ATLANTIC AND GULF RAPID REEF ASSESSMENT (AGRRA) PROTOCOL v. 4.0 OCTOBER – NOVEMBER 2006: Quantifying the Impact of the 2005 Bleaching Episode in Dominica

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Research Supervisor & Team Members:*
*Sascha C.C. Steiner**
Jeremy M Kerr
Julie Sabattis
Jared Weems
Christine Davies
Stephanie Laffan

Institute for Tropical Marine Ecology Inc. ITME
P.O. Box 944, Roseau, Commonwealth of Dominica

www.itme.org

General Introduction

In 2005 the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol (v. 4.0) was implemented in Dominica for the first time. AGRRA allows for a standardized region-wide system of data collection regarding the characteristics of reef ecosystems making comparisons of communities within the Caribbean more precise. During the survey Dominica's reefs experienced a severe temperature-induced bleaching episode. In 2006, the protocol was re-implemented to assess how Dominica's reef communities had been impacted by this event. All sites, with one exception – Macoucherie, from the 2005 survey were revisited. Results from this year's survey cover species composition, coral disease and bleaching, coral recruitment, algal canopy height and *Diadema antillarum* densities.

Information from the 2006 survey will add to the body of knowledge relating to Dominica's coral communities that has been growing since the first comprehensive quantitative surveys were undertaken in 1999 (ITME Research Reports 2005). This information serves in solidifying the baseline information for monitoring the status of Dominica's coral reef communities.

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Study I: Stony Coral and Hydrocoral Community Structure Assessment: One Year After the 2005 Bleaching Episode in Dominica, West Indies

Julie Sabattis
Institute for Tropical Marine Ecology
P.O. Box 944, Roseau Commonwealth of Dominica

Abstract: An assessment of coral community structure was implemented using AGGRA protocol v.4.0 (Kramer 2005) to determine if the 2005 bleaching episode recorded last year (Byrd *et al.* 2005) had an impact. Species richness, surface area and species diversity were compared among all sites revisited. Twenty-one species were found each year; however the species richness was higher at the deeper sites than in the shallow sites. Four sites increased in species richness, four remained the same and seven sites exhibited a decrease in species richness. There was an overall reduction of 23% in surface area. Moreover, there was a reduction in surface area due to recent mortality at all sites except Champagne E. Species diversity expressed as H' showed there was a decrease in diversity from 2005 to 2006; but isolated increases occurred at some sites. The bleaching event resulted in a negative impact on the coral community structure of Dominica.

Keywords: Coral Community Structure, AGRRA, Dominica, Coral Reefs

Introduction

This assessment compares coral community structure at selected sites in 2005 and 2006 to determine the effects of a bleaching event. Comparisons were made to determine whether or not differences in coral community structure occurred at individual sites, or at particular depths. The principal points of the comparison are (1) species richness, (2) live coral cover and (3) species diversity.

A community is defined as a level of organization that cannot be studied by examining a single taxon (Karlson and Hurd 1992). The ability to examine communities such as coral reefs through their lifetime would take centuries or even millennia (Jackson 1992). Many species can be affected by disturbances such as hurricanes and increased sea surface temperatures; a few species can be affected from disturibances such as diseases. However, if an important framework builder within the reef is one of those effected species, it can change the structure of the community (Riegl and Riegl 1996). Main framework builders of reefs are scleractinians (stony corals) (Edmunds, Roberts and Singer 1990). In Dominica, these include *Montastraea faveolata, Montastraea annularis and Siderastrea siderea* (Kerr 2004). Mortality in such large corals could have long term detrimental effects in the future such as a habitat loss.

Caribbean coral reefs are continuously being affected by natural forces, including hurricanes, diseases and bleaching (Hinrichsen 1997). However, in more recent years anthropogenic influences such as coastal development, nutrient and pesticide run off have been causing increased chronic stresses on coral reefs. Dominica's narrow shelf area provides a limited area for its reefs, unlike other Caribbean Islands with wide shelves such as the Turks and Caicos Islands. Increased human activities on the western side of Dominica, such as the development of roads, agricultural run off and fishing can hinder the reefs ability to thrive due to increased sedimentation in the water. Fishing equipment thrown onto or dragged along reefs causes physical damage to the corals.

In 2005 Byrd *et al.* (2005) using the Atlantic and Gulf Rapid Reef Assessment (AGRRA) v. 4.0 determined the status of the scleractinian and *Millepora sp.* community structure in dominica. A massive bleaching event occurred during the time frame of the survey. Bleaching is a response to stress, typically induced by an increase in temperature, where the endosymbiotic zooxanthelle that live within the coral tissues leave the coral or the zooxanthellae loose their pigments and no longer are able to photosynthesize (Buddemeier and Fautin 1993). Bleaching can also make corals more susceptible to the infection of other diseases, causing further mortality. Diseases can be a "driving force" that can change the community structure by reducing the amount of coral diversity and the general abundances (Borger and Steiner 2005). This study looks at the coral communities at the same sites studied in 2005 (Byrd *et al.* 2005), to determine the effects of the bleaching event on species richness, live coral cover and species diversity. Shallow and deep sites were contrasted.

Materials and methods

Fifteen sites along the west coast, visited during last year's coral assessment were revisited and resurveyed using GPS coordinates along the western and northern coasts. Protocol AGRRA v. 4.0 (Kramer 2005) was followed. Snorkeling was used for shallow reef sites (0-5m) and SCUBA for the deeper depths (5-18m).

Modifications to the AGRRA protocol were that teams consisting of two people surveyed each transect. Each person focused on specific aspects of the protocol. One recorded all information regarding urchin density, algal cover and recruits while the other recorded coral species, sizes, disease and bleaching, death and the substratum composition. This paper is based on data from the coral and substrate survey only. Rock (rk) was added to the substratum categories, due to the high number of boulder field reefs found (Byrd *et al.* 2005). Corals and diseases were identified *in situ* in accordance with Humann and Deloach (2002). Sampling techniques were rehearsed both in and out-of-water and used both in snorkeling and SCUBA, before research began to assure consistency.

Species diversity was expressed by using the Shannon-Weiner Diversity Index (Shannon-Wiener 1948). Coral surface area was considered as the product of maximum diameter and width.

Results

Species Richness

Twenty-one species were found at the fifteen surveyed sites; the same species was also found in 2005. Coral species found were: *Acropora palmata*, *Colpophyllia natans, Dendrogyra cylindrus, Dichocoenia stokesii, Diploria clivosa, Diploria labyrinthiformis, Diploria strigosa, Eusmilia fastigiata, Isophyllia sinuosa, Madracis decactis, Madracis mirabilis, Meandrina meandrites, Montastraea annularus, Montastraea cavernosa, Montastraea faveolata, Mussa angulosa, Porites astreoides, Porites porites, Siderastrea siderea Stephanochoena intersepta*, and *Millepora* spp.. *D. cylindrus,* and *M. angulosa* were also recorded this year but not observed in '05. However, *Agaricia agaricites* seen in '05, was absent in '06. Species varied the most at Champagne E see Table 1.

Species richness in the shallows changed from 17 in '05 to 16 in '06 but remained at 19 in both years at the deep sites. Live *A. agaricites* was not observed this survey, however *D. clivosa* was not recorded in '06. *D. cylindrus* and *M. angulosa* were also observed.

The species richness among the shallow and deep sites differed in both years '05 and '06. There were fewer species observed in the shallow areas (4-11) than at the deep sites (9-15), with the exception of Champagne W which went from fifteen species to six, see Figures 1 and 2.

Live Coral Cover

The mean live coral cover (under transects) decreased from 16.97m in 2005 to 13.05m in 2006; a reduction of 23.1%. The decrease of live coral cover occurred at all sites surveyed except at Champagne E. Berry's Dream had the highest reduction of coral cover (56.13%) followed by Brain Reef (49.7%) both of which are located in the deep areas. Scott's Head East (shallow) and Colihaut (deep) exhibited the smallest amount of loss with 8.38% and 7.91% respectively. The greatest loss at the shallow sites occurred at Batalie Bay (26.35%) and Rodney's Rock (25.30%), see Table 2. *P. astreoides* constituted 28% and *S. siderea* 16% of live coral in 2005. *P. astreoides* in 2006 made up 21% and *S. siderea* 22%. *M. faveolata* went from 15% to 9%, while

Millepora spp. increased from 7% to 17%. Corals rare in this survey were grouped together in the “other” category. This year had a 1% increase in the amount of rare corals observed, see Figure 3 and 4.

Coral cover decreased by 18.46m^2 to 181.25m^2 between 2005 and 2006. There was a decline at all 2006 sites due to recent mortality. Brain Reef had the most recent mortality at 28.78%. Scott’s Head W had the smallest decline in surface area mortality at only 2.59% see Table 3.

Species Diversity

Species diversity (H’) decreased from 2.21 in 2005 to 2.17 in 2006. The shallow sites decreased from H’= 1.79 to 1.83 while the deep sites decreased from H’= 2.29 last year to H’= 2.02 this year. Batalie Bay, Fond Colé, Salisbury E and W and Scott’s Head E and W, all increased in species diversity. The greatest amount of change in diversity occurred at Batalie Bay (.86). The least amount of diversity change was at Rodney’s Rock (.06) (see Table 4).

Table 1 Species richness at each site in 2005 and 2006 sites. Shallow sites 0-5m and deep sites 5-15m

		2005	2006			2005	2006
Shallow	Batalie Bay	6	10	Deep	Brain Reef	13	11
	Calabishie	12	12		Champagne W	15	6
	Champagne E	11	11		Colihaut	14	14
	Fondcole	7	8		Floral Garden	11	11
	Rodney’s Rock	11	10		Rena’s Reef	13	11
	Salisbury E	4	7		Salisbury W	15	14
	Scott’s Head S	10	9		Scott’s Head N	9	10
	Berry’s Dream	15	12				

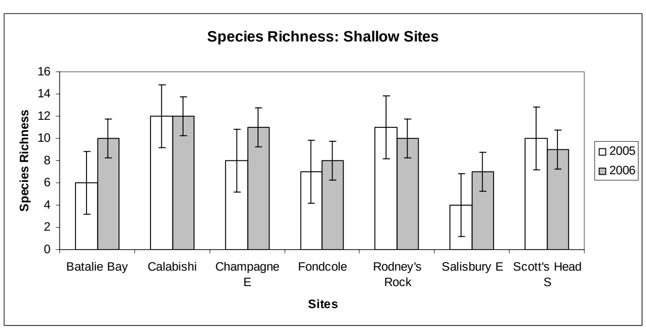

Figure 1 Species richness at each shallow (0-5m) sites. 2005 mean 8.29 ± 2.87. 2006 mean 9.57 ± 1.72.

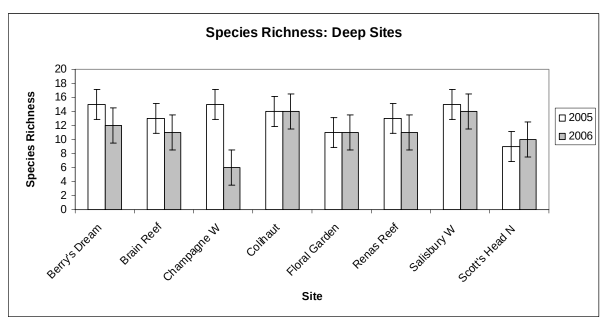

Figure 2 Species richness at deep (5-15m) sites. 2005 mean 13.13 ± 2.17. 2006 mean 11.13 ± 2.53.

Table 2 Mean coral cover (m) at each site during 2005 and 2006. Percent decrease in recent mortality.

		2005	2006	% decrease			2005	2006.00	% decrease
Shallow	Batalie Bay	1.67	1.23	26.35%	Deep	Berry's Dream	2.69	1.18	56.13%
	Calabishie	1	0.89	5.31%		Brain Reef	4.34	2.18	49.77%
	Champagne E	2.09	1.58	-6.04%		Champagne W	1.51	0.88	41.72%
	Fondcole	2.23	1.97	11.66%		Colihaut	2.53	2.33	7.91%
	Rodney's Rock	2.49	1.86	25.60%		Floral Garden	1.93	1.54	20.21%
	Salisbury E	1.83	1.56	14.75%		Renas Reef	2.08	1.66	20.19%
	Scott's Head S	1.67	1.53	8.38%		Salisbury W	1.83	1.56	14.75%
						Scott's Head N	3.48	2.55	26.72%

Decrease in live coral cover

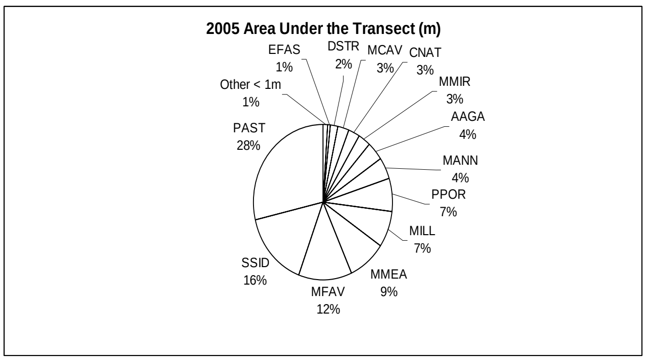

Figure 3 Percent of area (m) measured for each species in 2005. Other includes species that make up less than one meter. MCAV=*M. cavernosa*, CNAT=*C. natans*, MMIR= *M. mirabilis*, AAGA=*A. agaricites*, MANN= *M. annularis*, PPOR= *P. porites*, MILL= *Millepora* spp., MMEA= *M. meandrites*, MFAV= *M. faveolata*, SSID= *S. siderea*, PAST= *P. astreoides*. Other = *D. clivosa* (.07), *M. decactis* (.17), *M. areolata* (.2), *D. stokesii* (.39), *D. labyrinthiformis* (.4), *I. sinuosa* (.46), *S. intercepta* (.58).

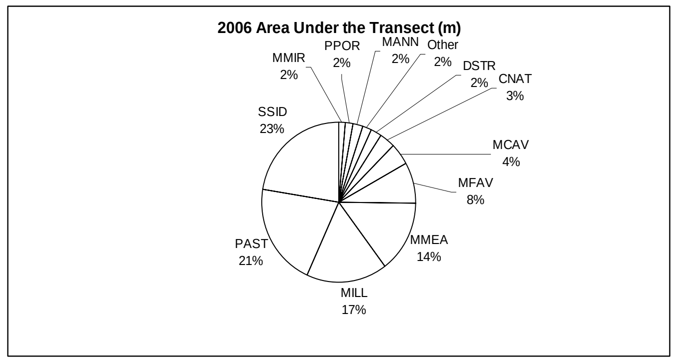

Figure 4 Percent of area (m) measured for each species in 2006. Other includes species that make up less than one meter. DSTR= *D. strigosa*, see 2005 area under the transect for other abbreviations. Other= *I. sinuosa* (.05), *D. clivosa* (.14), *E. fastigeata* (.15), *D. cylindrus* (.16), *M. angulosa* (.18), *M. decactis* (.4), *D. stokesii* (.6), *D. labyrinthiformis* (.99).

Table 3 Percent of recent mortality of entire surface area of coral cover at each site.

Rodney's Rock	4.33%
Rena's Reef	6.78%
Colihaut	7.03%
Batalie Bay	7.10%
Berry's Dream	8.31%
Fondcole	8.45%
Salisbury E	8.58%
Champagne E	11.21%
Scott's Head E	13.07%
Salisbury W	13.10%
Floral Garden	16.23%
Brain Reef	28.78%
Calabishie	4.15%
Champagne W	8.65%
Scott's Head W	2.59%

Table 4 Diversity using Shannon-Weiner (H') Index. **a** diversity between 2005 and 2006, diversity between all sites **c** diversity between shallow and deep depths.

A	2005	2006
	2.21	2.17

b

	Shallow			Deep	
Sites	2005	2006	Site	2005	2006
Batalie Bay	1.03	1.89	Berry's Dream	2.35	1.86
Calibishie	2.1	2.06	Brain	2.23	1.81
Champagne E	2.65	1.88	Champagne W	2.1	1.32
Fondcole	0.99	1.45	Colihaut	2.21	1.92
Rodney's Rock	1.72	1.66	Floral Garden	1.76	1.59
Salisbury E	0.96	1.06	Rena's Reef	1.74	1.52
Scott's Head E	1.76	1.82	Salisbury W	2.1	2.23
			Scott's Head W	1.83	1.88
c Total Shallow H'	1.79	1.83	Total Deep H'	2.29	2.02

Discussion

A. agaricites made up 4% of the entire coral cover surveyed in 2005, and was not observed at all in 2006, implying that they were heavily impacted by the bleaching episode. The increase in four coral species this year at Batalie Bay is most likely due to a larger sample size (two extra transects). Species *D. labyrinthiformis* and *D. stokesii* were rare as they only made up 7cm and 10cm within sixty meters. Similarly, Salisbury East had three more species this year than last; however, they each occurred once, with a combined coral cover of .034m within sixty meters. It is possible that larger sample sizes were required to overcome these discrepancies. After a bleaching event, coral species richness is unlikely to increase. They were just missed in the 2005 survey.

Coral cover was reduced at all sites; however, the deeper sites were impacted more heavily than the shallower sites. Diurnal fluctuations in surface temperature allow shallow coral communities to cool off whereas the deeper sites lack this temperature relief. The steady elevated water temperatures in these deep areas stress corals, making them more susceptible to bleaching, diseases and to subsequent mortality. There was a decrease in over 50% of the live coral cover present last year at Berry's Dream and a 49.8% reduction at Brain Reef. The corals present at these sites consist of *M. faveolata*, *M. mirabilis* and *P. astreoides*. They make up 44% of live coral in 2005 and 30% of live coral cover in 2006 and were highly impacted across all sites. The *Montastraea* spp. are important framework builders for the reefs in Dominica and are more prevalent in the deeper areas. They make up less than 3% of stony coral cover around Dominica (Steiner 2001), therefore, if deeper areas are more negatively impacted this could cause great concern for the future of the reefs. The lack of corals forming new substrate endangers the structural integrity and growth of reefs in the view of bioeroders and corroders. Furthermore, recent mortality in corals is quickly overgrown by first successional stages consisting algal species that out compete new coral recruits (Done 1999).

Although the species diversity decreased between last year and this year, the difference is not great enough to show a drastic change in the diversity of species from the '05 bleaching event. The increases in diversity that occurred at Batalie Bay, Fondcolé, Salisbury E and Scott's Head W could be directly related to the additional transects completed compared this year. The deep sites all showed a decrease in diversity with the exception of Scott's Head and Salisbury, which follows the trend seen in coral cover. An increase in species richness at deeper sites is due to optimal conditions for a greater variety. Species diversity at the shallow sites increased, implying that the sample size is too small.

There was a large decrease in coral cover in some species, even though there was not a change in species richness. The function of those corals within the reef community is reduced or lost. *A. agaracites* is a flat coral that grows on the sides of rocks, cementing the reef substrate together. It's decrease in presence weakens the stability of the surrounding community. Furthermore, the decrease in presence of *P. porites*, which is a "filler" coral, decreases the space available for juvenile fish and small organisms to enhabit and gain refuge.

MacArthur in Karlson and Hurd (1992) stated that the diversity of coral species will develop resistance to change by creating a new energy flow pathway within a community. A decrease in community diversity would limit there ability to be able to resist to future changes. The bleaching event that occurred in 2005 negatively impacted the coral community structures along the coast of Dominica. It's coral communities are more homogenous in the that the same coral species can be found along the entire coastline, unlike large reefs like the Great Barrier Reef that have more gradients and complexity within their community structure. (DeVantier *et al.* 2006). Therefore, if more bleaching events were to take place in Dominica's reefs, the community structure will loose structural complexity. Determining the status of "health" of coral reefs now and in the future, may indicate as to how these communities deal with abnormal conditions, such as bleaching and what they will look like for future generations.

Acknowledgments

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Study II: Assessment of Mortality, Bleaching, and Disease among Stony Corals and Fire Corals of Dominican Reefs: Post-2005 Caribbean Bleaching Event.

Jared D. Weems
Institute for Tropical Marine Ecology, PO Box 944 Roseau,
Commonwealth of Dominica, West Indies

Abstract The effect of elevated sea surface temperatures of the 2005 Caribbean bleaching event on corals was the most severe in recent history. This 2006 study looked into the health of reef communities on the western and northern coasts of Dominica (Lesser Antilles) to observe the recovery and current condition of stony corals and *Millepora* spp. Using the AGRRA v. 4.0 protocol (Kramer 2005) and utilizing comparisons with 2005 AGRRA implementation (Byrd *et. al* 2005), old mortality decreased 24.24 m^2 in surface area (47%); while, recent mortality increased in surface area of 13.51 m^2. Bleaching symptoms decreased by 71% and disease prevalence increased from 13 to 45 colonies. The relationship between the increases in recent mortality and more disease infections suggest that the 2005 bleaching caused weakening of corals, increased susceptibility to disease, and partial and/or complete mortality.

Keywords Coral Mortality, Coral Bleaching, Coral Disease, AGRRA, Dominica

Introduction

The stony corals (Scleractinia: Anthezoa) are an important base and building block of all true coral reefs. The relative abundance, health and development of certain species can give clues to what environmental factors affect the coral reef and what structural changes reefs may undergo. This study looks into the health of the corals (including the hydrozoans, *Millepora* spp.), one year after the most recent sea temperature induced bleaching episode, to qualitatively and quantitatively assess the recovery or degradation of Dominican coral species. The diagnoses of health will be based on coral mortality, coral bleaching, and the prevalence of diseased colonies. In addition, this study in comparison to Jordan (2005) and Zuercher (2005) will determine the recovery and change among species populations that may shape the future of Dominica's reef systems in the years to come.

Dominica rose from the ocean approximately 25 million years ago and is one of the least geologically eroded islands along the younger arc of volcanic islands in the Lesser Antilles. Much of the hard substrate is composed of volcanic boulders encrusted by corals creating a majority of patch reef systems teamed with a few small, true reef systems on the west coast. The narrow continental shelf along the island limits scleractinian accretion rates with a narrow neritic (euphotic) zone for photosynthesis within endosymbiotic zooanthellae, rough wave action, and terrestrial runoff turbidity (Steiner 2003). The eroded volcanic islands of the eastern Lesser Antilles arc are characterized by shallow, wide shelves and fringing reefs which can be seen on the southern portion of Martinique, Grande Terre, Guadeloupe, and Marie Galante (Honeychurch 1995).

Thus far, studies have identified abundance and live coral cover favored species of *Porites astreoides*, *Montastraea faveolata*, *Agaricia agaricites*, *Meandrina meandrites* and *Siderastrea siderea* (Knuth 2003; Borger 2005). The highest bleaching and disease prone corals in 2004 (Kerr Table 1) were those of the highest abundances in 2003, though ten other small surface area species were also affected. Jordan (2005) and Zuercher (2005) had shown that bleaching and diseases have taken a toll on once strong abundances of *A. agaricites and S. siderea*. Species suffered a live cover decrease of 66% from 2003 to 2005, in comparing extrapolated data from Knuth (2003) and Jordan (2005). During this period, annual bleaching episodes have been recorded in 2003 and 2004; the latter of which, had the least amount of documented coral stress. Borger and Steiner (2005) have also shown an overall increase in disease prevalence beforehand, over a multiyear (2000-2002) and detailed five-site study. The research conducted on Dominican reefs began in the late 1960's through the early 1970's, but complete reef community structures were not studied until 1999 (Steiner and Borger 2000).

This study looked into the mortality, bleaching and disease prevalence among reef sites in 2006 and allows for an applicable comparison to data from AGRRA 2005. Furthermore, a species specific analysis of the aforementioned dominant coral species was conducted to see if declining surface area trends and increasing stressors and death still exist. These recent annual stresses applied on the corals should then convey which are more susceptible to disease and eventual death. These observations will then provide a basis for inferring overall condition of existing corals and suggest future structural composition of Dominica's reefs.

Materials and methods

To make an *in situ* community condition estimate, this 2006 study on Dominican reefs used the AGRRA protocol v. 4.0 (Kramer 2005; Ginsburg 2006) for benthic reef survey techniques. These provides a common language and tool for a proper comparison with the 2005 Dominican AGRRA survey (Byrd *et al.* 2005); as well as, define certain parameters not found in Kramer (2005) to accommodate this island's typical reef formations; patch reefs on rock or boulder substrates (Jordan 2005; Zuercher 2005). A specific change was included in this study in relation to the measurement of old mortality in that, a separate substrate category was added to measure 100% old dead under the transect to distinguish completely dead colony area from bleached or small living area colonies present. Surface area was calculated with maximum diameter multiplied by width measurements in cm and converted to surface area in m². The identification of distressed corals, mortality, bleaching, and/or disease were diagnosed with aid from Kramer (2005) and Humann and Deloach (2002).

In analyzing the disease abundance, the terms prevalence and occurrence were used to portray two different aspects of community structure. Prevalence was defined as the individual diseased colonies observed and measured in the surveys. This was used to calculate total diseased colonies and distinguish which species of corals had the highest degree of infection. Occurrence was defined as the qualitative allocation of diseased corals in relation to other diseased colonies. The spread of the bacteria causing these particular diseases could be in clumped aggregations or randomly distributed (Borger 2005).

The coral habitats from which samples were taken are: Salisbury East (SE), Salisbury West (SW), Calibishie (CL), Floral Gardens (FG), Batalie (BT), Fond Colè (FC), Rena's Reef (RN), Rodney's Rock (RR), Brain Reef (BR), Macoucheri (MA), Berry's Dream (BD), Champagne East (CHE), Champagne West (CHW), Cachacrou shallows(CS), and Cachacrou (CD). Macoucheri (MA) was not included in this study due to time constraints. The individual transects did not mirror the 2005 research transects, as they were not permanently marked, but based on the strategy and alignments used in 2005 AGRRA protocol.

SCUBA and snorkeling techniques were decided by depth of each site, and equipment and data sheets needed are outlined in AGRRA v. 4.0 for measurement of physical structure and area surveys. Analysis of the data was conducted with the statistics programs within Microsoft Office Excel for the analysis within 2006's and 2005's sites (Jordan 2005; Zuercher 2005).

Results

Old Mortality

The 2006 overall old mortality surface area in eleven sites is 27.75 m² out of the total area of colonies affected of 87.79m². This is 32% of the total area of colonies that had shown old mortality or damage of corallite's structure, which was out of a total of n=470 colonies. The largest dead surface area measured was located at Cachacrou (CD) (7.56m²), Brain Reef (4.13m²), and Colihaut (2.94m²).The 100% dead under the transect was only measured in 2006, and in 15 sites and 123 transects, old mortality measures 81.92 m (linear) with an average of 5.99 m per site and 0.86 m for every transect. While in comparison to the same sites surveyed from 2005, the old mortality surface area measured 51.99 m² out of 168.33 m², which comes to a 31% area of old mortality colonies (n=852). Cachacrou (18.72m²), Brain Reef (10.57m²), and Rodney's Rock (4.75m²) had the highest old mortality (Fig. 1).

Recent Mortality

The 2006 recent mortality surface area was 16.1 m² out of the total area of colonies affected equaling 79.8 m². This was 20% of the total area of colonies that had shown recent mortality (n=496). Sites with the highest surface area recent mortality were: Brain Reef (6.1m²), Cachacrou (CD) (2.5m²), and Fond Colè (1.34m²). In 2005, a 2.59 m² recent death area was recorded out of 20.43 m² colonies measured (n=162). Recent mortality calculations were all <1m² in 2005 sites with the highest being Brain Reef (0.84m²). An average of 13% recent death per colony was calculated for all sites. The number of colonies exhibiting recent death in 2006 ranged from a 70-90% increase per site, and surface area increased by nearly 80% each (Fig. 2).

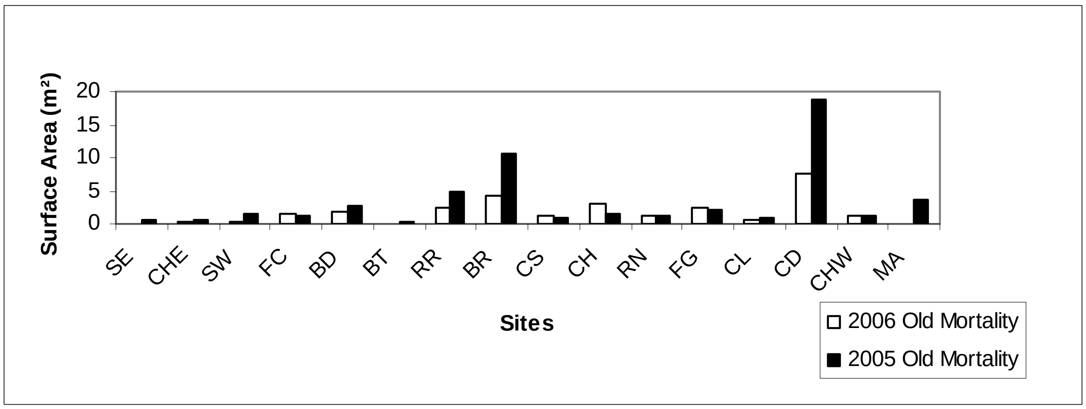

Figure 1 Surface area of old mortality between 2006 and 2005.

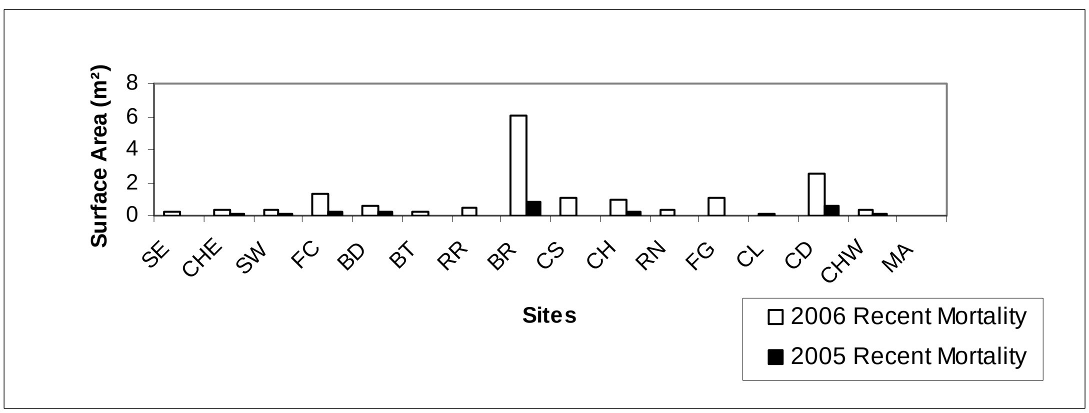

Figure 2 Recent mortality in 2006 and 2005 at each site surveyed.

Bleaching

In 2006, signs of coral stresses that trigger the bleaching and subsequent color change were down from 2005. The observed pale, partially bleached, and bleached colonies were recorded in n=201, 69, and 6 colonies. Three hundred fifty-five colonies were affected in total. This was a 71% decrease in bleaching prevalence among all surveyed reef sites from 2005. In total, 618 pale, 266 partially bleached, and 278 bleached colonies were recorded in 2005. The largest difference between the years was a 98% decease in bleached corals.

Disease

Disease prevalence and occurrence have drastically risen in comparison between 2006 and 2005. The largest increase was seen in with the species *S. siderea* infected with dark spot syndrome (+14); of which, the prevalence on each individual colony was not quantified as well as the death associated with the disease infected area. It has also been seen that an increase in yellow blotch disease prevalence occurred (+12); while only 2 cases of black band disease were recorded in 2006. Also, hyperplasm irregular growths were observed (n=2) in 2006 in contrast to not being recorded in 2005. Qualitatively, the disease pattern on the reefs or occurrence was usually in clumps or in close, neighboring species.

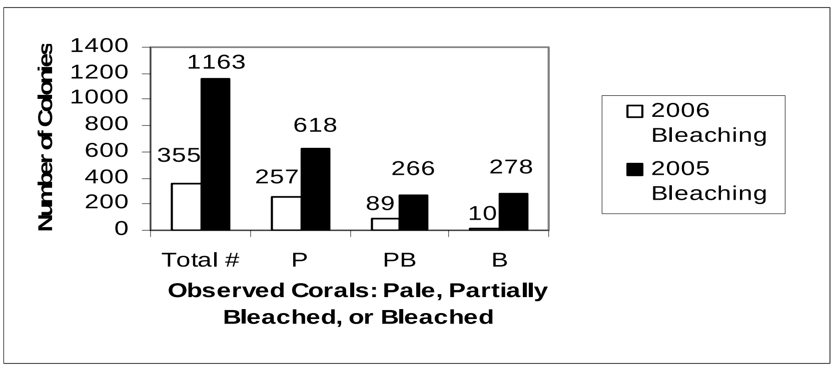

Figure 3 Overall bleaching effects of 2005 compared to 2006. Pale coloration (P), partially bleached colonies, and bleached (completely white colonies) were the categories defined by Kramer (2005).

Table 1 Disease breakdown of prevalence among species between 2006 and 2005.

Disease	2006	Species	2005	Species
BBD	n=2	*Mfav*	n=3	*Aaga, Dstr, Ssid*
WBD	n=1	*Apal*	n=1	*Mfav*
WP	n=6	*Ssid (3), Cnat, Mfav, Mann*	n=0	
YBD	n=14	*Mfav (9), Mann (2), Ssid, Dstr, Dcli*	n=2	*Past*
DSS	n=20	*Ssid*	n=6	*Ssid*
Hyperplasm	n=2	*Dstr, Ssid*	n=0	
Unknown	n=0		n=1	

*Abbreviations are as follows: BBD-Black Band Disease, WBD-White Band Disease, WP-White Plague, YBD-Yellow Blotch Disease, DSS-Dark Spot Syndrome, *Aaga-Agaricia agaricites, Apal-Acropora palmata, Cnat-Colpophyllia natans, Dstr-Diploria strigosa, Dcli-D. clivosa, Mann-Montastraea annularis, Mfav-M. faveolata, Past-Porites astreoides, Ssid-Siderastrea Siderea*

Species Specific Records

These species specific data comparisons follow the relative trends found in the overall old mortality, recent mortality, bleaching, and disease prevalence (see Table 2). Total old and recent mortality of 2006 was curved towards the large reef building species *S. siderea* and the *Montastraea* spp., while only *M. meandrites* shows an increase in both types of mortality. All species except that of pale *M. faveolata* showed decreases in all three bleaching categories, while diseases were more prevalent among the reef building species. *A. agaricites* had a 100% decrease in all categories.

Table 2 The all-inclusive records of the top corals in Dominica: their mortality surface area, bleaching, and diseased colonies (with % changes from '05-06).

2006 Species	Old SA m² (%Δ'05-06)	Rec. SA m² (%Δ'05-06)	# Pale (%Δ'05-06)	# Pt. BL (%Δ'05-06)	# Bleached (%Δ'05-06)	# Disease (# '05)
P. astreoides	0.73(-75.7%)	1.88(+63.3%)	42(-88.1%)	2(-69.0%)	79(100%)	2 (0)
M. faveolata	5.89(-27.5%)	6.33(+99.5%)	20(+25.0%)	20(-20.0%)	2(-89.5%)	12 (1)
A. agricites	0.81(-100%)	0.053(-100%)	21(-100%)	17(-100%)	63(-100%)	0 (1)
S. siderea	8.88(-16.2%)	2.86(+90%)	42(-6.67%)	2(-91.67%)	3(-100%)	25 (7)
M. meandrites	1.87(+15.5%)	0.49(+84.4%)	47(-34.7%)	6(-54%)	1 (-83.3%)	0(0)
Montastraea spp	11.3(-51.9%)	12.7(+94.8%)	33(-13.2%)	31(-39.2%)	2(-94.3%)	15 (1)

**Montastraea* spp= *M .annularis, M. cavernosa, M. faveolata*

*numerical values in association with percent changes of 100% are 2005 results

Discussion

The general conclusion that can be drawn from the 2006 survey is that Dominica's reefs have an overall decrease in old mortality, increase in recent mortality, a relatively low number bleached colonies, and high number of diseased colonies. Within the old mortality category: the total number of colonies, total surface area, and old mortality surface area showed decreases of 45%, 48%, and 47% between autumn 2005 to autumn of 2006. A small percentage of old mortality was likely overgrown by algae, sponges, and other sessile flora or fauna, but the large decrease within the year that was recorded is likely due to the method application. In carrying out 2006 survey transects, the 100% dead category was added to better compare with the live under the line category stated in AGRRA v. 4.0 (Kramer 2005), but this linear number cannot compare to the area calculations done on measuring every coral, dead or alive, as was done in 2005. Qualitatively, in the field old dead area cannot change that rapidly in short amounts of time, barring any catastrophic changes in structure.

Recent mortality in 2006 had shown a 68% increase in number of colonies showing recent death, an 84% increase in recent mortality surface area, and a 74% increase in total area of colonies. This data is conclusively relevant to the impact of last years bleaching affects that many of the colonies had dead skeleton showing or only a small mat of filamentous alga overtop. The majority of the recent death was very distinguishable from old death, *in situ,* even with the low cover and canopy height of alga species normal to Dominican reefs (Wallover 2005). The colonies most hit by recent mortality, *M. faveolata* and *S. siderea*, had the highest surface areas and percent increases dead coral between the 2005 and 2006 time span. No live A. agaricites colonies were seen in 2006; therefore, the local mass die off of this species in recent history is likely to continue (Knuth 2003; Kerr 2004; Jordan 2005; Zuercher 2005).

Bleaching in 2005 did affect 82.9% (Zuercher 2005) of the total number of corals surveyed, while in 2006 only 26.4% of the colonies showed signs of bleaching. This large decrease shows just how wide spread and all-encompassing the bleaching episode of 2005 was. The significance of the 2006 bleaching cues are not in question, as nearly thirty percent bleaching among all colonies can still have large affects; however, the somewhat cooler waters in 2006 should give relief to struggling corals and possibly continue with the recovery process and intake of new endosymbiotic zooanthellae.

This study has shown a large increase seen in disease prevalence that is most likely attributed to the 2005 bleaching event. Coral polyp energy allocation dramatically shifts in bleaching events toward survival and recovery, but the weakened coral still remains more vulnerable to diseases (Steiner pers com). Thus, in the extreme conditions of 2005, disease bacteria and cyanobacteria were able to infect and spread over many more colonies (Borger 2003, Humann and Deloach 2002, Lesser 1997). The occurrence of disease was still seen in clumped aggregations, but many more colonies were seen with disease than in 2005. The largest increase in dark spot syndrome can be attributed to over production in zooanthellae pigments that hinders photosynthesis (Borger 2005). Yellow blotch disease, also, was seen with a substantial increase in colonies affected; although previous research suggests that it is independent of bleaching events, the bacteria consortium did colonize the *Montastraea* spp. complex with high prevalence (Goreau 1998). Black band disease did show a decrease, contrary to all other diseases colonization rates in Dominica.

The reduced prevalence of bleached corals in 2006 allowed for a quantification of the effect of the 2005 Caribbean wide mass bleaching of 2005 in Dominica. A previous report by Peckol *et al.* (2003) also recorded decreases in coral surface area and large die-offs after the 1998 bleaching in their AGRRA method protocol in water of the coast of Belize. Such data can then reflect the abiotic, biotic and anthropomorphic factors that caused the harsh conditions in 2005. The probable main factors to which the 2005 bleaching event occurred could be related to the highest combined land and sea temperatures on record that occurred in 2005 (Tankersley ed. 2006). The records from our survey period shows a 29.4°C late October sea temperature and 28.85°C early November sea temperature. In comparison to 2005's late October temperature of 30.5°C, early November temperature of 29.5°C, and a middle November temperature of 29.25° (Steiner pers comm). Temperature tolerance in corals is narrow with an optimum temperature at 26°C (with geographic variations); however, the range of 30-34°C over a few weeks time can cause devastating bleaching effects (Veron 1995; Winter 1998; Buddenmeier and Fautin 1993). Higher sea temperatures coupled with the extreme hurricane season and storm surges which produced twenty-seven storms, twenty-one named hurricanes, and four category 5 hurricanes (Tankersley ed. 2006) within the Western Atlantic could likely be the cause of the extreme coral bleaching in 2005.

The 2005 storm season may have also caused higher turbidity of the coastal sea water surrounding Dominica that may have lead to further stressing of corals (Nugues and Roberts 2003). The suspended particles in the water may have had two effects. The deposited debris may exceed the polyp's ability to clear the particles away from the mouth with its cilia; wasting energy and eventually causing a clog that limits feeding (Steiner 2000). While the suspended sediments could also create a smaller photic zone by limiting light penetration, so corals may expel their zooanthellae to find a better suited dinoflagellate for photosynthesizing under the darker conditions (Nugues and Roberts 2003; Kinze III et al. 2003, Veron 1995). The large amount of precipitation runoff from Dominica's mountainous interior could have a continuous clouding effect in the water during high storm frequency periods (Borger 2005).

In looking at recent history of bleaching in Dominica it is seen that many of the coral species of highest abundance and prevalence are dieing at increasing frequency over this short time frame beginning in the late 1990's (Steiner and Borger 2000). The biggest potential problem could be the expanding diseased prevalence and whether the corals, with or without human intervention, can do anything to save the reefs from over-whelming mortality risks (Aronson and Precht 2006).

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Study III: Coral Recruitment on Dominican Reefs: One Year after the 2005 Bleaching Event

Christine Davis
Institute for Tropical Marine Ecology
P.O. Box 944, Roseau
Commonwealth of Dominica

Abstract In 2005, Dominica's coral communities suffered a severe temperature induced bleaching episode. In late October and early November 2005 the Atlantic and Gulf Rapid Reef Assessment protocol (AGRRA) (v. 4.0) was executed to determine the impacts this event had on Dominica's reefs. Using this information as a baseline, this study tracked changes in coral recruit density and overall abundance of coral recruits by re-visiting and re-surveying the 15 sites used for the 2005 survey. Overall, there has been a 59.5% decrease in coral recruit density. A continued decline in the number of coral recruits over a period of several years would be serious cause for concern as recruitment of new coral colonies is necessary for maintenance of a healthy reef ecosystem.

Keywords Coral Recruits, AGRRA, Dominica, Coral Reefs

Introduction

The Commonwealth of Dominica is a small island located close to the center of the arc of islands that make up the Lesser Antillies (Honychurch 1995). It is bounded on the east by the Atlantic Ocean and to the west by the Caribbean Sea. The island has a land mass of approximately 467 km^2 being ~ 47km long and ~ 26 km wide at its broadest point. Dominica is a young volcanic island and has a very narrow sub-littoral shelf. True limestone accretions commonly built by coral reefs are absent in most part from Dominica's coastline. Because Dominica's shelf is so narrow, it is subject to chronic disturbances from incoming storms and wave action that would otherwise be dissipated over a wider and shallower shelf such as is found on older volcanic islands and the carbonate islands in the Caribbean. Instead, most corals and associated sessile coral reef species have settled the boulders and rocks that litter the island's coastline. The few locations where true coral reefs exist are in the Grande Savane area along the west coast and in the area between Anse Soldat and Marigot on the northeast coast. These reefs have historically supported island inhabitants in a number of ways – for example, by subsistence fishing to provide food for the fisherman's family, artisnal fishing for profit, or even by providing the raw materials to produce lime that was used up to the 1950s to construct buildings for habitation, storage or defense. More recently, Dominica and its reefs have become a destination for

SCUBA divers thus adding support to the island's economy via an influx of revenue from tourism.

In October and November of 2005 the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol (v. 4.0) (Kramer *et al.* 2005) was undertaken for the first time in the Commonwealth of Dominica to assess the state of Dominica's reefs. The protocol was implemented during an intense bleaching event that followed on the heels of similar events in 2003 and 2004 and provided a synoptic view of condition of Dominica's reefs. The AGRRA survey of 2005 serves as a baseline for continued monitoring and assessment of Dominica's reefs. The results from last year's study covered a broad spectrum of topics and focused mainly on sites on the western coast of Dominica.

The 2005 AGRRA survey reported a limited number of coral recruits (coral colonies smaller than 2 cm) with the majority being from small, "constructional" species such as *Porites astreoides*, *Agaricia agaricites*, *Siderastrea radians* and *Madracis mirabilis*, rather than hermatypic species (McNeal 2005). Recruits from only one hermatypic species, *Siderastrea siderea*, were reported and these were in low numbers (7.24% of total recruits). McNeal (2005) found a positive correlation between high densities of *Diadema antillarum* and coral recruit abundance indicating that the opening of substrate for settlement by recruits by removal of macroalgal cover led to a higher number of recruits in areas with higher *D. antillarum* density.

This study serves as a follow up to the AGRRA survey undertaken in October and November 2005 and is limited specifically to the study of coral recruits. In particular, it looks at whether or not results from the 2006 survey track the trends shown in the 2005 survey and if not, where differences occur. Of specific importance is whether or not the paucity of hermatypic recruits seen in last year's survey is repeated this year. Continued low recruitment numbers among hermatypic species such *S. siderea* would be cause for alarm as these framework building species are vital to the continued overall health of Dominica's coral reefs. Without these reef-building species, the reefs themselves will suffer a loss in the structural complexity that is requisite to maintaining their ecosystems which has the potential to have serious cultural and economic repercussions. Recent heavy bleaching events as experienced in 2003, 2004 and 2005 may have deleterious effects on the reproductive capabilities of Dominica's corals. According to Rotjan *et al.* (2006) recovery after a bleaching event is imperative to the ability to produce gametes for fertilization during the next reproductive season. Therefore, it can be assumed that an overall lower total number of coral recruits will be found this year. If this is the case this is cause for extreme concern regarding the continued survival of Dominica's coral reefs.

Materials and methods

This study quantified coral recruits by following the Atlantic and Gulf Rapid Reef Assessment protocol v. 4.0 (Kramer *et al.* 2005). Sites selected for use during the first implementation of the AGRRA protocol in 2005 were revisited during this study with one exception - Macoucherie. Sites were selected strategically to best fit procedures as outlined in the AGRRA protocol. The sites surveyed for this study were split into two classes – shallow (<5m deep) and deep (>5m deep). The sites are: Berry's Dream (deep); Brain Reef (deep); Scott's Head (shallow) and Scott's Head (deep); Calibishie (shallow); Champagne (shallow) and Champagne (deep); Colihaut (shallow); Floral Gardens (deep); Fond Colé (deep); Rena's Reef (deep); Rodney's Rock (shallow); and Salisbury East (shallow) and Salisbury West (deep). Shallow sites were surveyed using snorkeling equipment. For site descriptions and maps of these sites see Byrd (2005). Deep sites were surveyed using SCUBA equipment. Site information for deep sites including maps and GPS coordinates can be found in McNeal (2005).

Slight modifications have been made to AGRRA protocol for the purpose of this study. The three swims specified in AGRRA protocol were divided as follows: the first (counting of *Diadema antillarum*, *Panulirus argus* and *Strombus gigas* within 50 centimeters to either side of the transect line) and third (surveying the benthic environment at 1, 3, 5, 7 and 9 meter intervals) swims will be carried out by one individual and the second swim (assessing the cover, size and condition of any stony coral 10 cm or greater in size and located immediately below the transect line) by a second individual. The methods inherent to this study were contained within the first and third swims. To duplicate methods used in the 2005 implementation of the protocol, the alga *Ventricaria ventricosa* will be included in algal measurements (see McNeal 2005).

All species were identified *in situ* using Humann and DeLoach (2003) for coral species identification. Statistical analyses were undertaken using Microsoft Excel XP Professional version.

Results

This year's implementation of the AGRRA protocol has clearly shown that recruitment in 2006 has not followed the same patterns as shown in 2005. Overall there has been a 48.6% decrease in the total number of recruits (401 in 2005 versus 206 in 2006). Recruitment of *Agaricia agaricites* has dropped 90.1% from 2005 (141 recruits) to 2006 (14 recruits). *A. agaricites* had the highest number of recruits in 2005. In 2006, *Porites astreoides* had the highest number of recruits (96) (see also Figure 1). Only three sites have shown an increase in the percentage of recruits from last year – Scott's Head (shallow) showed a 50.0% increase in number of recruits;

Scott's Head (deep) showed a 66.7% increase and Batali Bay showed a 13.4% increase in number of recruits (see also Table 1). There were 29.1 recruits·m^{-2} for 2005 versus 11.8·m^{-2} for 2006. Overall, there has been a 15.0% decrease in the number of species represented in 2006 (17) (see also Figure 2) than were present in 2005 (20) (see also Figure 3).

As in the 2005 implementation there was a paucity of recruits from hermatypic species in 2006. The difference in the findings for this year was that there were even fewer recruits found for *Siderastrea siderea* (a 57.1% decrease over last year) and *Montastraea faveolata* and none for *Montastraea annularis* (see also Figure 4).

Table 1 Percentage Change in Average Number of Recruits per Square Meter between 2005 and 2006.

Site	2005	2006	Percent Change
Batali Bay	8	9.1	+ 13.4%
Berry's Dream	25.6	6.4	- 75.0%
Brain	9.1	7.6	- 16.9%
Calibishie	13.5	4.5	- 66.4%
Champagne (deep)	10.7	5.9	- 45.0%
Champagne (shallow)	17.17	3.2	- 81.3%
Colihaut	14.4	6.8	- 52.4%
Floral Gardens	10.8	6.8	- 37.0%
Fond Colé	13.2	0	- 100.0%
Rena's	11.0	7.8	-29.0%
Rodney's Rock	12.5	7.9	- 37.3%
Salisbury East	12.8	3.7	- 70.9%
Salisbury West	8.0	5.9	- 26.6%
Scott's Head (shallow)	1.6	2.4	+ 50.0%
Scott's Head (deep)	1.6	2.7	+ 66.7%

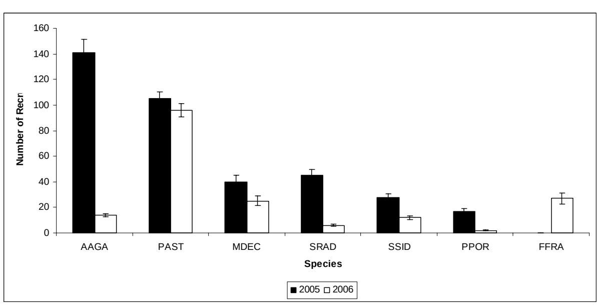

Figure 1 Comparison of Total Number of Recruits from top recruiting species between 2005 and 2006. Data covers only the species with seven highest numbers of recruits.

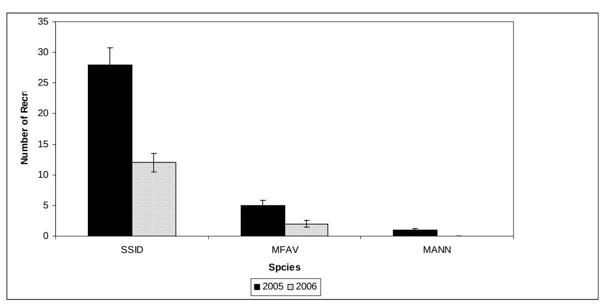

Figure 4 Comparison of Total Number of Recruits of hermatypic species between 2005 and 2006.

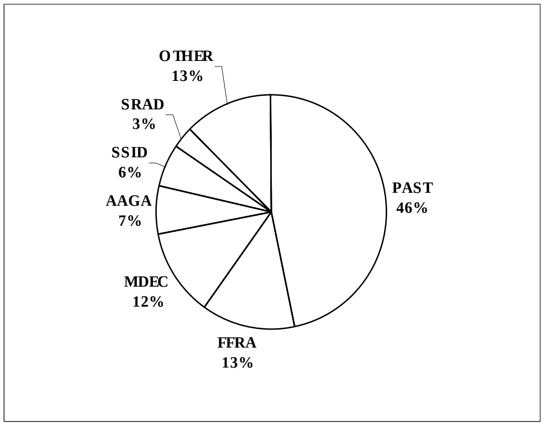

Figure 2 Species Composition of Recruits for 2006. Shown as a percentage of total number of recruits (n=206)

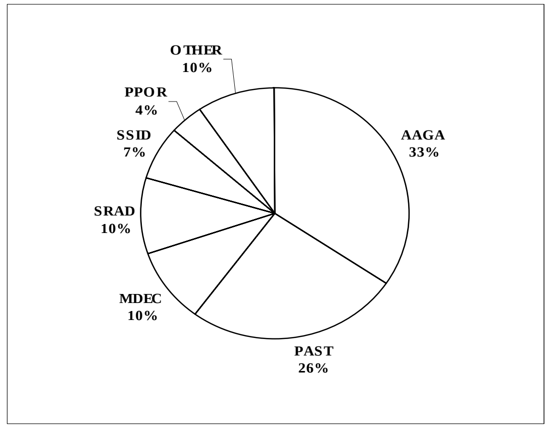

Figure 3 Species Composition of Recruits for 2005. Shown as a percentage of total number recruits (n=410)

Discussion

Dominica suffered from a severe temperature-induced bleaching episode in 2005 with 88.9% of all coral species surveyed displayed effects of bleaching (Zuercher 2005). This episode followed on from similar bleaching episodes in both 2003 (25 sessile reef invertebrates identified displaying bleaching effects) and 2004 (18 sessile reef invertebrates identified displaying bleaching effects) (Kerr 2004). It is a recognized fact that corals that have suffered stress from bleaching have little energy to undertake gamete production (Wellington and Fitt 2003; Tamelander 2002; Rotjan *et al*. 2006). It is therefore likely that the reduction in numbers of recruits found between the 2006 implementation of the AGRRA protocol and the 2005 implementation are attributable to this phenomenon. This could be a direct result of the reduced gametogenesis and spawning following the 2005 bleaching episode, the 2004 episode, the 2003 episode or any combination of these. Assuming that this is the case Dominica's corals would seem to be, for the most part, expending their energy in an effort to regain colony health at the expense of propagating the species. This trend is likely to continue over the coming years given that global temperatures are predicted to continue to rise – as much as 4.5 degrees Celsius over the next 100 years – unless corals are able to adapt to the ambient temperature change in their environment (McCarthy *et al.* eds. 2001).

Implementation of the AGRRA protocol on a Caribbean-wide scale in 2006 has seen a marked decrease in the presence of colonies from small, non- reef building species such as *Agaricia agaricites* and *Porites astreoides* particularly in Barbados and Martinique (Steiner, pers. comm.). The potential implication of these findings with regards to Dominica is that, despite its relatively low population density and lack of wide-scale commercial development, it is not isolated from global disturbances. While Dominica has no control over these types of global disturbances, it can take steps to minimize its impact on local-scale disturbances. Better land management practices can reduce or prevent high sediment load in run off from land and rivers; better agricultural practices can reduce or prevent the introduction of hazardous pesticides and nutrient overloading from fertilizers. Emissions inspections can be introduced to lower vehicle emissions (particulates from diesel engines, for example) from Dominica's numerous vehicles. Better water treatment and sewage management practices can be implemented to reduce or prevent contamination of Dominica's coastal waters. More frequent waste management collection can reduce or prevent introduction of trash into the environment. Educational programs in schools can help to teach Dominica's younger generations about different types of pollution and the damage it can do to their environment. Collectively, these practices can help Dominica to make as minimal an impact on its environment as possible.

Yet another possible cause for the reduced number of recruits is that the currents surrounding Dominica tend to carry planktonic organisms away from the island including larvae from organisms such as *Diadema antillarum* (Steiner, pers. comm.). It is likely that this movement of larvae away from island is also applicable to larvae from Dominica's corals. Larvae drift away to the west, potentially helping to seed reefs around other Caribbean islands while Dominica's reefs continue to decline. While this is true, larvae from farther south should move up to seed Dominica's reefs in turn. However, if there has been a wide-scale mortality event as has been seen in Barbados and Martinique (as mentioned in the preceding paragraph) there can be no replacement of larvae.

In 2005, the average maximum relief (rugosity) across all sites was 58.0 cm. In 2006, this value was 80.6 cm. This decline in recruit numbers serves to highlight the severity in reduction of coral recruit numbers in this year's survey because a greater number of recruits would be expected in areas of greater rugosity as a greater amount of surface area is available for settlement.

Of particular importance in the findings of this study is the continued paucity of recruits from hermatypic species such as *S. siderea*, *M. annularis* and *M. faveolata.* While past studies have found that these reef frame-work building species have low recruitment rates as a whole (Miller *et al.* 2000) the continued decline in recruitment by these species on Dominica's reefs is troubling. These frame-work builders are requisite to proper functioning of the reef ecosystem (Arthur *et al.* 2006). Without them there will likely be a knock-on degradation of the reefs as whole over time. This in turn will have a negative impact on the supply of reef fishes as they will not be able to survive if their habitat disappears. This potential phenomenon has both cultural and economic implications. If fish stocks disappear artisnal fishing, such as the use of fish pots, will collapse. This would undoubtedly force many small-scale fishermen to look for other types of work and would be devastating to subsistence-level fishermen. If the reefs themselves collapse revenue from tourism, in particular from the scuba diving industry, will be lost. In 2004, the travel and tourism industry accounted for $21.1 million (USD) in revenues or 8.2% of Dominica's GDP (World Travel and Tourism Council 2004). This is predicted to rise to $43.4 million (USD) or 11.3% of GDP by 2014. However, if the reefs collapse, demand for diving will inevitably go down as will revenues associated with it.

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Study IV: Atlantic and Gulf Rapid Reef Assessment (AGRRA) of *Diadema antillarum* Density and Macroalgal Height: Post 2005 Bleaching Event

Stephanie Laffan
Institute for Tropical Marine Ecology
P.O. Box 944, Roseau
Commonwealth of Dominica

Abstract In the autumn 2005, a severe bleaching event occurred in Dominica, and elsewhere in the Caribbean. This study addressed the impacts of this bleaching event on the macroalgal canopy height and the density of *Diadema antillarum*. Mean macroalgal height increased by 0.15cm to 1.33cm from 2005 to 2006. It increased at 10 of the 15 sites surveyed. *D. antillarum* density increased overall 0.25 $ind \cdot m^{-2}$ to 1.52 $ind \cdot m^{-2}$. The deeper sites were more affected by the bleaching, with significant increases in macroalgal height of 0.34cm and juvenile *D. antillarum* density of 0.36 $ind \cdot m^{-2}$.

Keywords: *Diadema antillarum*, AGRRA, Canopy Height, Bleaching, Dominica

Introduction

Diadema antillarum, the Long-Spined Urchin, is a herbivorous echinoid. *D.antillarum* is found in the western Atlantic and throughout the Caribbean between Florida and Surinam. It is also in the eastern Atlantic in the Azores, Madeira, the Canaries, Cape Verde Islands to the Gulf of Guinea, Africa (Randall *et al.,* 1964). It is ecologically significant to coral reefs because it grazes on the macroalgae which can overgrow corals in a competition for space.

In 1983, a mass morality of *D. antillarum* in the Caribbean and Western Atlantic Ocean was reported by Lessios (1988). As one of the main grazers of algal growth on and around the reefs, *D. antillarum*'s morality affected the benthic composition of coral reef communities (Carpenter, 1990). There is no quantitative data on *D. antillarum* densities in Dominican waters prior to the mass mortality and only minimal data available from one site surveyed in a study by Hunte and Yunglao (1988) until 2001. Since 2001 there has been an ongoing study of the density of *D. antillarum* at six sites along Dominica's west coast. This study has found the densities of *D. antillarum* in Dominica are greater than other areas in the Caribbean (Steiner and Williams, 2006). It is unclear whether the population in Dominica was affected and recovered quickly or if it was not affect at all.

Those areas where mass mortality of *D. antillarum* was recorded and there had been a previously low to moderate pressure on herbivorous fishes, such as Panama, there were varied increases in algal cover (Lessios, 1988). The herbivorous fishes do not always have the capability to increase the amount of macroalgae consumed in the absence of a macroalgal grazer, *D. antillarum* (Lessios, 1988). This situation leaves coral reef communities at risk to have macroalgae dominating an open space which becomes available. Open space can be created through different means, including mortality after bleaching events.

The coral reefs on Dominica were affected by a severe temperature-induced bleaching event in 2005, following bleaching events in 2003 and 2004. The first AGRRA survey of Dominica was done during the 2005 bleaching event (Byrd *et al.*, 2005). The AGRRA survey includes *D. antillarum* density and macroalgal canopy height because each is part of the coral reef community structure. This study was carried out one year after the severe bleaching event to determine its effect of *D.antillarum* density and macralgal canopy height. Did the density of *D. antillarum* change? Did the bleaching event affect macroalgal canopy height? Is there a relationship between *D. antillarum* density and macroalgal height? Is there a difference between shallow and deep sites, in regard to macroalgal canopy height and *D. antillarum* density?

Materials and methods

For this study the Atlantic and Gulf Rapid Reef Assessment Methodology version 4.0 (Kramer *et al.,* 2005), with modifications made (McNeal, 2005), was used to survey 15 sites along Dominica's west coast with one site (Calibishie) on the northern coast. Three days were used for consistency training, both on land and in water, for all aspects of this survey, which included proper categorization of juvenile and adult *D. antillarum*. Humann and DeLoach(2003), as well as Littler and Littler (2001), was used for species identification of algae.

The AGRRA protocol was used to quantify the macroalgal canopy height and the density of *D. antillarum* at stragetically chosen, representative reefs of Dominica. The sites fom 2005 were revisited in 2006. The maximum relief was compared between 2005 and 2006 to determine if there was a relationship between *D. antillarum* density and rugosity. The shallow sites (0-5m), surveyed by snorkeling, were Salisbury East, Batalie, Fond Colé, Rodney's Rock, Cachacrou (sn), Champagne East, and Calabishie. The deeper sites (5-15m), surveyed by SCUBA, were: Salisbury West, Floral Gardens, Rena's Reef, Brain Reef, Berry's Dream, Champagne West, and Cachacrou (sc). Macoucherie was not surveyed (McNeal, 2005) (See Fig. 1).

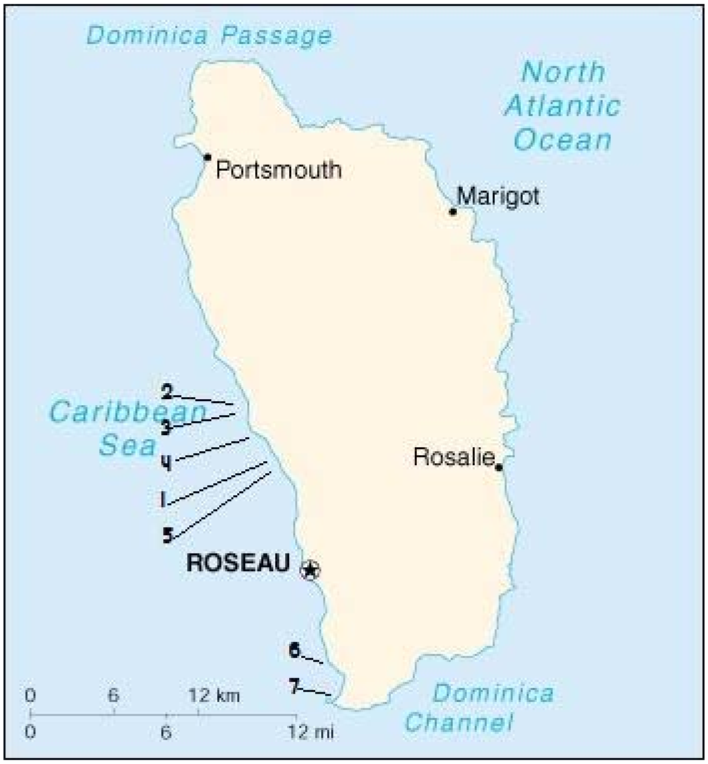

Fig. 1 Map of Dominica numbered with deep sites that were surveyed by SCUBA diving. (McNeal, 2005) 1. Salisbury West, 2. Floral Gardens, 3. Rena's Reef, 4. Brain Reef, 5. Barry's Dream, 6. Champagne, 7. Champagne

Results

Density *Diadema antillarum*

An increase of 0.25 ind·m^{-2} was observed overall between 2005 and 2006, at an increase of 20% it was not significant (P=0.58). Fond Colé had the highest observed density at 3.60 ind·m^{-2} and Calibishie had the lowest at 0.005 ind·m^{-2}. Significant increases were observed at Rodney's Rock (P<0.05), Brain Reef (P<0.05), and Floral Gardens (P<0.01) (See Table 1).

Density Adult *D. antillarum*

The overall density of adult *D.antillarum* decrease by 0.02 ind·m^{-2}, a decrease of 1.84% was not significant (P=0.96). Fond Colé had the highest observed density a

3.44 ind·m^{-2} and Calibishie had the lowest at 0 ind·m^{-2}, which was not a change. The density increased at 9 out of the 15 sites. The density decreased at 5 sites, and significantly at 3 sites: Salisbury West ($P < 0.01$), Batalie ($P<0.05$), and Barry's Dream ($P<0.05$) (See Table 2).

Density Juvenile *D. antillarum*

The density of juveniles significantly increased by 0.27 ind·m^{-2}, an increase of 363% ($P<0.01$). Barry's Dream had the highest observed density at 1.21 ind·m^{-2} and Calibishie had the lowest at 0.01 ind·m^{-2}. The density of juveniles increased at every site. Density increased significantly ($P<0.05$) at Salisbury-West, Barry's Dream, Fond Colé, Floral Gardens, and Colihaut (See Table 3).

Macroalgal height

There was an overall increase of 0.15 cm in mean macroalgal sites between 2005 and 2006, this is not significant ($P=0.76$). Cachacrou (sc) had the highest mean canopy height at 5.17cm and Fond Colé had the lowest at 0.13cm. There was an increase at 10 sites and a decrease at 5 sites. A significant increase was observed at Salisbury West ($P<0.01$), Fond Colé ($P<0.05$) and Cachacrou(sn) ($P<0.05$). A significant decrease was observed at Rena's Reef ($P<0.001$), Rodney's Rock ($P<0.05$), and Champagne East ($P<0.05$) (See Table 4).

Calcareous macroalgal height

There has been a 0.02 cm decrease in mean calcareous height between 2005 and 2006, a 10.77% decrease which is not significant ($P=0.84$). No change was observed at 4 sites, where no calcareous macroalgae were recorded in 2005 or 2006. The highest mean canopy height was observed at Cachacrou (sc) with 0.55cm. A significant decrease was observed at Champagne West ($P<0.05$). A significant increase was observed at Cachacrou (sc) ($P<0.01$) (See Table 5).

Prostrate Growth

In the 2005 study a note of prostrate growth was used to classify macroalgae which was not erect (McNeal, 2005) and no measurement was recorded. This was noted at Salisbury West, Barry's Dream, Brain Reef, Colihaut, Cachacrou(sc), and Champagne West. To determine if this would change the mean macroalgal or calcareous macroalgal heights a value of 0.05 cm was assigned to it. The means at each site were compared and showed no significant difference.

Density *D.antillarum* and macroalgal height

Mean *D. antillarum* densities and mean macroalgal height were evaluated and found to have no relationship in this study ($R^2 = 0.33$, n=15) or in the 2005 study ($R^2 = 0.24$, n=15).

Rugosity

The rugosity, mean maximum relief, changed significantly at 3 sites: Champagne East increase 92% ($p<0.05$) to 73cm; Rodney's Rock increased 83% ($p< 0.05$) 156cm; and Fond Colé decreased 70% ($p< 0.01$) to 42cm. Rodney's Rock had the highest mean relief.

Rugosity vs. Density *D. antillarum*

The rugosity and density of *D. antillarum* were evaluated. No relationship exists between rugosity of a site and density of *D. antillarum* in this study ($R^2 = 0.0006$, n=15) or in 2005 ($R^2 = 0.07$, n=15).

Shallow vs. Deep Sites

The shallow and deep sites were separated and evaluated to determine a difference in mean macroalgal height, mean calcareous height, density of *D.antillarum*, density of adult *D.antillarum*, and density of juvenile *D.antillarum*. No significant difference was found between shallow and deep sites with these variables (See Table 6).

Shallow sites

Comparing the shallow sites mean values of 2005 and 2006, there was a decrease in macroalgal height, calcareous macroalgal height, and density of adult D. antillarum. There was an increase of total density and juvenile density of D. antillarum. None of the changes were significant (See Table 7).

Deep Sites

Comparing the deep sites mean values of 2005 and 2006, there was an increase in macroalgal height, calcareous macroalgal height, total, adult, and juvenile densities of *D. antillarum*. There was a significant increase of 0.34cm in mean macroalgal height ($P<0.05$) and an increased density of 0.36 ind·m^{-2} of juvenile *D. antillarum* ($P<0.05$) (See Table 8).

Table 1 A comparison of total density of *D. antillarum* between 2005 and 2006 at 15 sites.

	2005 Density (ind·m^{-2})	2006 Density (ind·m^{-2})	Change in Density	Percent Change
Salisbury East	2.02	3.40	+ 1.38	+ 68.59
Salisbury West	0.83	0.83	0	0
Floral Gardens	0.45	1.05	+ 0.60	+ 133.33
Batalie	4.45	2.75	- 1.70	- 38.20
Fond Colé	3.52	3.60	+ 0.08	+ 2.21
Rena's Reef	0.43	0.82	+ 0.39	+ 89.75
Rodney's Rock	1.44	2.44	+ 1.00	+ 69.66
Brain Reef	0.66	1.31	+ 0.65	+ 99.74
Barry's Dream	2.59	2.40	- 0.19	- 7.25
Champagne E	1.30	1.23	- 0.07	- 5.15
Champagne W	0.60	1.23	+ 0.63	+105.50
Cachacrou (sn)	0.22	0.29	+ 0.07	+ 32.67
Cachacrou (sc)	0.23	0.57	+ 0.33	+ 142.61
Colihaut	0.30	0.90	+ 0.60	+ 200
Calibishie	0	0.005	+ 0.005	
Overall	1.27	1.52	+ 0.25	+ 19.93

Table 2 Comparison of density of adult *D. antillarum* between 2005 and 2006

	Diadema Adult Density 2005	*Diadema* Adult Density 2006	Change	Percent Change
Salisbury East	2.00	3.1	+ 1.10	+55%
Salisbury West	0.72	0.23	- 0.49	- 67.74%
Floral Gardens	0.43	0.63	+ 0.20	+ 47.06%
Batalie	4.13	2.00	- 2.13	- 51.52%
Fond Colé	3.47	3.44	- 0.03	- 0.84%
Rena's Reef	0.43	0.53	+ 0.10	+ 23.08%
Rodney's Rock	1.41	2.07	+ 0.66	+ 47.09%
Brain Reef	0.56	0.99	+ 0.43	+ 77.26%
Barry's Dream	2.26	1.19	- 1.07	- 47.45%
Champagne East	1.23	1.13	- 0.10	- 8.11%
Champagne West	0.58	1.13	+ 0.55	+ 94.24%
Cachacrou (sn)	0.18	0.23	+ 0.04	+ 22.75%
Cachacrou (sc)	0.23	0.33	+ 0.10	+ 41.45%
Colihaut	0.27	0.57	+ 0.30	+ 114.25%
Calibishie	0	0	0	0
Overall	1.19	1.17	- 0.02	- 1.84%

Table 3 Comparison of juvenile *D. antillarum* densities between 2005 and 2006.

	Diadema Juvenile Density 2005	*Diadema* Juvenile Density 2006	Change	Percent Change
Salisbury East	0.02	0.30	+ 0.28	+ 1696.41
Salisbury West	0.11	0.60	+ 0.49	+ 440.05
Floral Gardens	0.03	0.43	+ 0.40	+ 1600.00
Batalie	0.33	0.75	+ 0.43	+ 130.77
Fond Colé	0.06	0.16	+ 0.11	+ 192.27
Rena's Reef	0	0.29	+ 0.29	
Rodney's Rock	0.03	0.36	+ 0.34	+ 1231.87
Brain Reef	0.10	0.33	+ 0.23	+ 225.00
Barry's Dream	0.33	1.21	+ 0.89	+ 272.62
Champagne East	0.07	0.10	+ 0.03	+ 49.93
Champagne West	0.02	0.10	+ 0.08	+ 498.80
Cachacrou (sn)	0.03	0.06	+ 0.03	+ 87.69
Cachacrou (sc)	0	0.23	+ 0.23	
Colihaut	0.03	0.33	+ 0.30	+ 886.79
Calabishe	0	0.005	+ 0.005	
Overall	0.08	0.35	+ 0.27	+ 362.75

Table 4 Comparison of Macroalgal height between 2005 and 2006 at 15 sites.

	Mean Macroalgal height (cm) 2005	Mean Macroalgal height (cm) 2006	Change	Percent Change
Salisbury East	0.52 (±0.46)	0.24 (±0.26)	- 0.28	- 53.55
Salisbury West	0.51 (±0.51)	1.33 (±0.30)	+ 0.82	+ 170.04
Floral Gardens	1.30 (±1.13)	1.60 (±0.55)	+ 0.30	+ 23.41
Batalie	0	0.17 (±0.24)	+ 0.17	
Fond Colé	0	0.13 (±0.13)	+ 0.13	
Rena's Reef	2.51 (±0.44)	1.02 (±0.51)	- 1.50	- 59.59
Rodney's Rock	0.59 (±0.81)	0.21 (±0.41)	- 0.37	- 63.42
Brain Reef	0.92 (±1.07)	1.48 (±0.92)	+ 0.56	+ 60.36
Barry's Dream	0.88 (±0.90)	0.73 (±0.34)	- 0.13	- 14.93
Champagne East	2.23 (±0.90)	0.76 (±0.25)	- 1.48	- 66.05
Champagne West	0.59 (±0.41)	0.95 (±0.29)	+ 0.36	+ 61.58
Cachacrou (sn)	1.85 (±0.93)	2.94 (±0.65)	+ 1.08	+ 58.53
Cachacrou (sc)	4.38 (±2.13)	5.17 (±1.75)	+ 0.78	+ 17.86
Colihaut	1.26 (±0.67)	2.84 (±2.83)	+ 1.58	+ 125.63
Calibishie	0.31 (±0.58)	0.45 (±0.43)	+ 0.14	+ 45.92
Overall	1.19 (±1.16)	1.33 (±1.38)	+ 0.15	+ 12.22

Table 5 Comparison of Calcareous Macroalgal height between 2005 and 2006.

	Mean Calcareous height (cm) 2005	Mean Calcareous height (cm) 2006	Change	Percent Change
Salisbury East	0	0	0	0
Salisbury West	0	0	0	0
Floral Gardens	0	0.25 (±0.42)	+ 0.25	
Batalie	0	0	0	0
Fond Colé	0	0	0	0
Rena's Reef	0	0.11 (±0.17)	+ 0.11	
Rodney's Rock	0.06 (±0.81)	0	- 0.06	- 100
Brain Reef	0.16 (±0.16)	0.26 (±0.39)	+ 0.09	+ 56.54
Barry's Dream	0.18 (±0.29)	0	- 0.18	- 100
Champagne East	0.51 (±0.52)	0	- 0.51	- 100
Champagne West	0.07 (±0.16)	0	- 0.07	- 100
Cachacrou (sn)	0.50 (±1.13)	0.48 (±0.63)	- 0.03	- 5.00
Cachacrou (sc)	0.12 (±0.20)	0.55 (±0.53)	+ 0.43	+ 371.29
Colihaut	0.13 (±0.28)	0.43 (±0.38)	+ 0.30	+ 225.81
Calibishie	1.21 (±2.03)	0.55 (±0.76)	- 0.67	- 55.29
Overall	0.20 (±0.33)	0.17 (±0.22)	- 0.02	- 10.77

Table 6 A comparison between the shallow and deep sites in 2006.

	Shallow	Deep	Difference	Percent Difference
Mean Macroalgal (cm)	0.70 (±1.01)	1.90 (±1.37)	0.81	114.79%
Mean Calcareous (cm)	0.14 (±0.25)	0.20 (±0.20)	0.03	21.81%
Total Diadema Density (ind·m^{-2})	1.96 (±1.46)	1.14 (±0.53)	0.74	37.75%
Adult Diadema Density (ind·m^{-2})	1.71 (±1.33)	0.70 (±0.34)	1.02	59.70%
Juvenile Diadema Density (ind·m^{-2})	0.19 (±0.27)	0.44 (±0.32)	0.34	185.64%

Table 7 Comparison of Shallow sites between 2005 and 2006.

	2005	2006	Change	Percent Change
Mean Macroalgal (cm)	0.79 (±0.90)	0.70 (±1.01)	- 0.08	- 10.52
Mean Calcareous (cm)	0.32 (±0.45)	0.14 (±0.25)	- 0.18	- 55.14
Total Diadema Density (ind·m^{-2})	1.85 (±1.64)	1.96 (±1.46)	+ 0.11	+ 5.96
Adult Diadema Density (ind·m^{-2})	1.77 (±1.56)	1.71 (±1.33)	- 0.06	- 3.45
Juvenile Diadema Density (ind·m^{-2})	0.07 (±0.11)	0.19 (±0.27)	+ 0.11	+ 0.07

Table 8 Comparison of Deep Sites between 2005 and 2006.

	2005	2006	Change	Percent Change
Mean Macroalgal (cm)	1.56 (±1.34)	1.90 (±1.37)	+ 0.34	+ 21.90
Mean Calcareous (cm)	0.08 (±0.08)	0.20 (±0.20)	+ 0.12	+ 144.32
Total Diadema Density (ind·m^{-2})	0.75 (±0.77)	1.14 (±0.53)	+ 0.39	+ 52.33
Adult Diadema Density (ind·m^{-2})	0.69 (±0.66)	0.70 (±0.34)	+ 0.02	+ 2.26
Juvenile Diadema Density (ind·m^{-2})	0.07 (±0.11)	0.44 (±0.32)	+ 0.36	+ 475.67

Discussion

Density *Diadema antillarum*

The increase in total density of *D.antillarum* between 2005 and 2006 of 27% to 1.62 ind·m^{-2}, could be from an ongoing trend on found in the study by Steiner and Williams (2006) which documented an overall increasing density of 33.33% per year at 6 sites monitored in Dominica. The mean density observed in this study is greater than the other published density of 0.5 ind·m^{-2} in 1988 at Scott's Head (Hunte and Younglao, 1988).

An increase in the density of *D. antillarum* could be part of the trend observed by Steiner and Williams (2001). This increase could be related to the physical disturbances in Dominica; Hurricane Lenny in June 1999 and the bleaching events in 2003, 2004, and 2005; which have the potential to increase coral mortality. An increase in coral mortality opens space which can be colonized by other organisms. It is often inhabited by those organisms which are opportunistic and grow quickly. Algae are opportunistic organisms and are the first organisms to overgrow dead coral. An increase in dead coral increases the macroalgal height, which should generate a response from *D. antillarum* because macroalgae its food source. The bleaching event in 2005 increased the amount of recent mortality and decreased the amount of old mortality present (Weems, 2006). This bleaching event and the previous ones could generate a response to increase the *D. antillarum* population. If physical disturbances continue, and cause coral mortality, it is likely *D. antillarum* populations will continue to increase.

The decrease density of adult *D.antillarum* was minimal and was not significant. The bleaching event did not affect the density. A population increase in adults would suggest an increase in population through recruitment prior to last year, because it takes longer than the 6 months between breeding season in March and the survey in autumn for *D. antillarum* to grow into an adult from a juvenile.

The density of juveniles increased between 2005 and 2006 suggesting an increased recruitment of *D. antillarum* from the past couple years. The bleaching events from the past 3 years could be increasing the recruitment rate of *D. antillarum* by increased macroalgal height because of an increase in space availability due to increased coral mortality as an after affect of bleaching.

The reason for increased recruitment of *D. antillarum* could also be related to the overall increase in *D. antillarum* densities. Steiner and Williams (2001) suggested in their study the reason for the increasing densities could be related to a die-off caused by Hurricane Lenny in June 1999. For an increased population there needs to be an increase in recruitment.

Macroalgal height

The increased macroalgal canopy height between 2005 and 2006 was not significant. Macroalgal canopy height increases with increased space availability. The bleaching in 2005 did cause mortality of corals, which opens space, generally colonized by filamentous turf algae. Macroalgae generally overgrow corals later on in a succession. The severity of the bleaching event means a significant increase in macroalgal height would be observable in future years, unless grazing pressure increases which would generally be from *D. antillarum* or herbivorous fishes.

Calcareous macroalgal height

There was slight decrease in calcareous macroalgal height between the 2005 and 2006 survey. The overall decrease was insignificant. It is not related to increased *D. antillarum* densities.

Shallow and deep sites

The differences noted in the comparison between shallow and deep sites (See Table 6) could be attributed to deeper sites being more influenced by bleaching events than shallow sites. Deeper sites were more affected by the 2005 bleaching event (Sabattis, 2006). Shallow sites diurnally experience more variation in conditions possibly leading to being less affected by bleaching episodes than deeper sites. This could be due to surface waters having the ability to cool during night hours, whereas deeper sites do not have the ability to cool. The deep sites in this study had a higher mean macroalgal height, which could be due to the bleaching events over the past several years increasing mortality and opening space for colonization. The juvenile *D.antillarum* density increased, possibly in relation to an increase the population, to maintain the macroalgal height, its food source, as it grows.

The deeper sites showed an increase in both macroalgal height and juvenile *D. antillarum* density. The past bleaching events have increased macroalgal height, and *D. antillarum* could be responding with an increase in recruitment. The increase in juveniles in deep sites could possibly be due to juveniles settling in different areas than adults, in addition to the food source being abundant.

The differences between 2005 and 2006 in the shallow sites included a decrease in macroalgal height, negatively related to an increase in *D. antillarum* density. The shallow sites were not impacted heavily by the affects of the bleaching event. The increasing density of *D. antillarum* shows its ability to manage macroalgal height by consumption.

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