Benthic and fish population monitoring associated with a marine protected area in the nearshore waters of Grenada, Eastern Caribbean

Robert Anderson[1], Clare Morrall[2], Steve Nimrod[2], Robert Balza[1], Craig Berg[3], Jonathan Jossart[1]

1. Wisconsin Lutheran College, 8800 W. Bluemound Rd., Milwaukee, WI 53226, USA; banderson@wlc.edu, rob.balza@wlc.edu, jossart1@gmail.com
2. St. George's University, P.O. BOX 7, St. George's, Grenada, West Indies; cmorrall@sgu.edu, snimrod@sgu.edu
3. Milwaukee County Zoo, 10001 W Bluemound Road, Milwaukee, WI 53226, USA; craig.berg@milwcnty.com

Received 15-VII-2011. Corrected 1-XII-2011. Accepted 20-XII-2011.

Abstract: Annual benthic and fish population surveys were completed at five locations in the nearshore waters along Grenada´s southwest coast during 2008 - 2010. Two survey sites are located in a newly launched Marine Protected Area (MPA). Photo Quadrat (PQ) and Point Line Intercept (PLI) surveys were used to determine substrate cover. Algae was the primary live cover increasing significantly from 45.9% in 2008 to 52.7% in 2010 (PLI). Algae was also predominant (61.0% - 59.3%) in the PQ surveys although annual variation was not significant. Hard coral cover ranged from 16.5% to 15.4% (PLI) and 11.4% to12.0% (PQ) with no significant differences between years. Branching and encrusting corals occurred more frequently than massive corals. In the three annual surveys neither algal cover nor hard coral varied significantly between MPA and non-protected areas (PLI). Relative abundance of fishes along 30x2m belt transects did not vary significantly among years however density of fishes decreased significantly across years for most major groups. *Chromis* spp. dominated the survey sites at 65.2% in 2008 and 49.8% in 2010, followed by territorial damselfish,11.1% and 15.5%, wrasse increased from 7.3% to 15.5%. Both the substrate cover and fish survey data analyses indicated a stable but degraded community. Annual surveys are planned at these sites for the foreseeable future. Existing and future data from this project will be valuable in determining the efficacy of MPA management, guiding resource management decisions and monitoring the health status of Grenada's valuable reef systems. Rev. Biol. Trop. 60 (Suppl. 1): 71-87. Epub 2012 March 01.

Key words: benthic cover, coral, reef fish, monitoring, Grenada, Eastern Caribbean, marine protected area.

The island nation of Grenada is part of the Eastern Caribbean region recently classified as being at "very high risk" by the Reefs at Risk in the Caribbean report (Bouchon *et al.* 2008). Of the 160 km^2 of reef area in Grenada 41% were listed as having a high-risk threat index and 40% were listed as very high (Burke & Maidens 2004). The primary contributors to this rating were coastal development and fishing pressure.

Coral communities rely on large herbivorous fish species to manage levels of macroalgae (Burkepile & Hay 2010, Ceccarelli *et al.* 2011, Walsh 2011). In an analysis of the Grenadian demersal fish catch and fishing effort from 1986 to 1993, Jeffrey (2000) found that the number of boats employed in the demersal fishery off the west coast of Grenada increased by 200% however the catch declined by nearly 75% during this seven year period. Local overfishing often targets large herbivorous species reducing these fish stocks thus contributing to increased abundance of macroalgae on coral reefs (Hawkins & Roberts 2003). One impact of increased algal abundance is reduced growth and recruitment of coral polyps (Bascompte *et al*. 2005, Arnold 2007, Birrell *et al.* 2008, Mora 2008).

Introduction of excess nutrients to coral reef systems from coastal development further enhances overgrowth of algae (Lapointe *et al.*1997) and directly inhibits coral recruitment and growth (Littler *et al.* 2009). These local stressors weaken a coral community's resilience (Hughes 1994, Hughes *et al.* 2003, Gardner *et al.* 2003, Wilkinson 2008) making it more vulnerable to global climate change and increased storm activities (Goldenberg *et al.* 2001, Eakin *et al.* 2010, Hughes *et al.* 2010). Grenada has been impacted by two major hurricanes in the past decade: Ivan in September 2004 and Emily in July 2005. Major storms such as these can result in devastating effects on reefs breaking down the basic structure and dislodging corals leaving leveled areas of rubble (Woodley *et al.* 1981).

Many countries have established Marine Protected Areas (MPAs) that restrict some uses of coastal reef systems with the hope that these sections will provide a source of biodiversity to adjacent or "down current" locations. Unfortunately, there is a paucity of data that demonstrates the effectiveness of specific management practices. While the Grenadian government established legislation for the Moliniere-Beausejour MPA on the southwest coast of the island in 2001, no significant management practices were implemented until 2010. Permanent mooring buoys were established in 2009, warden patrols began in 2010 and some fishing practices were restricted from September 2010.

A development plan for Grenada's National Protected Areas System identified the need for external assistance in research and monitoring of Grenada's protected areas (Mac Leod 2007). Initial surveys at nine sites off the southwest coast of Grenada in 2006 and 2007 identified macroalgae was the most abundant substrate cover ranging from 36.5% (± 0.8%) to 53.2 % (± 1.2%). Hard corals covered 23.8% (± 0.9%) to 38.1% (± 1.2%) (Bouchon *et al.* 2008). This 2008-2010 study builds on the initial survey and establishes a foundation upon which the effectiveness of the Moliniere-Beausejour MPA management techniques may be evaluated.

Study Area: Five sites ranging in depth from 5.2m-12.2m, located along Grenada's southwest coast were established in 2008. Similar reefs both inside and outside the MPA that are frequently used by the dive industry were selected. Dragon Bay (12° 5'6.00"N 61°45'45.36"W) and Flamingo Bay (12° 5'30.36"N 61°45'30.60"W) are in MPAs, while Northern Exposure Shallow (12° 1'57.30"N 61°46'14.28"W), Northern Exposure Deep (12° 2'22.14"N 61°46'4.74"W) and Quarter Wreck (12° 1'40.98"N 61°47'0.84"W) are in non-protected areas. Four 30m parallel transects were set up at 5m intervals. Metal stakes mark the beginning and end of each permanent transect.

MATERIALS AND METHODS

The substrate composition of Grenada's southwest coast was surveyed with the Photo Quadrat (PQ) and Point Line Intercept (PLI) methods. The PQ method allows for careful identification of substrate types from a digital photograph. Although identification of substrate types is not always optimal based on digital photos this approach allowed more intense scrutiny of the substrate since time is not a factor in the sampling process. In addition using Coral Point Count with Excel extensions (CPCe) v.3.6 allowed a randomized sampling scheme for each picture (Kohler & Gill 2006). Since there are 60 pictures associated with each transect this increases the total number of observations. The PLI method developed by Crosby & Bruckner in 2002 based on Crosby & Reese (1996) was used to estimate relative abundance of major types of substrate cover and fish species associated with the coral reefs in Grenada's nearshore waters. Four 30m permanent transects were surveyed at each of the five locations. Fish species, as well as *Diadema antillarum*, abundance occurring within a two-meter wide belt (AGRRA Protocol v. 4.0) from the substrate to water surface along each transect were recorded. Benthic substrate was identified and recorded at a point directly below each half-meter mark along each transect.

Divers completed fish data collections along each transect in ten minutes.

Sixty photo quadrats from each transect were processed using Coral Point Count with Excel extensions (CPCe) v.3.6 (Kohler & Gill 2006). A Canon EOS Digital Rebel XTI camera in an Ikelite underwater housing was used to take a picture at every half-meter mark. Attached to the underwater housing was a tube with a calibrated scale used to maintain a consistent distance (60cm) from the substrate and to assist with scaling in the CPCe software program. The images were uploaded into the CPCe software program, and a 20cm by 20cm square was superimposed on the image. Eight points were randomly generated inside the square, and the substrate under each point was identified. Dumas *et al*. (2009) found that whether nine or ninety-nine points were used in a1m^2 area, the difference for large categories was not significant. Thus for the 400 cm^2 area in this study 8 points were deemed sufficient. Also, a Sony HDR-SR8 video camera in an Amphibico underwater housing was used to take video of each location to record a broader perspective of the survey sites.

For both the PLI and PQ data a repeated measure analysis of variance (ANOVAR) using transects as the sampling unit was used to monitor Grenada's southwest benthic community and fish assemblage from 2008 to 2010. To satisfy the assumption of normality, proportional data was arcsine square root transformed and all non-proportional data was log transformed. The Shapiro-Wilk test, as well as skewness and kurtosis values were used to assess normality. Non-normal distributions were examined, and if appropriate outliers were removed (Zar 1999). Mauchly's sphericity test was used to determine sphericity, if violated the Greenhouse-Geisser correction was used to determine significance. Additionally all cases of significance were verified with the multivariate analyses, which do not assume sphericity. A Bonferroni correction (significance value (0.05)/ number of comparisons made) was used when determining significance (Sokal and Rohlf 1995). Also, the Bonferroni correction multiple comparison test was used to determine among which years a significant difference occurred.

To identify interactions between the MPA and non-protected area from 2008 to 2010 a two-way ANOVAR was used. This was only done for the PLI data, because the PQ data had an insufficient sample size. In order to effectively make this comparison the same sample size needed to be used for the MPA and non-protected area. This was accomplished by selecting two of the three non-protected locations, Quarter Wreck and Northern Exposure Shallow. The above criteria for assessing normality, sphericity, and significance were used. When an interaction was found to be significant a follow up one-way analysis of variance (ANOVA) test was used to further examine the interaction. The same criteria for assessing normality were used, and Levene's test of homogeneity was used to evaluate the equality of variances. If the results of Levene's test were found to be significant, then a p<0.01 was used to determine significance. The Bonferroni correction was still used when determining significance as well (Sokal and Rohlf 1995).

RESULTS

Substrate (PLI): Algae was the dominant substrate cover found at all locations off Grenada's southwest coast (Fig. 1). Algae increased significantly from 45.9% (SE=1.7; n=35) in 2008 to 52.7% (1.4; 35) in 2010 (ANOVAR, F=7.431, p=0.001). Comparison of major algal groups (macroalgae, turf and coralline) showed that macroalgae consistently dominated the algal community. Turf algae decreased significantly in 2010 and coralline algae increased significantly in 2010 (Tables 1 & 2).

Algal cover in the MPA ranged from 46.3% (3.9; 12) to 51.4% (3.5; 12) over the three years, while in the non-protected area it ranged from 44.0% (3.2; 12) to 50.3% (2.2; 12); no significant interaction between time and location was found (Two-way ANOVAR, F=1.528, p=0.239) (Table 3). Yet the different types of algae experienced significant interaction. Turf algae did have

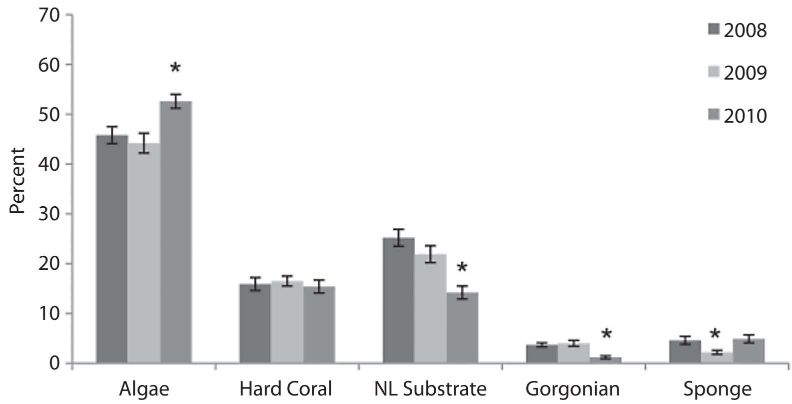

Fig. 1. Mean substrate cover with error bars (SE) based on Point Line Intercept surveys from Grenada's southwest reefs during 2008-2010; * indicates a significant difference (ANOVAR; p<0.017).

TABLE 1
Mean percent cover for algal categories based on Point Line Intercept and Photo Quadrat surveys from Grenada's southwest reefs during 2008-2010. A Bonferroni correction of p<0.017 was used to determine significance

Category	PLI			Bonferroni Comparision	PQ			Bonferroni Comparision
	n	Mean %	SE		n	Mean %	SE	
Macroalgae 2008	32	74.7	2.1		18	70.6	1.9	2010 > 2008 (0.002)
Macroalgae 2009	32	72.4	4.7		18	67.2	1.7	2010 > 2009 (0.001)
Macroalgae 2010	32	71.7	2.2		18	78.0	2.1	
Turf 2008	33	14.8	2.1	2010 < 2008 (p = 0.000)	17	3.8	0.6	2009 < 2008 (0.002)
Turf 2009	33	23.1	4.6	2010 < 2009 (p = 0.000)	17	0.8	0.3	2009 < 2010 (0.001)
Turf 2010	33	2.4	0.6		17	6.0	1.4	
Coralline 2008	24	9.0	1.2	2010 > 2008 (p = 0.000)	16	24.7	2.1	2010 < 2008 (0.001)
Coralline 2009	24	4.2	0.7	2010 > 2009 (p = 0.000)	16	32.6	1.4	2010 < 2009 (0.000)
Coralline 2010	24	23.4	2.1		16	15.9	1.0	

TABLE 2
ANOVAR for major Algal groups based on Point Line Intercept and Photo Quadrat surveys from Grenada's southwest reefs during 2008-2010. Bonferroni correction of p<0.017 was used for determining significance (* indicates significant)

Category	PLI			PQ		
	n	F	p	n	F	p
Macroalgae 2008-2010	32	1.306	0.271	18	13.795	0.000*
Turf 2008-2010	33	14.577	0.000*	17	12.476	0.000*
Coralline 2008-2010	24	31.393	0.000*	16	35.969	0.000*

TABLE 3
Substrate mean based on the Point Line Intercept surveys in non-protected and marine protected areas from Grenada's southwest reefs during 2008-2010. When the Two-way ANOVAR showed a significant interaction between time and location, a one way ANOVA was done for further examination. A Bonferroni correction of p<0.017 was used when determining significance

Substrate	Non-Protected Area			Marine Protected Area			ANOVA	
	n	Mean %	SE	n	Mean %	SE	F	p
Coral 2008	12	15.9	2.6	12	16.4	2.3		
Coral 2009	12	17.6	1.3	12	15.2	2.2		
Coral 2010	12	14.3	1.4	12	19.9	4.3		
Gorgonian 2008	12	3.7	0.9	12	4.6	1.1	0.452	0.508
Gorgonian 2009	12	3.7	1.1	12	6.5	1.3	4.249	0.051
Gorgonian 2010	12	0.7	0.3	12	1.8	0.5	3.137	0.090
Algae 2008	12	47.6	2.6	12	46.9	3.3		
Algae 2009	12	44.0	3.2	12	46.3	3.9		
Algae 2010	12	50.3	2.2	12	51.4	3.5		
NL Substrate 2008	12	21.6	2.5	12	23.2	3.1		
NL Substrate 2009	12	23.1	2.7	12	16.1	2.5		
NL Substrate 2010	12	13.6	1.9	12	15.3	3.1		
Sponge 2008	12	5.6	1.9	12	5.5	0.8	0.857	0.365
Sponge 2009	12	1.4	0.7	12	4.4	1.0	7.511	.012
Sponge 2010	12	4.0	1.2	12	8.0	1.2	7.027	.015

a significant interaction (Two-way ANOVAR, F=6.738, p=0.005), but the follow up tests showed no significant differences between the MPA and non-protected area. Coralline algae also exhibited a significant interaction (Two-way ANOVAR, F=17.752, p=0.000), and for 2010 the 32.4% (3.3; 12) found in the non-protected area was significantly greater than the 18.2% (3.6; 12) in the MPA. Macroalgae did not exhibit any significant interaction (Two-way ANOVAR, F=1.581, p=0.237) (Table 4).

The hard coral cover did not vary significantly from year to year ranging from 16.5% (1.0; 35) to 15.4% (1.3; 35) (Fig. 1) (ANOVAR, F=0.531, p=0.591) (Fig. 1). However the type of hard coral (massive, encrusting and branching) observed did change across the years. Encrusting coral occurred most frequently in 2008 however by 2010 branching coral occurred most frequently (Tables 5 & 6).

Hard coral cover ranged from 15.2% (2.2; 12) to 19.9% (4.3; 12) in the MPA, and 14.3% (1.4; 12) to 17.6% (1.3; 12) in the non-protected area (Table 3). Although hard coral did not differ significantly (Two-way ANOVAR, F=0.072, p=0.931) in overall percent between the MPA and non-protected area encrusting coral did have a significant interaction between time and location (Two-way ANOVAR, F=7.049, p=0.004). Yet in follow up analyses no significant differences between the MPA and non-protected area was found. Massive (Two-way ANOVAR, F=3.555, p=0.046) and branching (Two-way ANOVAR, F=3.170, p=0.091) coral had no significant interaction between time and location (Table 7).

While hard coral cover remained stable, gorgonian cover significantly dropped from 3.7% (0.4; 32) and 4.0% (0.6; 32) in 2008 and 2009 to 1.8% (0.3; 32) in 2010 (ANOVAR, F=19.609, p=0.000). Other significant changes in the substrate were seen in the sponge and non-living categories. Sponge cover saw a sudden decrease from 4.6% (0.8; 35) in 2008 to 2.2% (0.4; 35) in 2009, but recovered to 4.9% (0.8; 35) in 2010 (ANOVAR, F=6.212, p=0.005). Also non-living substrate significantly decreased from 25.2% (1.7; 35) and 21.9% (1.9; 35) in 2008 and 2009 to 14.2% (1.3; 35) in 2010 (ANOVAR, F=14.745, p=0.000) (Fig. 1).

TABLE 4

Algae type mean based on the Point Line Intercept surveys in non-protected and marine protected areas from Grenada's southwest reefs during 2008-2010. When the Two-way ANOVAR showed a significant interaction between time and location, a one way ANOVA was done for further examination. A Bonferroni correction of p<0.017 was used when determining significance

Algae Type	Non-Protected Area			Marine Protected Area			ANOVA	
	n	Mean %	SE	n	Mean %	SE	F	P
Macroalgae 2008	12	70.3	2.9	12	75.6	2.9		
Macroalgae 2009	12	64.0	8.1	12	87.3	2.5		
Macroalgae 2010	12	63.7	3.2	12	78.5	4.1		
Turf 2008	12	17.7	4.1	12	16.1	2.0	0.005	0.945
Turf 2009	12	29.9	7.9	12	8.4	2.0	4.595	0.043
Turf 2010	12	2.1	0.9	12	3.1	1.2	0.237	0.631
Coralline 2008	12	10.6	2.8	12	8.5	1.8	0.143	0.709
Coralline 2009	12	4.9	2.0	12	4.4	1.1	0.161	0.692
Coralline 2010	12	32.4	3.3	12	18.2	3.6	7.329	0.013

TABLE 5

Mean percent cover for hard coral categories based on Point Line Intercept and Photo Quadrat surveys from Grenada's southwest reefs during 2008-2010. A Bonferroni correction of p<0.017 was used to determine significance

Category	Photo Quadrat			Bonferroni Comparison	Point Line Intercept			Bonferroni Comparison
	n	Mean	SE		n	Mean	SE	
Massive 2008	18	36.8	3.6		35	12.9	2.1	2008<2009 (p=0.003)
Massive 2009	18	31.3	3.4		35	27.6	3.1	2008<2010 (p=0.007)
Massive 2010	18	30.5	3.1		35	26.4	3.4	
Branching 2008	19	41.0	6.0		35	32.3	3.9	
Branching 2009	19	43.5	4.1		35	45.8	3.5	2008<2010 (p=0.017)
Branching 2010	19	42.8	4.1		35	44.7	3.9	
Encrusting 2008	19	22.2	4.0		31	47.9	4.5	2008 > 2009 (p=0.000)
Encrusting 2009	19	22.0	2.8		31	21.9	2.9	2008 > 2010 (p=0.000)
Encrusting 2010	19	25.2	2.8		31	21.1	2.9	

TABLE 6

ANOVAR for major coral forms based on Point Line Intercept and Photo Quadrat surveys from Grenada's southwest reefs during 2008-2010. Bonferroni correction of p<0.017 was used for determining significance

Coral Form	Point Line Intercept			Photo Quadrat		
	n	F	p	n	F	p
Massive 2008-2010	35	8.626	0.000*	18	1.630	0.211
Branching 2008-2010	35	4.714	0.012*	19	0.100	0.799
Encrusting 2008-2010	31	13.409	0.000*	19	0.798	0.458

Further comparisons of percent cover in the MPA to non-protected areas revealed that gorgonian cover did have a significant interaction (Two-way ANOVAR, F=13.005, p=0.000). Additional tests of gorgonian cover in the MPA and non-protected areas showed no significant difference among years. Sponge cover also exhibited a significant interaction (Two-way ANOVAR, F=8.654, p=0.002). The sponge cover in the MPA was not significantly different

TABLE 7
Coral Form mean based on the Point Line Intercept surveys in non-protected and marine protected areas from Grenada's southwest reefs during 2008-2010. When the Two-way ANOVAR showed a significant interaction between time and location, a one way ANOVA was done for further examination. A Bonferroni correction of p<0.017 was used when determining significance

Coral Form	Non-Protected Area			Marine Protected Area			ANOVA	
	n	Mean %	SE	n	Mean %	SE	F	P
Massive 2008	12	7.8	2.6	12	19.9	5.0		
Massive 2009	12	23.4	4.9	12	34.1	6.2		
Massive 2010	12	24.6	5.2	12	30.7	6.6		
Branching 2008	12	39.9	9.4	11	29.1	7.0		
Branching 2009	12	58.5	4.7	11	40.6	4.9		
Branching 2010	12	54.1	7.1	11	34.2	9.0		
Encrusting 2008	12	46.9	8.7	12	42.6	8.2	0.195	0.663
Encrusting 2009	12	13.5	3.4	12	17.7	3.3	0.568	0.459
Encrusting 2010	12	18.1	4.0	12	17.7	6.7	0.137	0.714

from the non-protected area in 2008; however sponge cover in 2009 and 2010 showed that the MPA sponge cover was significantly greater than the non-protected area (Table 3).

Substrate (Photo Quadrat): Algae, the dominant substrate cover, ranging from 61.0% (1.5; 19) in 2008, 59.9% (1.9; 19) in 2009 and 59.3% (1.8, 19) in 2010 showed no significant annual differences (ANOVAR, F=0.373, p=0.616) (Fig. 2). Although the percent cover of algae did not change across years, the type of algae observed did. Macroalgae which occurred more frequently than other types of algae increased significantly in 2010. Turf algae dipped significantly in 2009 and coralline algae decreased significantly in 2010 (Table 1 & 2).

Percent hard coral cover remained stable across years ranging from 11.4% (0.7; 18) to 12.0% (1.1; 18) (ANOVAR, F=0.037, p=0.964). Of the three hard coral forms recorded branching coral occurred most frequently with no significant annual variation (Table 3 & 4). Cyanobacteria which was not recorded over the three year sampling period with the PLI method was similar in percent cover to hard coral ranging from 14.7% (1.5; 19) to 11.9% (1.7; 19) (ANOVAR, F=1.314, p=0.277). Percent sponge cover did increase significantly from 1.6% (0.4; 19) in 2008 to 4.2% (0.7; 19) in 2010 (ANOVAR, F=9.478, p=0.002, Bonferroni p=0.004) (Fig. 2).

Fish: A total of 62 fish species were observed at the five sampling locations from 2008 to 2010 (Table 8). The major groups of fish analyzed included *Chromis spp.*, damselfishes, parrotfishes, surgeonfishes, and wrasse. *Chromis spp.* were separated from the damselfishes because of their large number. Diversity indices were quite high and similar across all sites (Table 9).

Relative abundance of all but one of the most frequently occurring groups of fishes did not vary significantly across the three years of this study. *Chromis spp.*, the largest group observed, showed a downward trend going from 65.2% (3.5; 34) to 49.8% (4.2; 34); however the difference was not significant (ANOVAR, F=3.611, p=0.032). Damselfishes ranged from 11.1% (1.7; 32) to 15.5% (1.7; 32) (ANOVAR, F=3.531, p=0.035) and parrotfishes from 10.1% (1.6; 36) to 6.4% (0.7; 36) (ANOVAR, F=1.732, p=0.184) (Fig. 3). Surgeonfishes also remained stable between 0.9% (0.1; 31) and 1.3% (0.2; 31) (ANOVAR, F=0.146, p=0.864). Wrasse however showed a significant increase from 7.3% (1.0; 35) to 15.5% (2.1; 35) (ANOVAR, F=7.341, p=0.001) (Fig. 3).

TABLE 8

Fish species observed during surveys at five sampling locations over Grenada's southwest reefs during 2008-2010

Acanthuridae	**Haemulidae**	**Pomacentridae**
Acanthurus coeruleus	*Haemulon chrysargyreum*	*Holacanthus tricolor*
Acanthurus chirurgus	*Haemulon flavolineatum*	*Chromis cyanea*
Acanthurus bahianus	*Haemulon* spp.	*Chromis multilineata*
Acanthurus spp.	**Holocentridae**	*Stegastes partitus*
Apogonidae	*Myripristis jacobus*	*Abudefduf saxatilis*
Apogon townsendi	*Holocentrus rufus*	*Stegastes leucostictus*
Apogon spp.	*Holocenthus coruscus*	*Stegastes diencaeus*
Aulostomidae	*Holocentrus adscensionis*	*Stegastes planifrons*
Aulostomus maculatus	**Grammatidae**	*Microspathodon chrysurus*
Balistidae	*Gramma loreto*	**Scaridae**
Monacanthus spp.	**Labridae**	*Scarus vetula*
Blenniidae	*Thalassoma bifasciatum*	*Sparisoma aurofrenatum*
Blennidea spp.	*Clepticus parrae*	*Sparisoma viride*
Bothidae	*Halichoeres bivittatus*	*Scarus* spp.
Bothus lunatus	*Bodianus rufus*	**Sciaenidae**
Carangidae	*Halichoeres garnoti*	*Equetus lanceolatus*
Carangoides ruber	*Xyrichtys* spp.	*Equetus punctatus*
Decapterus macarellus	**Lutjanidae**	**Scorpaenidae**
Cirrhitidae	*Lutjanus synagris*	*Scorpaena plumieri*
Amblycirrhitus pinos	*Lutjanus mahogoni*	**Serranidae**
Chaetodontidae	*Ocyurus chrysurus*	*Cephalopholis fulva*
Chaetodon capistratus	*Lutjanus* spp.	*Cephalopholis cruentata*
Chaetodon striatus	**Mullidae**	*Serranus tigrinus*
Chaetodon spp.	*Pseudupeneus maculatus*	*Hypoplectrus* spp.
Diodontidae/Tetraodontidae	*Mulloidichthys martinicus*	*Hypoplectrus guttavarius*
Canthigaster rostrata	**Ophichthidae**	*Hypoplectrus chlorurus*
Gobiidae	*Myrichthys breviceps*	**Synodontidae**
Coryphopterus glaucofraenum	**Ostraciidae**	*Synodus intermedius*
Coryphopterus hyalinus	*Acanthostracion quadricornis*	
Elacatinus genie	*Acanthostracion polygonius*	
Muraenidae	**Priacanthidae**	
Echidna catenata	*Priacanthus arenatus*	

TABLE 9

Shannon-Wiener diversity index based on identified species observed during surveys over Grenada's southwest reefs during 2008-2010. (Chromis were excluded because their large numbers would dominate the index)

Location 2008-10	2008		2009		2010	
	H'	Richness	H'	Richness	H'	Richness
Dragon Bay	2.346	37	2.032	29	2.218	36
Flamingo Bay	2.183	27	2.459	30	2.217	30
N.E Shallow	2.417	29	2.143	32	2.061	25
N.E. Deep	2.392	35	2.608	33	2.411	30
Quarter Wreck	2.527	38	2.309	31	2.333	32
All Locations	2.548	51	2.598	49	2.500	53

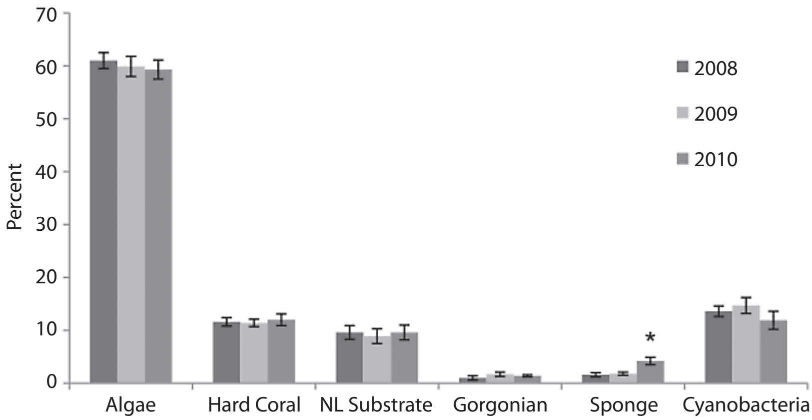

Fig. 2. Mean substrate cover with error bars (SE) based on Photo Quadrat surveys from Grenada's southwest reefs during 2008-2010; * indicates a significant difference (ANOVAR; p<0.017).

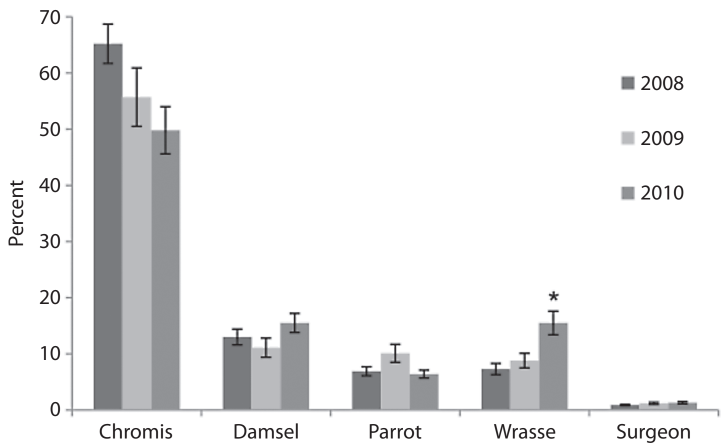

Fig. 3. Mean fish composition with error bars (SE) based on Point Line Intercept surveys from Grenada's southwest reefs during 2008-2010;* indicates a significant difference (ANOVAR; p<0.017).

In comparing the MPA to the non-protected area, a significant interaction between time and location was observed for the chromis, which ranged from 47.8% (6.8; 12) to 77.1% (3.7; 12) in the MPA and 42.0% (6.4; 12) to 45.8% (6.7; 12) in the non-protected area (Two-way ANOVAR, F=6.303, p=0.007). Additional tests revealed that percent chromis observed in 2008 was significantly lower in the non-protected area then the MPA (Table 10). The wrasse group also had a significant interaction between time and location (Table 11). During 2008 the wrasse were significantly higher in the non-protected area at 11.9% (1.9; 12), whereas the MPA only had 3.5% (1.1; 12) wrasse (Table 10). None of the other fish groups showed a significant interaction at time and location (Table 11).

The density of fishes on the other hand did show significant differences for most groups

TABLE 10
Mean Fish percent based on the Point Line Intercept surveys in non-protected and marine protected areas from Grenada's southwest reefs during 2008-2010. When the Two-way ANOVAR showed a significant interaction between time and location, a one way ANOVA was done for further examination. A Bonferroni correction of p<0.017 was used when determining significance

Fish Observed	Non-Protected Area			Marine Protected Area			ANOVA	
	n	Mean %	SE	n	Mean %	SE	F	p
Chromis 2008	12	42.7	6.4	12	77.1	3.7	20.476	0.000
Chromis 2009	12	42.0	7.6	12	63.2	8.2	3.529	0.074
Chromis 20010	12	45.8	6.7	12	47.8	6.8	0.025	0.876
Damselfish 2008	12	21.1	2.9	12	9.7	1.4		
Damselfish 2009	12	15.3	3.3	12	9.3	2.7		
Damselfish 2010	12	18.0	3.0	12	14.6	2.8		
Parrotfish 2008	12	9.6	1.7	12	3.9	0.6		
Parrotfish 2009	12	13.2	2.8	12	6.4	1.8		
Parrotfish 2010	12	7.0	1.1	12	5.3	1.5		
Surgeonfish 2008	11	1.7	0.4	12	0.6	0.1		
Surgeonfish 2009	11	1.2	0.4	12	1.0	0.4		
Surgeonfish 2010	11	0.8	0.3	12	1.7	0.5		
Wrasse 2008	12	11.9	1.9	12	3.5	1.1	18.988	0.000
Wrasse 2009	12	8.0	2.0	12	10.3	2.4	0.522	0.478
Wrasse 2010	12	14.8	2.2	12	23.5	4.5	2.576	0.123

over the years of the study. *Chromis spp.* decreased significantly from 669.3 fish/100m^2 (180.5; 30) to 286.6 fish/100m^2 (78.3; 30) (ANOVAR, F=9.215, p=0.000). Damselfishes density also significantly decreased from 70.3 fish/100m^2 (3.7; 34) in 2008 to 40.6 fish/100m^2 (2.7; 34) in 2009 (Bonferroni, p=0.000) and 55.3 fish/100m^2 (5.2; 34) in 2010 (Bonferroni, p=0.015) (ANOVAR, F=17.994, p=0.000). The density of parrotfishes significantly decreased from 39.5 fish/100m^2 (3.2; 30) and 39.7 fish/100m^2 (4.2; 30) in 2008 and 2009 to 26.3 fish/100m^2 (4.5; 30) in 2010 (ANOVAR, F=10.786, p=0.000). Wrasse density however showed an increase from 37.6 fish/100m^2 (4.6; 34) and 30.2 fish/100m^2 (3.5; 34) in 2008 and 2009 to 68.6 fish/100m^2 (15.4) in 2010 but the change was not significant (ANOVAR, F=3.525, p=0.035). The density of surgeonfishes did not significantly change, however it showed a downward trend going from 6.3 fish/100m^2 (0.8; 25) in 2008 to 5.9 fish/100m^2 (1.4; 25) in 2009, and finally to 4.5 fish/100m^2 (0.5; 25) in 2010 (ANOVAR, F=1.859, p=0.179) (Fig. 4). The only fish group that experienced a significant interaction between time and location for density was damselfish (Two-way ANOVAR, F=7.288, p=0.016) (Table 11). Damselfish in 2010 were significantly higher in the non-protected area at 54.9% (3.5; 11), while only 36.8% (4.8; 12) were observed in the MPA (ANOVA, F=9.600, p=0.005) (Table 12).

The observed fish assemblage was divided into feeding groups based on the classification of Sadin (2008b). Combined data from all sites across years (2008-2010) showed the dominant feeding group of the assemblage to be planktivores at 81.3% (1.8%; 35) to 74.7 (3.5%; 31). Herbivores represented 9.7% (1.0%; 35) to 13.6 (2.0%; 36), while carnivores comprised 10.9 (1.3%; 30) to 14.9% (2.2; 34). Fish feeding groups were not significantly different between years. In addition there was no significant difference between the MPA and non-protected areas in the percent planktivores (Two-way ANOVAR, F=3.891, p=0.036), herbivores (Two-way ANOVAR, F=2.900, p=0.078) or carnivores (Two-way ANOVAR,

TABLE 11
Two-way ANOVAR of Fish percent and density at time and location from non-protected and marine protected areas from Grenada's southwest reefs during 2008-2010. A bonferroni correction factor of p<0.017 was used to determine significance (*indicates significant)

Interaction	Fish Percent			Fish Density		
	n	F	p	n	F	p
Chromis Time*Location	12	6.303	0.007*	10	1.965	0.169
Damsel Time*Location	12	4.424	0.024	11	7.288	0.016*
Parrotfish Time*Location	12	1.784	0.191	12	0.072	0.931
Surgeonfish Time*Location	10	2.279	0.131	10	0.192	0.183
Wrasse Time*Location	12	13.656	0.000*	11	3.595	0.046

TABLE 12
Mean Fish density based on the Point Line Intercept method from non-protected and marine protected areas from Grenada's southwest reefs during 2008-2010. If the Two-way ANOVAR showed a significant interaction between time and location, a follow up one way ANOVA was done for further examination. A Bonferroni correction of p<0.017 was used when determining significance

Fish Group	Non-Protected Area			Marine Protected Area			ANOVA	
	n	Mean (fish/100m^2)	SE	n	Mean (fish/100m^2)	SE	F	p
Chromis 2008	11	439.6	88.6	11	498.6	112.2		
Chromis 2009	11	422.0	192.7	11	972.3	378.6		
Chromis 20010	11	348.3	171.6	11	171.1	26.7		
Damselfish 2008	11	69.4	6.5	12	64.9	4.7	0.294	0.593
Damselfish 2009	11	43.4	4.4	12	27.9	4.7	7.559	0.012
Damselfish 2010	11	54.9	3.5	12	36.8	4.8	9.600	0.005
Parrotfish 2008	12	49.0	6.0	12	22.0	3.5		
Parrotfish 2009	12	41.3	5.4	12	18.9	3.9		
Parrotfish 2010	12	30.5	9.0	12	13.1	2.8		
Surgeonfish 2008	12	4.1	0.6	11	7.3	1.5		
Surgeonfish 2009	12	5.0	1.1	11	6.0	2.9		
Surgeonfish 2010	12	3.1	0.8	11	3.8	0.8		
Wrasse 2008	12	42.8	7.6	12	46.1	9.5		
Wrasse 2009	12	24.0	3.3	12	39.4	6.2		
Wrasse 2010	12	88.7	37.8	12	75.1	21.1		

F=2.490, p=0.111) since none exhibited a significant interaction between time and location.

Combined *Diadema antillarum* density for Grenada's southwest coast exhibited a significant downward trend having 3.1 urchins/100m^2 (0.5; 36) in 2008, to 1.9 urchins/100m^2 (0.5; 36) in 2009 and to only 0.2 urchins/100m^2 (0.1; 36) in 2010 (ANOVAR, F=6.078, p=0.004). It should be noted even after log transformation the data did not fulfill the assumption of normality, however sphericity could be assumed. There was also no significant interaction at time and location for diadema (Two-Way ANOVAR, F=1.853, p=0.197).

DISCUSSION

Data collected during three annual surveys indicates benthic cover in the nearshore waters off the southwest coast of Grenada was similar to many reported findings from across the Caribbean. Algae dominated the substrate (45.9% to 61.0%) and live hard coral coverage (16.5% to 11.4%) was quite low. Algae

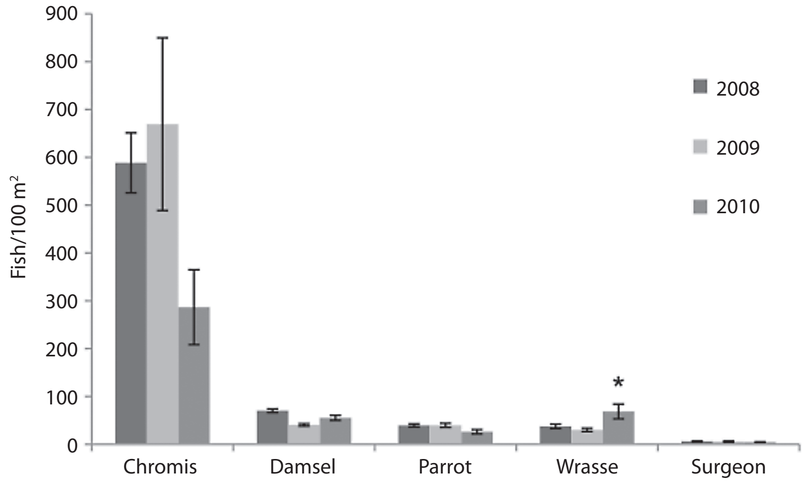

Fig. 4. Mean fish density with error bars (SE) based on Point Line Intercept surveys from Grenada's southwest reefs during 2008-2010; * indicates a significant difference (ANOVAR; $p<0.017$).

dominated systems have been reported for many nearshore communities in the Caribbean (Hughes 1994, Gardner 2003, Burke & Maidens 2004, Bouchon *et al*. 2008, Wilkinson 2008, Mumby 2009, Walsh 2011). Algae has been the dominant substrate cover on Caribbean reefs since a major ecological phase shift occurred in the 1980s. Overfishing, hurricane damage and a disease-induced die-off of *D. antillarum* have been proposed as major factors in this shift (Hughes 1994, Gardner *et al.* 2003).

Low densities of *D. antillarum* in Grenadian nearshore waters may be one of the key factors in the high algal component of this benthic community. The mean *D. antillarum* density found in 2x30m belt transects off the coast of Grenada during this study ranged from $0.002/m^2$ to $0.031/m^2$ which is much lower than the $4.25/m^2$ densities measured in 2003 by Carpenter & Edmunds (2006) for these waters and the $1.7\text{-}8.9/m^2$ they found associated with reefs of six countries around the Caribbean. Based on general surveys across a spectrum of western Atlantic reefs between 1998-2000 Kramer (2003) reported mean *D. antillarum* densities of $0.029/m^2$. Newman *et al*. (2006) found mean densities of $0.019/m^2$ at similar depths in the western and northern Caribbean. In both studies fleshy macroalgae generally dominated the reef benthic communities where these low *D. antillarum* densities occurred.

Given the importance of *D. antillarum* in the coral reef community reestablishment of *D. antillarum* may have potential as a management tool to enhance coral growth in algal dominated systems. This potential became apparent when a phase shift reversal was noted on Jamaica's north coast. Coral cover increased from 23% in 1995 to 54% in 2004 with higher growth rates of juvenile corals and higher densities of small juvenile recruits in "dense urchin zones" (Idjadi *et al*. 2006, 2010, Bechtel *et al*. 2006). The potential impact of increased numbers of *D. antillarum* on coral recovery sparked introductions of additional *D. antillarum* into Grenada's MPA from adjacent populations in 2011 (Nimrod personal communication). These relocations will hopefully result in significant increases in local populations of *D. antillarum* that will reduce macroalgae and facilitate an increase in coral recruitment and growth.

Understanding the composition of Grenada's southwest coastal nearshore fish community will also inform existing and future fisheries management practices. Heavy fishing pressure has been identified as one of the key factors in transformation of coral reefs to algal dominated systems (Hawkins & Roberts 2003). Fishing methods in Grenada include beach seining, trap nets, hand lines and spearing. Target species are mainly carnivores such as Lutjanidae (snapper), Serranidae (groupers) and Carangidae (jacks, pompanos and mackerels and scad) (Finlay 2000). Large herbivores such as Scaridae (parrotfish) and Acanthuridae (surgeonfishes and tang) are also frequently seen in Grenadian fish markets. Observations during 2008-2010 indicated that planktivores (74.7 - 81.3%) dominated the nearshore Grenadian fish community followed by herbivores (9.7 - 13.6%), carnivores (10.9 - 13.9%). The herbivore component of Grenada's nearshore fish assemblage seems low when compared to other studies. Toller *et al*. (2010) found 65% herbivores off Saba Island in habitat types similar to those in Grenada. In a synthesis of Caribbean wide surveys between 1998 and 2000, Kramer (2003) found herbivores made up 64.6% of the fish community sampled. Simply determining that the herbivore component of the Grenadian fish community is low compared to other locations does not allow a full understanding of the impact this has on substrate cover. Burkepile & Hay (2010) pointed out the importance of species level identification in reef fish monitoring. Each herbivorous species can have unique impacts on algal succession and coral growth. A diverse assemblage of herbivorous fishes can reduce development of macroalgae communities and thereby enhance recruitment of coral to open substrates. Ceccarelli *et al*. (2011) divides herbivorous fishes into roving herbivores or "foragers" (parrotfish *Scarus* spp. and surgeonfish *Acanthurus* spp.) and "farmers" (territorial damselfish *Stegastes* spp.) in order to evaluate their potential influence on algal succession and coral reef recovery. "Farmers" tend to suppress algal succession preventing development of the fleshy macroalgae stage. "Foragers" have an intermediate effect allowing development of some macroalgae but not a late-successional assemblage (Ceccarelli *et al*. 2011). In Grenada's nearshore fish community herbivores were dominated by parrotfishes (Scaridae) at 70.2% followed by territorial damselfish fish (*Pomacentrus* spp., *Stegastes* spp., *Microspathodon* spp.) at 17.9% and surgeonfish (*Acanthurus* spp.) at 11.5%. Thus "farmers" comprised only 17.9% in the Grenadian nearshore herbivorous fish community while "foragers" made up 82.1%. It is understandable therefore that turf algae comprised such a small portion of the algal community and fleshy macroalgae made up the majority. Arnold (2007) demonstrated that grazing by scrapers such as parrotfish and urchins facilitate coral recruitment more than territorial damselfishes that maintain low levels of turf algae. Since the species composition of herbivores in Grenada's nearshore waters is primarily comprised of "foragers" rather than "farmers" potential benefits are likely for future coral recruitment if the overall number of herbivores can be increased. It is hoped that newly implemented fishing restrictions in the Moliniere-Beausejour MPA will facilitate increased abundance of herbivorous fishes.

In addition to low numbers of herbivores, algal dominance is also driven by increases in nutrients in nearshore waters. Littler *et al*. (2009) described the importance of taking into consideration the complex interaction of herbivory, nutrient levels and stochastic events in understanding existing conditions and developing management strategies for coral reef communities. Lapointe *et al*. (1997) argued that nutrient input from non-point source pollution related to development and population increases on the island of Jamaica was a major factor in driving the shift from a coral dominated system to an algal dominated community. In a comparative study of reef communities Sandin *et al*. (2008a) saw a shift from dominance by a few large top predator fish species to dominance by small lower trophic level consumers, primarily planktivores, in areas of increasing human populations. The dominance of planktivores (primarily *Chromis* spp.) in Grenadian nearshore waters may be an indicator of excess nutrients into these waters. Two major rivers (St. Johns and Beausejour), flow into the nearshore waters of Grenada's southwest coast. These rivers drain heavily populated areas as well as agricultural lands and have the potential of delivering excess nutrients into the reef communities. These nutrients have the potential of enhancing macroalgal growth and inhibiting the recruitment and growth of coral (Littler *et al.* 2009).

The three years of monitoring at permanent transects in this study provide a basis for future trend analysis and evaluation of management practices. Hughes *et al*. (2010) advocates long term monitoring of important taxonomic groups as well as identification of mechanisms and feedbacks in order to detect indicators of phase shifts. He also encourages agencies involved in research and management of reefs to take a proactive integrative approach through education of grassroots constituencies, enhancing access to existing information and expertise and strengthening regulations associated with harvesting important species from these communities. This approach is beginning to be implemented in Grenada through the work of the Grenada Government Fisheries Division and the Moliniere-Beausejour Marine Protected Area Stakeholder Group.

This study establishes a baseline of information but long term and more specific monitoring is needed to better understand the trajectory of Grenada's reef communities. Gardner *et al*. (2003) indicated that areas of coral recovery are often dominated by non-framework builders such as *Agaricia* and *Porites* rather than framework builders such as *Acropora* and *Montastrea*. These framework builders that formerly dominated reefs in the Caribbean are essential to surviving the destructive forces of major storms. The coral community in Grenada's nearshore waters is comprised primarily of branching coral much of which is *Agaricia* and *Porites*. Given the importance of framework builders to the resilience of coral reef communities identification of coral species will be added to the monitoring program to better understand the coral community.

The similarity between the MPA and non-protected areas seen in this study may be due to the fact that the Moliniere-Beausejour MPA management plan was not fully implemented until September 2010. After full implementation of the plan wardens began to patrol the area and prevent fishing from boats and enforce the use of permanent mooring buoys by divers and snorkelers in the MPA. Future monitoring efforts will be able to use the results of this study as a basis for comparison in order to assess the impact of the newly implemented management practices in the MPA. Expansion of current studies will allow a better understanding of mechanisms and feedbacks in these reef systems. Video and photographs of transects and surrounding habitats are being incorporated into public presentations for Grenadian resource managers and the general public to encourage a broader understanding of the importance of careful resource management.

In addition to focusing on local environments it is important to connect these studies to broader ecosystem wide analyses. Ogden (2010) encourages moving toward an ecosystem-based management plan for the Caribbean. Ogden cites plans for regional management inspired by the CARICOMP network of marine laboratories and encourages going beyond local problems and addressing issues like the *D. antillarum* die-off, wide spread white band disease and the annual plume of discharge from Venezuela's Orinoco River. Efforts are ongoing to strengthen connections of this ongoing monitoring effort to the network of Caribbean marine laboratories and provide information that will assist regional management.

ACKNOWLEDGEMENTS

Funding for this project was provided by the Fischer Family Foundation and Mr. Gary Stimac and is greatly appreciated. A special thanks to Jacob Krause for playing a major role in developing this program. Thanks are also offered to Jillian Groeschel, Kyle Foster, Svetlana Bornschlegl, Victoria Krueger, Thomas Dietrich, Ben Hermanson, Laurelyn Dexter, Angela Majeskie, Emily Bolda, Allison Page, and Angela Blasezyk for data collection. Kayli Giertych and Stephen Vandenberg are thanked for assistance with the manuscript. Billie Harrison of the Racine Zoo is also thanked for field assistance.

RESUMEN

Un estudio sobre poblaciones bentónicas y de peces fue realizado en cinco localidades en la zona costera en el suroeste de Grenada entre 2008 y 2010. Dos sitios se ubicaron en una Área Marina Portegida (AMP) recientemente creada. Para determinar la cobertura se utilizaron foto-cuadrantes (FQ) y transectos de intersección de puntos (TIP). Las algas fueron el principal componente del bentos, aumentando significativamente de 45,9% en 2008 a 52,7% en 2010 (TIP). Las algas también fueron predominantes (61,9%-59,3) en los FQ, aunque las diferencias anuales no fueron significativas. La cobertura de corales pétreos tenía un ámbito de 16,5% a 15,4% (TIP) y de 11,4% a 12,0% (FQ), sin diferencias significativas entre años. Los corales ramificados e incrustantes fueron más frecuentes que los corales masivos. En los tres años no hubo diferencias significativas entre las AMPs y las áreas no protegidas. La abundancia relativa de peces a lo largo de un transecto de 30x2m no varió significativamente entre los años, sin embargo, la densidad de peces decreció significativamente a través de los años, para los grupos principales. *Chromis* spp. predominó con 65,2% en 2008 y 49,8% en 2012, seguido por damiselas territoriales, 11,1% y 15,5%, y los lábridos aumentaron de 7,3% a 15,5%. Tanto la coberura del sustrato como los datos de peces indican una comunidad estable pero degradada. Sondeos anuales están planeados para el futuro. Los datos existentes y futuros de este proyecto serán muy útiles para determinar la eficacia de la gestión de las AMPs y el estado de salud de los sistemas arrecifales de Grenada.

Palabras clave: cobertura bentónica, coral, peces de arrecife, monitoreo, Grenada, Caribe Oriental.

REFERENCES

Arnold, S.N. 2007. Running the gauntlet to coral recruitment through a sequence of local multiscale processes. MSc Thesis, Univ. Maine, Orono, Maine, USA.

Bascompte, J., C.J. Melian & E. Sala. 2005. Interaction strength combinations and the overfishing of a marine food web. Proc. Natl. Acad. Sci. USA 102: 5443-5447.

Bechtel, J.D., P. Gayle & L. Kaufman. 2006. The return of *Diadema antillarum* to Discovery Bay: patterns of distribution and abundance. Proc. 10th Int. Coral Reef Symp., Okinawa 1: 367-375.

Birrell, C.L., L. J. McCook, B.L. Willis & G.A. Diaz-Pulido. 2008. Effects of benthic algae on the replenishment of corals and the implications for the resilience of coral reefs. Oceanogr. Mar. Biol. Annu. Rev. 46: 25-63.

Bouchon, C., P. Portillo, Y. Bouchon-Navaro, M.Louis, P. Hoetjes, K. De Meyer, D. Macrae, H. Armstrong, V. Datadin, S. Harding, J. Mallela, R. Parkinson, J. van Bochove, S. Wynne, D. Lirman, J. Herlan, A. Baker, L. Collado, S. Nimrod, J. Mitchell, C. Morrall, C. Isaac. 2008. Chapter 19. Status of coral reefs of the Lesser Antilles: The French West Indies, The Netherlands Antilles, Anguilla, Grenada, Trinidad and Tobago, p. 265-279 *In*: Wilkinson, C. (Ed.). Status of coral reefs of the world 2008. Global Coral Reef Monitoring and Reef and Rainforest Research Centre, Townsville, Australia.

Burke, L. & J. Maidens. 2004. Reefs at Risk in the Caribbean. World Resources Institute, Washington D.C., USA.

Burke, L., K. Reytar, M. Spalding & A. Perry. 2011. Reefs at Risk Revisited. World Resource Institute, Washington, D.C., USA.

Burkepile, D.E. & M.E. Hay. 2010. Impact of herbivore identity on algal succession and coral growth on a Caribbean reef. PLoS ONE 5: e8963.

Carpenter, R.C. & P.J. Edmunds. 2006. Local and regional scale recovery of *Diadema* promotes recruitment of scleractinian corals. Ecol. Lett. 9: 268-277.

Ceccarelli, D.M., G.P. Jones & L.J. McCook. 2011. Interactions between herbivorous fish guilds and their influence on algal succession on a coastal coral reef. J. Exp. Mar. Biol. Ecol. 399: 60-67.

Crosby, M.P. & E. S. Reese. 1996. A manual for monitoring coral reefs with indicator species: butterfly fishes as indicators of change on the Indo-Pacific reefs, Office of Ocean and Coastal Resource Management, NOAA, Silver Spring, Maryland, USA.

Dumas, P., A. Bertaud, C. Peignon, M. Leopold & D. Pelletier. 2009. A "quick and clean" photographic method for the description of coral reef habitats. J. Exp. Mar. Biol. Ecol. 368:161-168.

Eakin, C.M., J.A. Morgan, S.F. Heron, T.B. Smith, G. Liu, L. Alvarez-Filip, B. Baca, E.

Bartels, C. Bastidas, C. Bouchon, M. Brandt, A. Bruckner, L. Bunkley-Williams, A. Cameron, B.D. Causey, M. Chiappone, T.R.L. Christensen, M.J.C. Crabbe, O. Day, E. de la Guardia, G. Díaz-Pulido, D. DiResta, D.L. Gil-Agudelo, D. Gilliam, R. Ginsburg, S.

Gore, H.M. Guzman, J.C. Hendee, E.A. Hernández-Delgado, E. Husain, C.F.G. Jeffrey, R.J. Jones, E. Jordán-Dahlgren, L. Kaufman, D.I. Kline, P. Kramer, J.C. Lang, D. Lirman, J. Mallela, C. Manfrino, J.P. Maréchal, K. Marks, J. Mihaly, W.J. Miller, E.M. Mueller, E. Muller, C.A. Orozco-Toro, H.A. Oxenford, D. Ponce-Taylor, N. Quinn, K.B. Ritchie, S. Rodríguez, A. Ramírez, S. Romano, J.F. Samhouri, J.A. Sánchez, G.P. Schmahl, B. Shank, W.J. Skirving, S.C.C. Steiner, E. Villamizar, S.M. Walsh, C. Walter, E. Weil, E. H. Williams, K. W. Roberson & Y. Yusuf. 2010. Caribbean corals in crisis: record thermal stress, bleaching, and mortality in 2005. PLoS ONE 5: e13969.

Finlay, J. 2000. Grenada: National Biodiversity Strategy and Action Plan: Assessment and Analysis of Fisheries Marine and Coastal Areas, Consultants Report. United Nations Development Programme; Global Environmental Facility. Project No.: GRN/98/G31/A/1G/99

Gardner, T.A., I.M. Côté, J.A. Gill, A. Grant & A.R. Watkinson. 2003. Long term region-wide declines in Caribbean corals. Science 301: 958-960.

Goldenberg, S.B., C.W. Landsea, A.M. Mestas-Nuñez & W.M. Gray. 2001. The recent increase in Atlantic hurricane activity: causes and implications. Science 293: 474-479.

Hawkins, J.P. & C.M. Roberts. 2003. Effects of artisanal fishing on Caribbean coral reefs. Conserv. Biol. 18: 215-226.

Hughes, T.P. 1994. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. Science 265: 1547-1551.

Hughes, T.P., A.H. Baird, D.R. Bellwood, M. Card, S.R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J.B.C. Jackson, J. Kleypas, J.M. Lough, P. Marshall, M. Nystrom, S.R. Palumbi, J. M. Pandolfi, B. Rosen & J. Roughgarden. 2003. Climate change, human impacts, and the resilience of coral reefs. Science 301: 929-933.

Hughes, T.P., N. Graham, J.B.C. Jackson, P.J. Mumby & R.S. Steneck. 2010. Rising to the challenge of sustaining coral reef resilience. Trends Ecol. Evol. 25: 633-642.

Idjadi, J.A., S.C. Lee, J.F. Bruno, W.F. Precht, L. Allen-Requa & P.J. Edmunds. 2006. Rapid phase shift reversal on a Jamaican coral reef. Coral Reefs 25:65-68.

Idjadi, J.A., R.N. Haring & W.F. Precht. 2010. Recovery of the sea urchin *Diadema antillarum* promotes scleractinian coral growth and survivorship on shallow Jamaican reefs. Mar. Ecol. Prog. Ser. 403: 91-100.

Jeffrey, C.F.G. 2000. Annual, coastal and seasonal variation in Grenadian demersal fisheries (1986-1993) and implications for management. Bull. Mar. Sci. 66: 305-319.

Kohler, K.E. & S.M. Gill. 2006. Coral Point Count with excel extensions (CPCe): A visual basic program for the determination of coral and substrate coverage using random point count methodology. Comput. Geosci. 32: 1259-1269.

Kramer, P.A. 2003. Synthesis of coral reef health indicators for the western Atlantic: results of the AGRRA program (1997-2000). Atoll. Res. Bull. 496: 1- 57.

Lapointe, B.E., M.M. Littler & D.S. Littler. 1997. Macroalgal overgrowth of fringing coral reefs at Discovery Bay, Jamaica: bottom-up versus top-down control. Proc. 8th Int. Coral Reef Symp., Panama. 927-932.

Littler, M.M., D.S. Littler & B.L. Brooks. 2009. Herbivory, nutrients, stochastic events, and relative dominances of benthic indicator groups on coral reefs: a review and recommendations. Proc. Mar. Sci. Network Symp., Washington, DC, USA. Smithsonian Contr. Mar. Sci. 38: 401-414.

Mora, C. 2008. A clear human footprint in the coral reefs of the Caribbean. Proc. Royal Soc. B. 275: 767-773.

Mumby, P.J. 2009. Phase shifts and the stability of macroalgal communities on Caribbean coral reefs. Coral Reefs 28: 761-773.

Newman, M.J.H., G.A. Paredes, E. Sala & J.B.C. Jackson. 2006. Structure of Caribbean coral reef communities across a large gradient of fish biomass. Ecol. Lett. 9: 1216-1227.

Ogden, J. 2010. Marine spatial planning (MSP): A first step to ecosystem-based management (EBM) in the wider Caribbean. Rev. Biol. Trop. 58 (Suppl. 3): 71-79.

Sandin, S.A., J.E. Smith, E.E. DeMartini, E.A. Dinsdale, S.D. Donner, A.M. Friedlander, T. Konotchick, M. Malay, J.E. Maragos, D. Obura, O. Pantos, G. Paulay, M. Richie, F. Rohwer, R.E. Schroeder, S. Walsh, J.B.C. Jackson, N. Knowlton & E. Sala. 2008. Baselines and degradation of coral reefs in the Northern Line Islands. PLoS ONE 3: e1548.

Sokal, R.R. and J.F. Rohlf. 1995. Biometry. 3rd ed. W.H. Freeman, New York.

Toller, W., A.O. Debrot, M.J.A. Vermeij & P. C. Hoetjes. 2010. Reef fishes of Saba Bank, Netherlands Antilles: assemblage structure across a gradient of habitat types. PLoS ONE 5: e9207.

Walsh, S.M. 2011. Ecosystem-scale effects of nutrients and fishing on coral reefs. Mar. Biol. 2011: 1-13.

Wilkinson, C. 2008. Status of Coral Reefs of the World: 2008. Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville, Australia.

Woodley, J. D., E.A Chronesky, P.A. Clifford, J.C.B. Jackson, L.S. Kaufman, N. Knowlton, J.C. Lang, M.P. Pearson, J.W. Porter, M.C. Rooney, K.W. Rylaarsdam, V.J. Tunnicliffe, C.M. Wahle, J.L. Wulff, A.S. . Curtis, M.D. Dallmeyer, B.P. Jupp, M.A.R. Koehl, J. Neigel & E.M. Sides. 1981. Hurricane Allen's impact on Jamaican coral reefs. Science 214: 749-755.

Zar, J.H. 1999. Biostatistical Analysis. 4th ed. Prentice Hall, New Jersey.