07	-	0.06	-	-	0.4	0.04	0.2	0.02	0.2	-
4 (surface)	-	0.05	-	0.07	-	-	0.24	0.04	0.35	0.04	-	-	0.2	-
4 (10 m)	-	0.03	-	0.05	1.34	0.12	0.13	0.03	0.3	0.04	-	0.02	0.2	-
5 (surface)	-	0.03	-	0.06	-	0.05	0.06	0.03	0.35	0.04	0.5	0.05	0.2	-
5 (10 m)	-	0.03	-	0.06	-	0.06	0.24	0.04	0.37	0.04	0.2	0.02	0.2	-
6 (surface)	-	-	-	0.15	-	0.02	0.32	0.04	0.4	0.04	0.4	0.03	0.2	-
6 (10 m)	-	-	-	0.13	-	0.02	-	-	0.54	0.05	0.2	0.02	0.3	-
7 (surface)	NA	NA	1.25	0.19	-	-	-	-	0.9	0.13	-	-	0.2	-
7 (10 m)	NA	NA	-	0.06	-	0.03	-	-	0.47	0.05	0.2	0.02	0.3	0.03
8 (surface)	NA	NA	4.2	0.43	14.3	0.42	0.06	0.03	0.5	0.02	1.3	0.12	1.4	0.23
8 (10 m)	NA	NA	10	1.6	21.4	0.58	-	0.03	3.46	0.26	2.3	0.23	1.6	0.26
Detection limit	0.5	0.01	0.03, 0.4	0.008	0.21, 0.13	0.01	0.03	0.02	0.05	0.01	0.1	0.01	0.1	0.03
Std. Dev.	NA	0.003	0.02	0.008	0.02	0.01	0.02	0.01	0.06	0.01	0.1	0.01	0.1	0.01

The observed increases in coral cover were most likely due to recruitment and growth of opportunistic, fecund colonizers such as *Porites astreoides, Porites porites* and *Agaricia agaricites* in a recovery from hurricanes Allen and Gilbert. The increase in abundance of the grazing urchin *Diadema antillarum* at 5 m, which reduced algae, would have aided coral recruitment and growth there. There may be a shift in coral species dominance occurring on the reefs from the once dominant *Acropora cervicornis* and *Acropora palmata* to more fecund corals. Conversely, cover by macroalgae has decreased (from 79% to 50.6%), especially at the shallower sites, where the abundance of *Diadema* and other sea urchins has increased in recent years (Woodley et al. 1999, Aronson and Precht 2000).

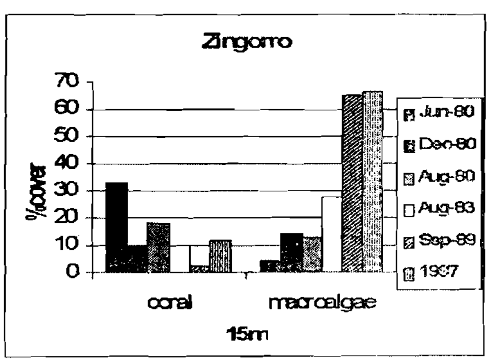

Fig. 7 Change in coral and macroalgal cover at 15 m on Zingorro reef from 1980 to 1997.

Comparisons of the coral data with those of Liddell and Ohlhorst (1992), Edmunds and Bruno (1996) and Andres and Witman (1995) showed that there was a significant increase in coral abundance at all depths, while macroalgal cover decreased at all depths but was significant only at 5 m where grazing by *Diadema* occurred. At 5 m, the variation in macroalgal cover was significantly negatively correlated to *Diadema* density and the increase in coral cover was most pronounced (e.g. 2.3% to 17.8%), possibly due to the increase in grazing.

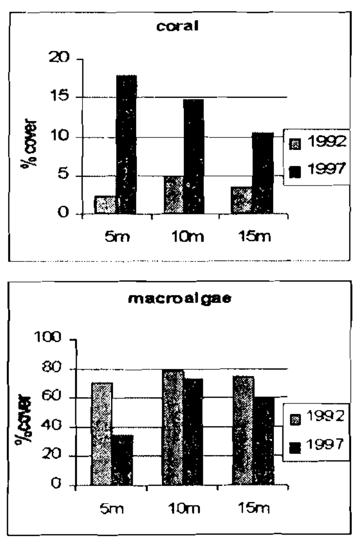

Fig. 8 Change in coral and macroalgal cover on LTS reef at 5, 10 and 15 m depth between 1992 and 1997.

This suggests that increased *Diadema* are exerting top-down control on macroalgal abundance, thereby facilitating the increase in coral. At 10 m and 15 m, the increase in coral cover may be largely due to gradual recovery from hurricanes by recruitment of fecund corals, which are mostly hermaphrodite brooders.

The nutrient content of the water was mostly undetectable with a few sites showing slight enrichment at or above the critical threshold (Lapointe 1997) of 1.0 μM DIN and 0.1 μM DIP. The enrichment at these sites were usually related to lowered salinity and rain (McFarlane 1991), possibly due to groundwater seepage from the town east of Discovery Bay at site 7, and out the bay from the numerous submarine springs at site 3. Freshwater has been shown to carry dissolved inorganic nutrients (D'Elia et al. 1981) as run-off from land, fluctuating with seasonal flows. Generally, the reefs of Discovery Bay were not exposed to nutrient enrichment.

The data suggest that the recovery of the sea urchins may be a facilitator of increased coral abundance, through 'top-down' control resulting in decreased macroalgal cover on the reefs. Since there is little or no nutrient enrichment, the absence of herbivores after the loss of corals may have been the key factor in the degradation of reefs to a weedy state. A recent study provides evidence to support this, where it was shown that the recovery of *Diadema antillarum* had reduced macroalgal cover and increased the abundance of juvenile corals on the reefs of Discovery Bay by 2000, (Edmunds et al. 2001). The findings presented here lend support to the argument that "top-down" rather than "bottom-up" factors were largely responsible for the decline of coral reefs at Discovery Bay (Hughes et al. 1999, Lapointe 1999).

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