

# TEMPORAL ASSOCIATIONS OF CORAL AND ZOOPLANKTON ACTIVITY ON A CARIBBEAN REEF

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*Abstract:* Coral prey on zooplankton for nutrients not provided by their symbiotic zooxanthellae. Zooplankton stay in the benthos during the day and emerge into the water column to feed at night. We examined zooplankton densities and their relationship to feeding by the coral *Montastrea annularis* at Grape Tree Bay, Little Cayman Island. We predicted coral polyps would open when density of small zooplankton ( $< 1\text{mm}$ ) was highest, which we expected at night and in calm weather. These predictions were supported by the data, with percent open polyps responding sharply to increasing small zooplankton density over a “threshold range” of  $5\text{--}10\text{ m}^{-3}$ . The trends are also consistent with the hypothesis that polyps are genetically programmed to open at night, but respond plastically to zooplankton density during the day.

*Key words:* *Montastrea annularis*, *Little Cayman*, *zooplankton assemblage*, *copepod*

## INTRODUCTION

Corals acquire most of their energy from symbiotic zooxanthellae, but are also carnivorous, using nematocysts to capture zooplankton suspended in passing currents. Zooplankton contribute a small percentage of the coral's diet but provide critical nutrients such as nitrogen and phosphorus that zooxanthellae cannot supply (Ohlhorst 1982). Fish also prey on zooplankton, which causes many zooplankton, especially large ones, to hide in the benthos during the day when foraging ability of visual planktivores is greatly reduced. Smaller zooplankton can feed in the water column during the day with lower risk, as their size is

below the visual threshold of most predatory fish (Ohlhorst, 1982).

A diel vertical migration of zooplankton into the water column at night occurs on the back reef at Grape Tree Bay, Little Cayman Island (Jones et al. 2007). We studied this pattern and its association with feeding activity of the boulder star coral *Montastrea annularis* in a period of high wind and a period of relative calm. Since corals open their polyps to feed, we predicted an increase in coral polyp openness with greater density of accessible prey (zooplankton  $< 1\text{ mm}$ ). We also predicted that high wind would decrease zooplankton density and reduce coral activity.

Zooplankton densities in windy conditions may be influenced by increased water turbulence,

which could mix spatially patchy zooplankton distributions, potentially increasing or decreasing densities near the back reef. Zooplankton may also respond to increased water turbulence by staying in the benthos.

Finally, we predicted that lower zooplankton density and increased risk of damage by sedimentation would decrease overall coral polyp openness during periods of high wind.

## METHODS

We measured coral and zooplankton activity on February 29 and March 3, 2008, on the back reef at Grape Tree Bay, Little Cayman Island. These dates corresponded with a period of high wind (20-25 knots) and of relative calm (10-15 knots), respectively. We sampled zooplankton density during the day (1400) and at night (2200) using 4 contiguous 26 m straight line transects 0.5 m from the back reef parallel to shore.

At each sample time, we towed a plankton net (diameter = 0.3 m, mesh size 153  $\mu\text{m}$ ) twice through each transect, in opposite directions, 0.5 m below the surface for a total sample volume of 3.67  $\text{m}^3$ . We preserved zooplankton samples in 50% ethanol and a 5% formalin solution and sorted them under a dissecting microscope. We separated zooplankton by taxonomic group

(Copepoda, Decapoda, Mysida, Amphipoda, Isopoda, Polychaeta, Chordata (Fish larvae), and Bivalvia. We also grouped by size ( $> 1 \text{ mm}$  or  $\leq 1 \text{ mm}$ ) to estimate zooplankton densities in a size range available to corals ( $\leq 1 \text{ mm}$ ). We examined the association of small zooplankton with changing wind conditions and time of day using a full factorial, two-way ANOVA. We tested for equal variances and used pooled-variance one-tailed t-test to compare temporal differences in small and large zooplankton abundance.

We located every coral species *M. annularis* within 1m of the straight line zooplankton transect at least 0.25 m diameter and at least 0.5 m from the bottom. We visually estimated the percent of open coral polyps on each coral head in 10% interval classes. We used a full factorial, two-way ANOVA to compare the effects of time of day and wind on the percent open coral polyps per coral head. We performed piecewise linear regressions to examine possible correlations between zooplankton ( $< 1\text{mm}$ ) density and coral openness, fitting separate models for day and night.

## RESULTS

Consistent with our predictions, we found more total zooplankton in the water column at night than during the day (Table 1;

Table 2). Overall nighttime density was 33 times daytime density. Small zooplankton ( $\leq 1$  mm) made up 87.4% percent of total density in the day, while large zooplankton ( $> 1$  mm) comprised 86% of total density at night (one-tailed  $t = 23.3$ ,  $df = 6$ ,  $P < 0.0001$ ). Large zooplankton density was 250 times greater at night than during the day (890 versus 3.54 individuals per  $m^3$ , respectively). Copepods were the most abundant zooplankton  $< 1$  mm both day and night, making up 67% and 63% of total, respectively. In high winds, zooplankton density decreased, in both night and day, and for both size classes (Table 1).

Polyp openness corresponded to the diel vertical migration of small zooplankton, with more open polyps at night than in the day (Table 1). Coral openness increased with small zooplankton density during the day ( $F = 20.4$ ,  $df = 1, 6$ ,  $P = 0.004$ ; Figure 1) but not at night ( $F = 0.97$ ,  $df = 1, 6$ ,  $P = 0.36$ ).

During the day, polyps were more open in calm than in windy

conditions. However, at night, polyps were open, irrespective of wind conditions (Figure 1).

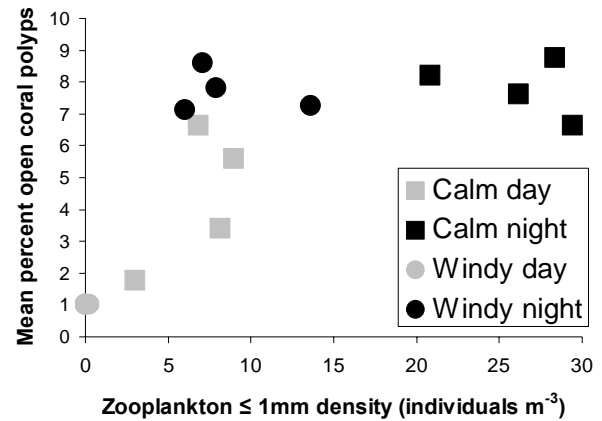


Figure 1. Relationship between mean percent open coral polyps per coral head and zooplankton density on the back reef at Grape Tree Bay, Little Cayman Island.

TABLE 1. Effects of wind, time of day, and their interaction on percent open coral polyps per coral head and small zooplankton abundance at Grape Tree Bay, Little Cayman Island. We collected zooplankton in four 26 m tows at 0.5 m depth, 0.5 m from the back reef.

	Source		df	F	P		df	F	P
Main Effects	Wind	Coral	1	3.40	0.0053	Zooplankton $\leq 1$ mm	1	8.4	<0.0001
	Time of Day	Coral	1	9.04	<0.0001	Zooplankton $\leq 1$ mm	1	9.73	<0.0001
Interaction	Wind x Time of Day	Coral	1	2.23	0.05	Zooplankton $\leq 1$ mm	1	3.77	0.003
Error		Coral	13			Zooplankton $\leq 1$ mm	13		

TABLE 2. Mean densities  $\text{m}^{-3}$  of common zooplankton taxonomic groups during day and night during periods of high wind (ca. 20-25 knots NNE) and relative calm (ca 10-15 knots SE) on the back reef at Grape Tree Bay, Little Cayman Island. See Table 1 for details. Densities of zooplankton  $>1\text{mm}$  are in regular type; those  $\leq 1\text{mm}$  in bold.

Taxa	Mean Density $\pm$ SE			
	Calm		High Wind	
	Day	Night	Day	Night
Copepoda	<b><math>5.79 \pm 1.56</math></b> $0.07 \pm 0.07$	<b><math>17.44 \pm 3.78</math></b> $12.26 \pm 5.58$	<b><math>0.07 \pm 0.07</math></b> 0	<b><math>4.63 \pm 1.56</math></b> $1.84 \pm 0.23$
Decapoda	<b><math>0.48 \pm 0.23</math></b> $0.20 \pm 0.13$	<b><math>3.27 \pm 2.31</math></b> $110.63 \pm 29.18$	<b>0</b> 0	<b><math>1.02 \pm 0.23</math></b> $2.52 \pm 0.53$
Mysidacea	<b><math>0.07 \pm 0.07</math></b> $0.07 \pm 0.07$	<b>0</b> $39.24 \pm 15.99$	<b>0</b> $0.27 \pm 0.16$	<b><math>0.67 \pm 0.28</math></b> $4.50 \pm 0.65$
Amphipoda	<b>0</b> $0.07 \pm 0.07$	<b><math>4.36 \pm 2.13</math></b> $27.52 \pm 12.49$	<b>0</b> 0	<b><math>0.95 \pm 0.14</math></b> $1.16 \pm 0.49$
Polychaeta	<b><math>0.14 \pm 0.14</math></b> $0.20 \pm 0.07$	<b><math>0.27 \pm 0.27</math></b> $2.45 \pm 0.69$	<b>0</b> $0.07 \pm 0.07$	<b><math>0.34 \pm 0.07</math></b> $0.75 \pm 0.30$
Isopoda	<b>0</b> 0	<b><math>0.27 \pm 0.27</math></b> $0.27 \pm 0.27$	<b>0</b> 0	<b><math>0.27 \pm 0.27</math></b> $0.20 \pm 0.13$
Bivalia	<b><math>0.27 \pm 0.27</math></b> 0	<b>0</b> $5.45 \pm 2.71$	<b>0</b> 0	<b><math>0.75 \pm 0.30</math></b> $1.43 \pm 0.46$
Fish Larvae	<b>0</b> 0	<b><math>0.58 \pm 0.30</math></b> $10.29 \pm 5.64$	<b>0</b> 0	<b>0</b> $0.61 \pm 0.26$

## DISCUSSION

Consistent with diel vertical migration patterns, zooplankton of  $> 1\text{ mm}$  length were more abundant in the water column at night when risk of predation by visual planktivores is reduced. Most zooplankton in the water column during the day were  $\leq 1\text{ mm}$ , possibly because their small size decreases risk of predation by visual predators. Our daytime zooplankton densities were similar to those of a recent Dartmouth study (Jones et al. 2007) at Little Cayman and Dartmouth studies of a Jamaican reef (Dartmouth FSP 2005, Sullan et al. 2006, Calvi et al. 2000). Our night zooplankton densities were slightly lower than those documented in Jamaica, but over 3.5 fold higher than those at Little Cayman in 2007.

This may reflect patchy distribution of zooplankton at Little Cayman, or lower densities at Little Cayman than at Discovery Bay, Jamaica.

Total zooplankton density increased at night, but varied in magnitude with weather conditions. Zooplankton density was lower during periods of high wind, perhaps because water turbulence decreases foraging ability, mixes localized zooplankton concentrations away from the reef, or zooplankton take refuge in the benthos to escape physical damage from collisions with the reef. It is unlikely that predation decreased zooplankton abundance during windy days. Control of zooplankton in marine systems is primarily bottom-up (Fredericksen et al. 2006), and total fish abundance decreased during our

period of high winds, including juvenile fish that tend to be planktivorous (Lappas et al. 2008).

Coral polyps opened more at night when zooplankton density was highest, regardless of winds. During windy days, however, all corals closed their polyps, perhaps because of low zooplankton density and high sedimentation associated with turbulence. During calm days, when physical stress is lower and zooplankton abundance varies, coral polyp openness increased with greater zooplankton densities.

The variation in openness during a clam day but not at night (Figure 1) suggests two possible mechanisms. The most parsimonious interpretation is that polyps respond to zooplankton density, with a threshold range between 5 and 10 zooplankton/m<sup>3</sup>, over which all corals open their polyps. Alternatively, corals may be genetically programmed to open at night, but able to respond plastically to zooplankton densities during the day. Controlled manipulations of zooplankton densities, with concomitant observations of polyp opening, would be needed to distinguish between these alternatives.

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# EFFECTS OF HIGH WINDS ON A CORAL REEF FISH COMMUNITY ON LITTLE CAYMAN ISLAND

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*Abstract:* Even relatively protected, shallow-water back reefs experience frequent disturbance from periods of high wind that increase turbulence and turbidity in the water column. We studied fish communities along the back reef on the north side of Little Cayman Island, and compared the abundance, taxonomic composition, and vertical distribution of fish between calm and windy days. We found higher abundances and taxonomic diversity of fish in the water column in calm periods, as the danger of displacement and injury diminished. We also predicted fish would move lower in the water column during high winds to avoid surface turbulence, but this did not occur.

*Keywords:* wind disturbance, shallow reef

## INTRODUCTION

Tropical coral reefs and their marine inhabitants are subject to weather disturbances of various frequencies and intensities. High intensity disturbances like cyclones bring extreme winds, rainfall, wave-action, and sedimentation. These can cause long-term changes in reef structure, substrate, and coral mortality, and alter behavior, species composition, and distribution of fish (Kim et al. 1997, Halford et al. 2004).

There is apparently little information on how less intense wind events affect reef fish behavior, taxonomic composition, and local distribution. High winds change shallow-water habitat conditions by increasing turbidity, water movement, and sedimentation (Sousa 1984, Kim et al. 1997,

Genevase & Witman 2004). These changes may negatively affect fishes' feeding efficiency, and increase their risk of injury on the reef.

We hypothesized that fish behavior would change during high winds to minimize energy expenditure and the threat of injury, resulting in changes in fish abundance, taxonomic diversity, and vertical distribution. We predicted that fish would either escape to deeper water (e.g. on the ocean side of the reef crest) to avoid surface turbulence, or take refuge deep in the back reef. We predicted that fish not hiding in the reef would swim near the bottom to avoid surface turbulence and wave action.

Alternatively, wave action and turbulence could stir food up from the sea floor, particularly benthic invertebrates, providing fish

with a feeding opportunity. Under this alternative hypothesis, we would predict that proportionally more fish would feed during high winds, resulting in greater abundance of visible fish.

We also predicted that we would observe more juveniles than adults along the reef edge in high winds, because stronger adults would out-compete juveniles for the best hiding places, or escape to deeper waters.

## METHODS

We studied fish communities along the back reef near the Little Cayman Research Center on the north side of Little Cayman Island. We measured the abundance and behavior of all fish encountered in plots, on two occasions: during the high winds of Feb 29 2008 (winds ca. 22 knots, visibility ca. 3.5 m) and during the relative calm of Mar 2 2008 (winds ca. 12 knots, visibility ca. 15.5 m). We used twelve 3x2 m plots, with adjacent plots separated by 10 m, along a 146 m transect placed parallel to and near the edge of the back reef, in water ca. 1.8 m deep. We observed each plot for 6 minutes after allowing 1 minute for fish to habituate to our presence. We carefully checked crevices on the reef surface for hiding fish for 1 minute plot<sup>1</sup>. We attempted to identify each species of fish, but because many were unidentifiable, we used higher

taxonomic groups for analysis (Appendix 1; Table A). We noted each fish's life stage (juvenile or adult), its location relative to the reef edge (in or out of the reef, where "in" = within 30 cm of the reef), its vertical position in the water column (high, middle or low, dividing the water column into thirds), and its behavior most represented during the observation period (feeding, hiding or swimming).

We paired our data in time, using the same plots for calm and windy conditions, and performed paired t-tests. We used a chi-squared test to test for how windy conditions affected fish behavior, vertical distribution, and juvenile and adult abundance.

## RESULTS

More fish were visible on the back reef during calm conditions than in high winds (paired t-test,  $t = -8.91$ ,  $df = 11$ ,  $P < 0.0001$ ; Fig. 1). We explored non-metric multidimensional scaling to search for patterns between taxonomic group abundances, by plot and weather. No single taxonomic group clearly drove the greater abundance during calm conditions, but damselfish, parrotfish and wrasses all increased in abundance (Fig. 2).



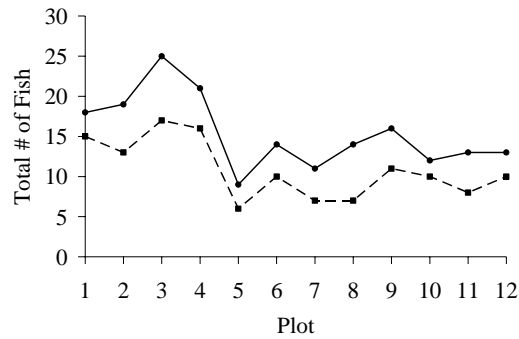


Figure 1. Total fish abundance per plot during windy (dashed line) and calm conditions (solid line), along the back reef near the Little Cayman Research Center on the north side of Little Cayman Island. Data from 12 plots, each 2 x 3 m, 10 m apart.

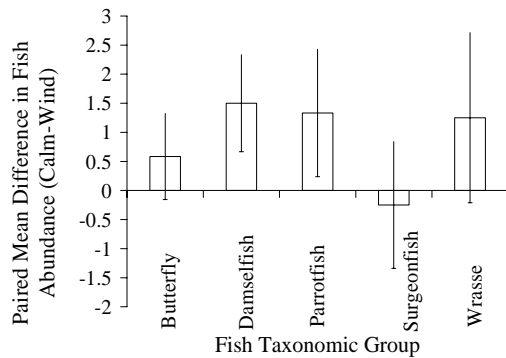


Figure 2. Paired mean differences (means and 95% confidence intervals) in fish abundance between calm and windy conditions, for the 5 major taxonomic groups, along the back reef near the Little Cayman Research Center, on the north side of Little Cayman Island. Data from 12 plots, each 2 x 3 m, 10 m apart.

There were also significantly more taxonomic groups visible under calm conditions (paired t-test,  $t = -2.69$ ,  $df = 11$ ,  $P = 0.021$ ; Fig. 3). Greater group richness was driven by several groups that were rare in our samples, and present only in calm conditions (angelfish, trunkfish, and blennies).

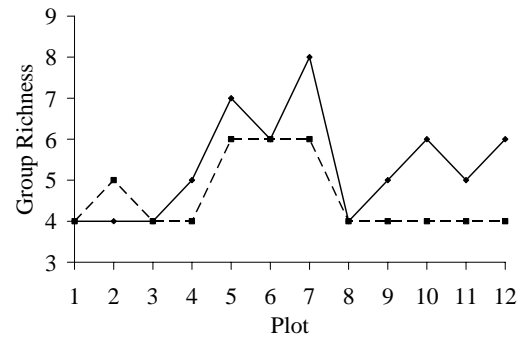


Figure 3. Number of taxonomic groups in each of 12 plots during windy (dashed line) and calm conditions (solid line), along the back reef off the northern side of Little Cayman Island. Data from 12 plots, each 2 x 3 m, 10 m apart.

The proportion of fish in low, middle or high strata of the water column did not change with weather ( $\chi^2 = 2.99$ ,  $df = 2$ ,  $P = 0.224$ ). In both windy and calm conditions, the highest proportions of fish were close to the bottom, and the least near the surface. There was a marginally significant trend toward a higher proportion of fish in the reef structure during the windy day sample ( $\chi^2 = 3.08$ ,  $df = 1$ ,  $P = 0.079$ ).

The distribution of behaviors differed significantly between weather conditions ( $\chi^2 = 13.2$ ,  $df = 2$ ,  $P = 0.0014$ ). There was a tendency for more feeding in calm conditions, and more swimming during high winds. The proportion of fish hiding remained similar, irrespective of wind conditions (Fig. 4).

We found no difference in adult to juvenile abundance ratios with weather ( $\chi^2 = 0.117$ ,  $df = 1$ ,  $P = 0.732$ ).

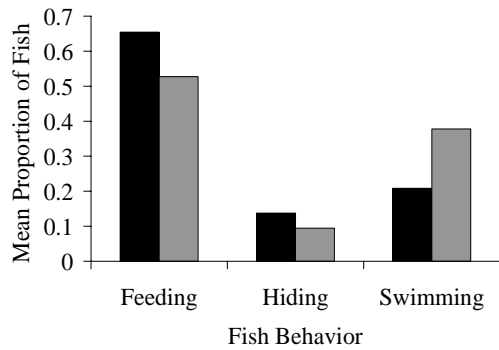


Figure 4. Proportional behavior in fish during calm weather (black) and high winds (gray) along the back reef near the Little Cayman Research Center. Pair-wise differences for each behavior by weather do not differ statically.

## DISCUSSION

Abundance and richness of observed fish decreased significantly during windy conditions. This was likely due to conditions of high turbulence and decreased visibility, forcing the fish to escape to deeper waters, or hide deeper in the back reef. The overall decline in abundance with windy conditions probably drove the decline in group richness. Alternatively, some groups may be better able to handle rough conditions than others. This could explain why certain groups of fish were absent from all plots during high winds.

There was no change in the ratio of adult to juvenile abundance between winds and calm, implying that adults and juveniles responded similarly. Many of the fish groups absent during high winds were moderately large species, such as snapper and grunts. Larger fish may

be more likely to move to deeper waters than smaller fish, to avoid high turbulence in shallow waters. It may be physically difficult for smaller fish to cross the reef crest, or the deeper waters may present a higher predation risk.

Surprisingly, fish preferred to stay near the bottom in both wind and calm conditions. Perhaps fish hide near the bottom to avoid detection by pelagic predators. Also, vertical position in the water column may be dictated by local food sources, particularly benthic invertebrates, that some fish search for regardless of weather conditions.

As predicted, windy conditions affected fish behavior, forcing fish to expend more time swimming and less time feeding, which might affect their growth rates. However, windy conditions are frequent around Caribbean islands, and our results show that fish associated with the back reef are capable of dealing with the rough conditions and re-establishing their local distribution and abundance quite rapidly.

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## APPENDIX 1.

TABLE A. Fish species abundance by life stage in calm and windy conditions along the back reef near the Little Cayman Research Center. Data from 12 plots, each 2 x 3 m, 10 m apart.

<b>Species</b>	<b>Life Stage</b>	<b>Calm</b>	<b>Wind</b>
Banded Butterflyfish	Adult	9	2
Bar Jack	Adult	1	1
Barred Butterflyfish	Adult	1	0
Barred Jack	Adult	1	0
Beaugregory	Adult	9	8
Beaugregory	Juvenile	7	2
Blenny	Adult	1	0
Bluehead Wrasse	Juvenile	21	20
Blue Tang	Adult	4	8
Blue Tang	Juvenile	6	5
Cocoa Damselfish	Adult	3	0
Cocoa Damselfish	Juvenile	4	1
Damselfish	Adult	0	1
Dusky Damselfish	Adult	1	1
Dusky Damselfish	Juvenile	1	0
French Grunt	Adult	4	1
Gray Angel	Juvenile	1	0
Hairy Blenny	Adult	1	0
Horse Eye Jack	Adult	0	1
Longjaw Squirrelfish	Adult	6	4
Mahogany Snapper	Adult	1	2
Mutton Snapper	Adult	1	0
Princess Parrotfish	Juvenile	0	1
Redtail Parrotfish	Adult	1	0

Redtail Parrotfish	Juvenile	2	0
Schoolmaster	Adult	0	1
Sergeant Major	Adult	2	0
Sergeant Major	Juvenile	0	3
Slippery Dick	Adult	0	2
Slippery Dick	Juvenile	14	8
Spotted Damselfish	Adult	1	0
Spotted Goatfish	Adult	0	1
Spotted Goatfish	Juvenile	2	2
Spotted Trunkfish	Adult	1	0
Stoplight Parrotfish	Adult	2	3
Stoplight Parrotfish	Juvenile	6	0
Unidentified	Adult	25	20
Unidentified	Juvenile	40	27
Unidentified	Unidentified	0	1
Yellow Tail parrotfish	Adult	3	0
Yellowtail Damselfish	Adult	3	4

# CORAL AND ALGAL COMMUNITIES IN GRAPE TREE BAY: A BASELINE STUDY

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*Abstract:* Phase shifts from coral to algal dominated communities are a major issue in the protection and conservation of coral reefs. Previous studies have shown that Little Cayman's coral reefs are in decline, although the mechanisms remain unclear. We established long-term plots for a study of algal and coral interactions in Grape Tree Bay near the Little Cayman Research Centre. We estimated coral and algal percent cover in twenty 1 m<sup>2</sup> plots along the back reef. Corky sea finger and boulder star were the most common corals, while an unidentified "short green" morphotype was the most abundant alga. Long term monitoring of these plots may help researchers to identify causes of coral decline.

*Key Words:* coral reef degradation, Little Cayman, Shannon diversity index

## INTRODUCTION

Coral reefs are declining around the world. Coral bleaching, overfishing, sedimentation, eutrophication, and disease are strongly correlated with human activity (Smith et al. 2006). These changes have facilitated "phase shifts" from coral to macroalgal domination of the communities, a critical step in reef degradation (Connell et al. 1997). Coral disease is often positively correlated with increasing algal cover, and algae can indirectly increase coral mortality by enhancing microbial activity (Smith et al. 2006). Algal cover on dead coral and other hard surfaces also inhibits coral recruitment (McCook et al. 2001). Documentation of long-term trends could help identify mechanisms of coral decline, which

would aid in conservation and management.

We studied coral and algal communities near the Central Caribbean Marine Institute, Little Cayman Island, establishing baseline data and permanent plots. Some reefs previously dominated by coral have become dominated by macroalgae within 20 years (Shulman & Robertson 1996). The reefs of Little Cayman are in better condition than those in most of the Caribbean. However, Coelho and Manfrino (2007) showed that, despite low anthropogenic impacts, corals between 9 m and 13 m depth have declined recently on Little Cayman. We decided to complement this study by initiating long term monitoring of coral and algal communities on the back reef (0-2m depth).

## METHODS

On February 28 and the March 1-2 2008, we estimated coral and algal cover on the back reef of Grape Tree Bay, ca. 100 m offshore from the Central Caribbean Marine Institute station on Little Cayman Island. Using PVC 1 m<sup>2</sup> quadrats, we established twenty 1 m<sup>2</sup> plots along a ca. 200 m long segment of the back reef. We first placed plot 1 (the most easterly), then proceeded ca. 10m westward to place each successive plot, up to plot 20. We used the following procedure to avoid potential bias in placement of plots. Each time we swam ca. 10 m to the west, we marked that point, then used a randomization procedure to place an individual plot on the back reef within 2m of that point. Detailed instructions for relocating plots are in Appendix A.

We divided each plot into four subplots. We visually estimated the percent of the total substrate surface area within the subplots (i.e. the projected area in the plane of the plot) covered by algae and coral. For this we considered the surface area of both hard and sandy bottom substrates. (We did not take into account the surface area of soft corals or fleshy algae, but rather the area of the substrate they were attached to). In each subplot we estimated percent cover of each genus of algae and each species of coral. Where we could not identify the organism, we

used morphotypes (see Results). We also noted the number of colonies of each coral species in each plot. Percentages did not necessarily sum to 100. The sum could be < 100 because of space occupation by organisms other than coral and algae, and unoccupied bare substrate (which was uncommon). The sum was > 100 only if there was some observer error. Coral and algal cover were estimated by two independent observers (one each for algae and for coral).

We mapped the precise position of each plot, for relocation in future (Appendix A). We first measured distance between neighboring plots using distances from a particular corner of plot N (N = 1-19) to each of the 4 corners of plot N+1. We also recorded the compass bearings between neighboring plots, and the inclination of each plot relative to the horizontal plane. We took 6 photographs of each plot: one of the entire plot, one of each of the 4 subplots, and one of the shoreline as viewed from each plot. Appendix B (intended for online access and archived records) contains full-color plot photographs.

In order to compare how similar subplots are to one another, we performed a clustering analysis with JMP, and quantified this result with MRPP in PC-ORD (McCune and Mefford 1999) to avoid the assumption of normality. For the MRPP, we chose the Sorensen (Bray-

Curtis) distance measure, with  $n/\sum(n)$  weighting of groups, and grouped the subplots according to plot number, and the distance matrix was rank transformed.

## RESULTS

We found nine species of coral and twelve genera of algae in our twenty 1 m<sup>2</sup> quadrats. For hard corals, we found boulder star (*Montastrea annularis*), massive starlet (*Siderastrea siderea*), mustard hill (*Porites astreoides*), branched finger (*Porites porites*), boulder brain (*Colpophyllia natans*), sinuous cactus (*Isophyllia sinuosa*), and lettuce (*Agaricia agaricites*). We found one hydrocoral, blade fire (*Millepora complanata*), and one octocoral, corky sea finger (*Briareum asbestinum*). Corky sea finger and boulder star coral were the most common corals, with the greatest number of total colonies, % cover, and frequency of occurrence. For algal genera we found *Halimeda*, *Dictyota*, *Ceramium*, *Galaxaura*, *Valonia*, *Liagora*, *Thalassia*, and five unidentified algae, which we refer to as “brown”, “short green”, “orange encrusting,” “long brown,” and “stringy yellow.” All algae other than “orange encrusting” and “short green” were fleshy. Appendix B (for online access and archived records) contains descriptions and full-color photographs of unidentified algae. The five most common algal groups

were unidentified “short green” algae, *Halimeda*, *Dictyota*, “orange encrusting” algae, and *Ceramium*. “Short green” was very abundant, with a mean cover of 23.5% (Table 1).

To quantify coral and algal diversity, we calculated the Shannon diversity index, separately for coral and algae, for all plots, as:  $H = - \sum P_i \times \ln P_i$ , where  $P_i$  = the proportion of each coral/algal species or genus in total coral/algal cover (Begon et al. 1996). For all plots,  $H$  ranged from 0 to 1.5720 for coral species and from 0.4412 to 1.7094 for algae. Coral diversity and richness (mean  $H = 0.762 \pm 0.075$  SE, mean richness =  $3.2 \pm 0.3211$  SE) were lower than for algae (mean  $H = 1.295 \pm 0.075$  SE, mean richness =  $5.1 \pm 0.2800$  SE).

Subplots of the same plot were far more similar to one another than to other more distant subplots (MRPP:  $T = -12.9$ , observed  $\delta = 0.26$ ,  $A = 0.48$ ,  $p < 0.0001$ ). This finding was not surprising, since coral colonies often spanned several subplots, and algae were often distributed on patches of dead coral which spanned several subplots of the same plot. A clustering analysis provided graphical confirmation of this result (Figure 1), with subplots often appearing as sister groups in the dendrogram. However, some subplots from different plots were more similar to each other than to subplots within the same plot.

Complete raw plot data (Excel file) are in Appendix D (for online access and archived records).

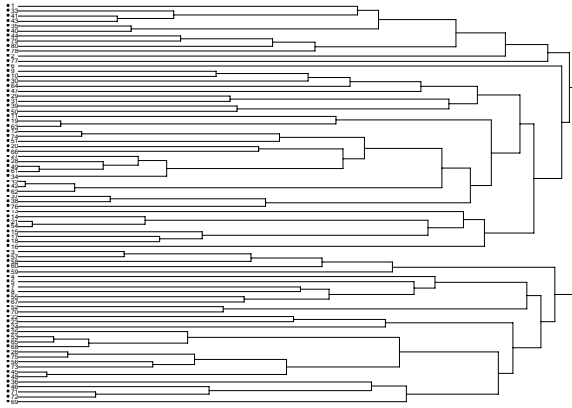


Figure 1. Dendrogram of the 0.25 m<sup>2</sup> (n = 80) subplots belonging to the 1m<sup>2</sup> plots (n = 20) sampled on the back reef of Grape Tree Bay, Little Cayman Island. Subplots 1-4 belong to plot 1, 5-8 belong to plot 2, etc.

TABLE 1. Summary of abundances of coral species and algal genera (or morphotypes) from twenty 1 m<sup>2</sup> subplots on the back reef of Grape Tree Bay, Little Cayman Island. The four subplot % cover values were averaged for each plot; mean % cover is the average of those plot means over all plots. Frequency refers to the proportion of plots in which we found each species/genus/morphotype. Relative density of coral colonies = # coral colonies for a species / total # colonies.

Genus or species	Mean % cover ± 1 SE	Frequency of occurrence	Total # colonies	Relative density of coral colonies
Unidentified "brown"	0.75 ± 0.58	0.10		
<i>Halimeda</i>	6.62 ± 1.34	0.90		
<i>Galaxaura</i>	0.72 ± 0.34	0.30		
<i>Dictyota</i>	6.41 ± 1.44	0.80		
<i>Ceramium</i>	2.81 ± 0.70	0.65		
<i>Valonia</i>	0.09 ± 0.07	0.10		
<i>Liagora</i>	0.44 ± 0.23	0.20		
<i>Thalassia</i>	0.56 ± 0.28	0.25		
"Short green"	23.50 ± 2.92	1.00		
"Orange encrusting"	4.62 ± 1.31	0.60		
"Long brown"	0.35 ± 0.19	0.20		
"Long stringy yellow"	0.1875 ± 0.1875	0.05		
<b>Total algae</b>	<b>47.08 ± 2.36</b>	<b>1.00</b>		
Boulder star	11.81 ± 3.64	0.55	76	0.2375
Greater starlet	4.15 ± 3.04	0.15	5	0.0156
Mustard hill	1.56 ± 0.67	0.30	24	0.0750
Branched finger	1.61 ± 1.01	0.20	9	0.0281
Boulder brain	2.62 ± 1.08	0.30	6	0.0188
Fleshy	0.36 ± 0.36	0.05	4	0.0125
Lettuce	1.55 ± 0.59	0.35	21	0.0656
Blade fire	2.72 ± 1.47	0.20	13	0.1083



Corky sea finger	$15.06 \pm 2.68$	0.90	146	0.4562
<b>Total coral</b>	<b><math>42.25 \pm 3.28</math></b>	<b>1.00</b>	<b>320</b>	<b>1</b>

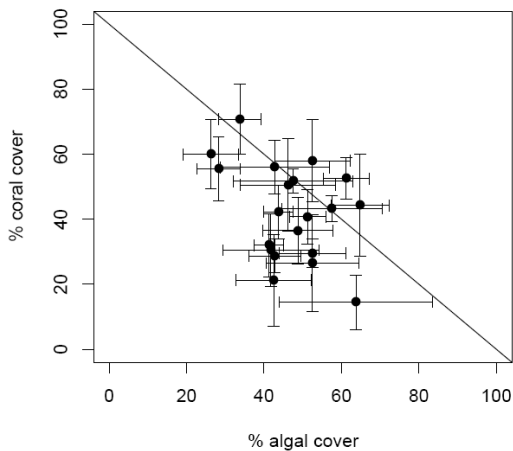


Figure 2. Estimated % coral cover vs. estimated % algal cover in twenty 1 m<sup>2</sup> plots in the back reef of Grape Tree Bay, Little Cayman Island. Each point represents data for one plot; error bars indicate  $\pm 1$  SE from 4 subplot measurements per plot. Along the line of slope = -1, coral and algal cover sum to 100%; thus points above the line represent plots with sums > 100% due to observer error.

## DISCUSSION

Most of the substrate along the back reef of Grape Tree Bay is occupied by coral or algae (Figure 2). We never observed any algae growing on live coral. The total percent cover for each plot ranged from ca. 15-70% for coral and from ca. 25-65% for algae, leaving relatively little space for bare substrates or other space-holding organisms. Thus, in plots with high algal cover, coral cover tended to be low, and vice versa. Plots that lie below the line in Fig. 1, representing 100% combined cover of coral and algae, contain bare substrate or other space-holding organisms that we did

not record. It may be useful to record their abundances in future. Plots above the line in Fig. 1 represent plots totally covered by algae and corals, although a sum of > 100% was due to observer error.

Some corals and algae were very common. Corky sea finger was the most common coral, and was the only octocoral in our plots. The second and third most common corals, boulder star and greater starlet, are hard corals that are important in reef building. The unidentified "short green" was the most dominant species in the algal community. Future species identification of "short green" is clearly important.

We found that the coral and algae are spatially aggregated in such a way that adjacent subplots often have similar communities. This pattern could be due to the large size of the aggregations of coral or algae, dispersal limitations, or to

unmeasured environmental differences among plots across Grape Tree Bay.

Using these permanent plots, researchers can monitor detailed changes in the algal and coral communities at Grape Tree Bay. We hope that such a long term study will help identify causes of coral decline on Little Cayman Island.

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#### APPENDIX A. PLOT LOCATIONS

To find all plots, begin with the most easterly 1 m<sup>2</sup> plot (Plot 1) along the back reef as viewed from shore, then move west. Plot 1 is marked by a permanent cement block on the ocean floor on the back reef ca. 5 m east of the furthest east permanent buoy. This buoy is between the bathhouse of the Little Cayman Research center and the first visible telephone pole to the east of the bathhouse (Fig. 2). Plot 1 GPS

coordinates are: N 19° 41.809'; W 080° 03.622', which are accurate to within 5 m. Using a compass, we also triangulated the plot 1 position using 4 permanent positions on the shore: the dining hall of CCMI, the bath house, and the first and second telephone poles to the east of the bath house (Fig. 2). Future researchers should use the information in Figure 2 as well as Plot 1 photographs to locate its position.

Table 2 contains all compass, distance, and inclination data. The compass heading should be taken from the center of each plot, moving progressively west along the back reef, to reach plots in ascending order (Plot 1 to plot 2 is 315 NW, plot 2 to plot 3 is 225 SW, etc.).

Corners of the 1 m<sup>2</sup> plots are numbered 1-4. Facing north (towards the open ocean with the plot in front of the observer), numbers are assigned clockwise, i.e. 1 = top left, 2 = top right, 3 = bottom right, 4 = bottom left (Fig. 3). The plots labeled as "opposite direction", (5 and 19), have the same clockwise number assignments, but are observed facing south (towards the beach with the plot in front of the observer) rather than north (towards the open ocean) (Fig. 4). We included "opposite direction" plots because at some plot locations, it was difficult to work on plots with the observer facing north; at these plots, measurements should be taken from the ocean side, facing

south. Plot sides are not oriented along compass directions; they should be determined using the archived photographs of each plot.

Each of the distances between neighboring plots was measured using a synthetic, flexible meter tape, from corner #1 to each of the four corners of the next plot, and similarly from plot 2 to plot 3, etc. We tied the tape measure to corner #1 of each plot to secure the tape for measurements to the next plot. A value of 0.3 m was subtracted from each of the measured distances to account for the tying of the tape measure to the corner of the plot. We made this "tying" length as close as possible to 0.3 m on each measurement, but a few cm of error should be expected in all distance measurements. Of course, in the future, this tying procedure should be eliminated, with one researcher holding the zero position of the tape in place by hand, while another worker takes the measurement. Then the inter-plot distances can be updated in Table 2 to more precise values, with appropriate clear documentation. Plot #20 has no associated compass or distance measurements, as it was the last plot.

Plot inclination data shows whether each plot was approximately in a vertical or horizontal plane. Vertical inclination means an angle > 45° and horizontal means an angle of < 45° to the horizontal. Those labeled as

vertical/horizontal were considered close to 45°. Photographs for each plot are labeled as “whole” (whole plot), TL (top left corner), TR (top right corner), BL (bottom left corner), and BR (bottom right corner). These labels assume one is facing the plot in the given direction (facing north

for most plots, or south for “opposite direction” plots) so TL = corner #1, TR = corner #2, BR = corner #3, BL = corner #4. Each plot also has one photograph labeled “shore”, which was taken above water, from that plot towards the shore.

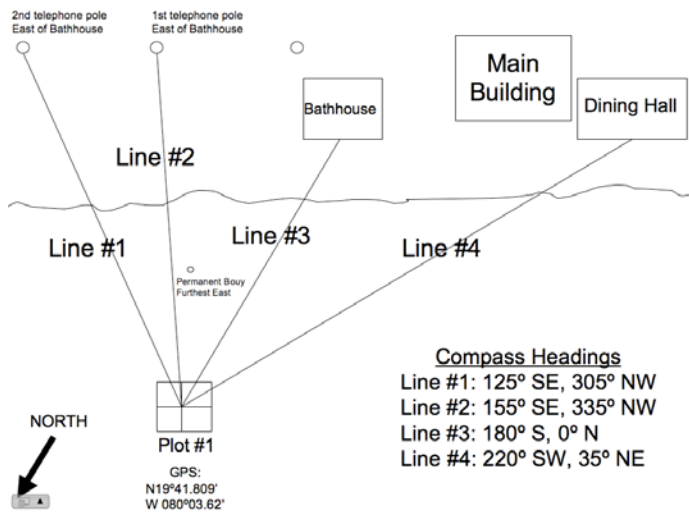


Fig. 2 Location of plot #1 from the ocean-facing deck of the Little Cayman Research Center.  
Map: Alex Spinoso.

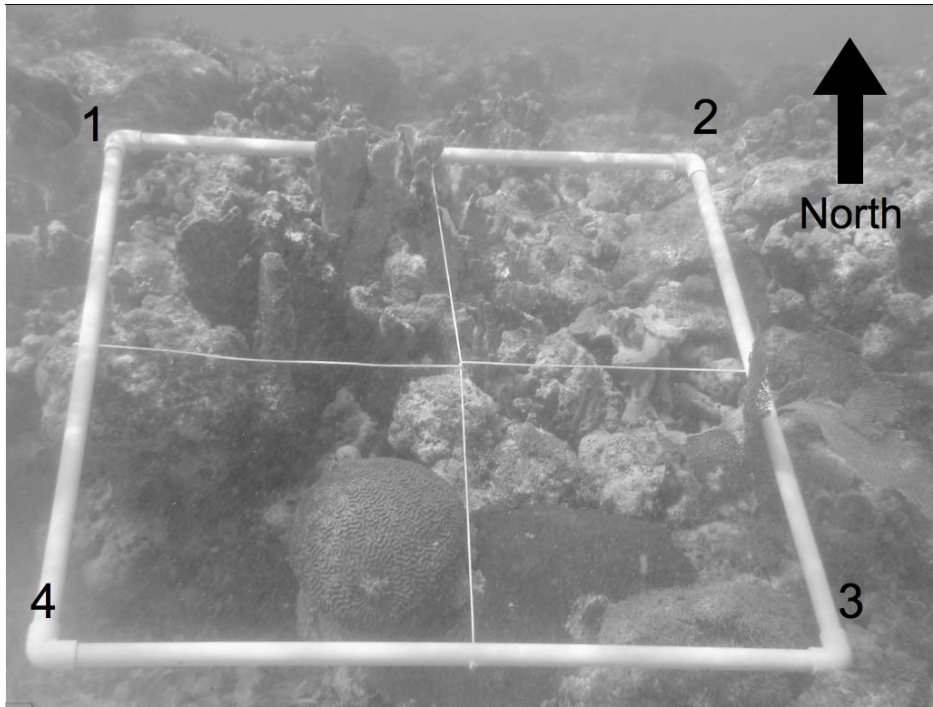


Fig. 3 Numbering system and orientation for plot 1. Photo: Samantha Kaplan.

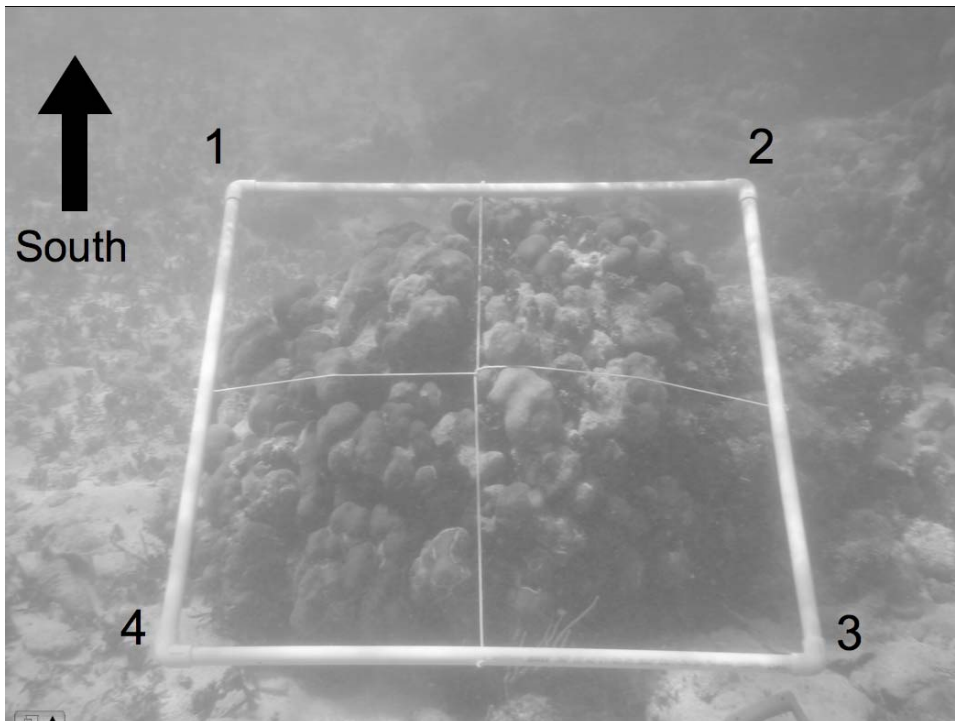


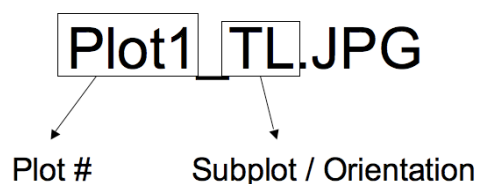
Fig. 4 Numbering system and orientation plot 5 (an opposite direction plot). Photo: Samantha Kaplan.

Table 2. Compass headings, distances between adjacent plots, and inclination of each plot to the horizontal. The observer faces north (toward the ocean with the plot in front of him/her) unless otherwise labeled as “opposite direction”, which assumes one is on the north side of the plot facing south (i.e. facing the beach with the plot in front of the observer). All measurements and directions in each row of the table are from corners of that plot to corners of the next consecutive plot (i.e. from plot N to plot N +1).

Plot #	Compass Heading	Distance between Corner #1 & #1 (m)	Distance between Corner #1 & #2 (m)	Distance between Corner #1 & #3 (m)	Distance between Corner #1 & #4 (m)	Inclination (Vertical/Horizontal)
1	315 NW	9.94	10.94	11.33	11.41	Vertical
2	225 SW	8.96	9.87	9.1	10.07	Vertical
3	235 SW	13.22	12.44	12.59	11.87	Horizontal
4	305 NW	11.71	11.82	11.68	11.7	Vertical
5						
(Opposite Direction)	265 W	9.38	8.48	9.65	9.95	Vertical
6	260 SW	11.21	9.84	11.13	10.22	Vertical
7	260 SW	10.51	10.42	10.2	10.32	Vertical
8	285 NW	11.05	10.11	10.55	11.3	Horizontal
9	300 NW	10.56	9.99	9.44	9.96	Vertical
10	240 SW	10.16	9.22	9.48	10.39	Vertical
11	275 W	9.89	8.96	8.93	9.88	Vertical
12	265 SW	9.04	8.24	8.38	9.19	Vertical/Horizontal
13	260 SW	10.85	10.85	9.9	10	Horizontal
14	225 SW	12.85	12.06	11.68	12.59	Vertical
15	260 SW	10.73	12.7	10.55	11.44	Horizontal
16	235 SW	14.01	14.1	13.29	13.42	Vertical
17	255 SW	9.11	8.13	8	8.91	Vertical/Horizontal
18	245 SW	9.94	10.94	11.33	11.41	Horizontal
19						
(Opposite Direction)	270 W	8.96	9.87	9.1	10.07	Horizontal
20						Horizontal

## APPENDIX B. PLOT PHOTOS

Six photographs for each plot are in the folder labeled “08' FSP Long Term Coral/Algae Study Plot and Unidentified Algae Pictures” Labels for each plot are as follows:



Pictures for each plot are labeled as WHOLE (whole plot), TL (top left corner), TR (top right corner), BL (bottom left corner), and BR (bottom right corner). These assume the observer is facing the plot in the appropriate direction (north for most plots, south for "opposite direction" plots), so TL = corner #1, TR = corner #2, BR = corner #3, BL = corner #4. Each plot also has one picture labeled SHORE, which was taken from that plot towards the shore for orientation. All photos by Samantha Kaplan.

#### APPENDIX C. UNIDENTIFIED ALGAE DESCRIPTIONS

Photographs for each unidentified alga are in the folder "08' FSP Long Term Coral/Algae Study Plot and Unidentified Algae Pictures".

**"Short green alga"** - Very common, on dead coral everywhere. Encrusting, with has a few thin hairs (ca. 5 mm long) protruding (ca. 5 per cm<sup>2</sup>).

**"Brown alga"** - Very common, on dead coral everywhere. Very much like the short green alga, but brown in color.

**"Orange encrusting alga"** - Red/orange; does not appear to have

attachment points within the coral, but covers it in a very thick plaque.

**"Long brown alga"** - Dense mat of brown filaments ca. 1 cm long (with a high density, maybe 20 per cm<sup>2</sup>). Rare.

**"Stringy yellow alga"** - Dense mat of yellow filaments ca. 1.5 cm long (with a high density, maybe 20 per cm<sup>2</sup>). Rare.

#### APPENDIX D. RAW DATA EXCEL FILE

Raw data on coral and algal cover for 2008 in the long-term plots are in the file "08' FSP Long Term Coral/Algae Study Raw Data.xls". All data collected from back reef of Grape Tree Bay, Little Cayman directly behind the Little Cayman Research Institute, from plot locations described above.

#### ARCHIVED DATA FILES

As noted above, there are two folders of archived data files. "08' FSP Long Term Coral/Algae Study Plot and Unidentified Algae Pictures" contains documentation as described in Appendices B and C. "08' FSP Long Term Coral/Algae Study Raw Data.xls" contains data as described in Appendix D.

# CORAL PATCHES ON A BACK REEF DO NOT CONFORM TO DIVERSITY-DISTANCE PREDICTIONS OF ISLAND BIOGEOGRAPHY THEORY

THOMAS J. LOBBEN AND LIA M. CHEEK

Faculty editor: David R. Peart

**Abstract:** The theory of island biogeography has been applied to fish on coral reefs, classifying the larger continuous reef as the “mainland”, and patches of isolated coral as “islands”, which the theory predicts should have higher diversity as their size increases and their distance from the mainland decreases. However, there is some evidence for the opposite trend with distance, perhaps explained by reduced predation with increasing distance. We tested which of these alternative predictions best matched fish diversity and abundance at isolated coral heads in a back reef on Little Cayman Island, at varying distances from the reef crest. We found that fish diversity and abundance increased significantly with coral patch surface area, consistent with the theory of island biogeography, but decreased with distance, opposite to the prediction of the theory.

*Key Words:* Island biogeography, Little Cayman, Surface area

## INTRODUCTION

The theory of island biogeography predicts the richness of species found on islands of various sizes and distances from a mainland (MacArthur & Wilson 1967, Lomolino 2000). This model assumes that as distance from the mainland increases, the colonization rates of species will be lower, and that extinction rates for species will be higher for smaller islands. Consequently, diversity should decrease with distance, and increase with island size. Molles (1978) found that this theory applied to the diversity of fish on reef patches; larger patches closer to the main reef were more diverse.

However, the opposite trend with distance has also been found. Shulman (1985), reported that fish diversity on reef patches actually increased with isolation. While colonization may follow the trend predicted by island biogeography; decreasing with distance from the main reef (Simberloff & Wilson 1969), there may be greater local extinction near the main reef due to intense predation. Belmaker et al. (2005) showed that high density, mixed-species predatory aggregations (frogfish, jacks, and scorpionfish) were responsible for the local extinction of certain prey fish species, and that these predatory aggregations occurred mainly close to the main reef. Another factor that could increase diversity in patch



reefs, relative to the main reef, is the additional food and habitat resource provided by the surrounding sand, where high invertebrate and zooplankton levels have been documented (Ault and Johnson 1998). However, sand habitats and their resources could not explain an increase in diversity with distance from the main reef.

We assumed that colonization would follow the trend predicted by island biogeography theory, and thus predicted juvenile abundance to decrease with distance from the back reef. However, we hypothesized that other factors would result in higher local extinction near the main reef, more than compensating for the colonization-distance trend, and resulting in higher richness and abundance on coral patches further from the continuous back reef. We considered predation the most likely mechanism to drive such a trend in extinction rates, but we did not have the time or resources to test specific mechanisms in this study.

## METHODS

From 28 February to 3 March 2008, we sampled 18 coral heads in the lagoon adjoining the Central Caribbean Marine Institute on the north side of Little Cayman Island. We sampled all isolated coral heads shoreward of the strip of continuous back reef, that were within 800 m east or west of CCMI, and a

minimum of 2 m from the reef crest. We defined “isolated” as being > 3 m from the nearest coral head.

We counted adults and juveniles of each fish species associated with (within 0.5 m of) each coral head sampled. We measured height and diameter of each coral head to calculate volume ( $\text{cm}^3$ ) and surface area ( $\text{cm}^2$ ), and distance (m) from the main back reef. We visually estimated percent algal cover on each coral head. We will refer to coral heads as “patches”.

We used a general linear model to predict fish richness and abundance on patches, using distance from the reef crest and patch surface area as the main effects. We square-root transformed the abundance of each species, number of species, and percent of juveniles for each patch, to meet assumptions of homoscedasticity. Because we had no *a priori* prediction for an interaction (distance  $\times$  surface area) we removed it from the full model when we found it was non-significant.

## RESULTS

Across our samples we tallied 986 fish of 39 species. The average number of species per patch was  $14 \pm 0.8$ , and the average number of fish was  $54 \pm 10.6$ . Surface area and distance were both positively related to fish abundance and diversity on patches (Table 1).

TABLE 1: Fish species and abundances on coral heads (patches), as a function of distance from back reef, and coral head surface area. Data from 18 coral heads shoreward of the back reef near the Little Cayman Research Center, Little Cayman Island, from February 28th to March 3<sup>rd</sup>, 2008.

	Fish species diversity			Number of fish		
	F-Value	df	P-Value	F-Value	df	P-Value
Distance	6.66	1	0.02	9.73	1	0.007
Surface area	8.94	1	0.009	7.56	1	0.01
Error		15			15	

Of the 39 fish species we observed, 18 were present only as adults, 1 as juveniles only, and 20 were represented by both juveniles and adults. The overall percentage of fish that were juveniles on a coral patch decreased significantly with distance from the continuous back reef (Figure 1;  $F = 6.16$ ,  $df = 1,15$ ,  $P = 0.02$ ).

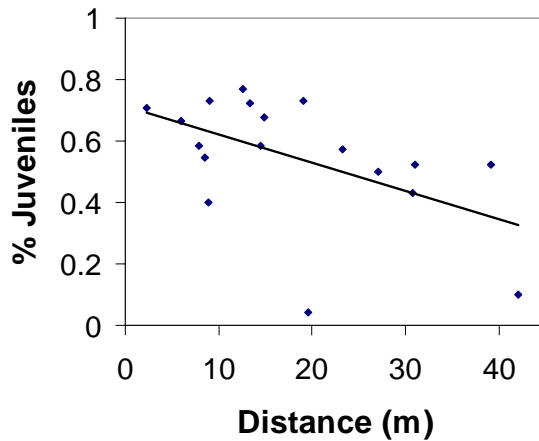


Figure 1. Linear regression of the percent juveniles in fish assemblages on coral heads, plotted against distance (m) from main back reef. Measurements were taken at each of 18 coral heads offshore of the Little Cayman Research Center, Little Cayman Island, from 28 February to 3 March 2008.

## DISCUSSION

The theory of island biogeography did not explain all

trends that we observed in fish diversity on patch reefs, as a function of distance from the main back reef. As predicted by this theory, abundance did increase with patch surface area; the simple explanation is that with more surface area, there are more refugia and resources available to fish. However, fish diversity and abundance on coral patches actually increased with distance, supporting our hypothesis and conflicting with the theory's predictions.

Trends in abundance and diversity are due to the combination of local colonization and extinction rates. The decrease in percent of juveniles with distance from the main reef (Figure 1) may occur because larvae carried by ocean currents come into contact with the main reef first, with most larvae settling there, decreasing the numbers that colonize more distant patches. We suggest that there is a strong trend in local extinction that counters this colonization trend, with higher rates of extinction closer to the reef. If sufficiently strong, this effect could overcome the presumed trend in colonization, producing the

observed positive relationship between distance and fish diversity and fish abundance.

One mechanism that could drive higher extinction rates closer to the reef is predation (Belmaker 2005). Predator density may be higher near the main reef. The extensive reef habitat there may sustain a larger prey population, which can in turn support more predators. Optimal foraging of predators resident on the back reef may contribute to the pattern we observed. Predators may not travel far from the main reef searching for the uncertain and limited resources available on patch reefs, due to low net energy returns.

Our study may be useful in coral reef and fish population management. Knowing the size and distance that artificial reefs should be placed to increase coral reef diversity and abundance can be of practical value in reef restoration.

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# WITH A LITTLE HELP FROM MY FRIENDS: BENEFITS OF SCHOOLING IN OCEAN SURGEONFISH

YIRAN GU AND ALANNA H. PURDY

Faculty editor: David R. Peart

*Abstract:* Fish schooling provides individuals with potential benefits such as predator avoidance, increased foraging efficiency and access to food resources. We tested whether schooling affects foraging rates of adult and juvenile Ocean Surgeonfish in Grape Tree Bay on Little Cayman Island. We hypothesized that 1) individual feeding rates would be greater in heterospecific than conspecific groups, and 2) individual feeding rates would be greater in groups than alone. Juveniles foraged mostly in heterospecific groups while adults foraged mostly alone. Juveniles fed significantly faster in heterospecific groups than with conspecifics or alone, in contrast to adults, whose feeding rates did not change when individuals associated with either con- or hetero-specifics. The number of Ocean Surgeonfish did not differ between conspecific and heterospecific groups, but heterospecific groups were always larger. Thus, we could not determine whether the benefits of heterospecific associations were a function of individual behavior influenced by species composition, or group size. Large, heterospecific groups may reduce predation risk in addition to increasing foraging rates, leading to the prediction that juveniles should associate with heterospecific groups whenever possible.

*Key Words:* *Acanthurus bahianus*, *schooling*, *predation*, *competition*

## INTRODUCTION

Mixed-species schooling is common in herbivorous coral reef-fish. Potential benefits include predator avoidance, increased foraging efficiency, and improved access to food resources (Lukoschek and McCormick 2000, Foster 1985). In many species, individuals have different schooling behavior and diet preferences at different life stages (Overholzer et al. 2000).

Ocean Surgeonfish (*Acanthurus bahianus*) is a generalist herbivore that occurs individually, in mixed-species groups, and (as adults) in conspecific groups (Deloach and Human 1999).

We evaluated the effects of schooling and lifestage on feeding rate of Ocean Surgeonfish in the back reef of Grape Tree Bay on Little Cayman Island. Con- and heterospecific schooling may allow individuals to spend more time foraging via increased predator detection (Lukoschek and McCormick 2000). If so, feeding rate of individuals in groups would be higher than that of solitary foragers. Alternatively, schooling could increase competition among individuals, leading to decreased feeding rate, which would favor solitary foraging. Competition may also be higher among conspecifics than among heterospecifics, leading to a lower

feeding rate of individuals in conspecific groups than those in heterospecific groups.

Juvenile Ocean Surgeonfish may school more often than adults, as diet, habitat and behavior changes with lifestage (Lawson et al. 1999). Predator-vigilance could be more important for juveniles than adults, favoring schooling behavior (Wolf 1984). Damsel fish defend patches of algal garden in their territories and limit access of other herbivorous fish (Deloach and Human 1999). Overcoming damselfish territoriality may be more difficult for solitary juveniles than solitary adults and juveniles in foraging groups, favoring schooling in juveniles.

## METHODS

We measured feeding rates of adult and juvenile Ocean Surgeonfish on Feb 29 and Mar 1- 2, 2008 along a 400 m stretch of the back reef in Grape Tree Bay, in front of the Little Cayman Research Center. During both morning and afternoon each day, we haphazardly sampled Ocean Surgeonfish by snorkeling over the reef until an actively traveling or feeding individual was located 1-10 m from the reef crest. We observed one focal fish per group encountered. We categorized individuals of 10-13 cm in length as adults, 4-6 cm as juveniles, and ignored fish outside these size classes.

After habituating fish to our presence for ca. 1 min, we counted # bites made by the focal fish for up to 5 minutes, and calculated bite rate (bites min<sup>-1</sup>). We recorded schooling behavior (solitary, conspecific, or heterospecific groups), group size, species composition, and whether foraging during each observation period occurred in damselfish territory. We ended an observation period before 5 minutes if the individual changed group association, began non-foraging activities (such as hiding, visiting cleaning station), or swam out of sight. For analysis, we retained all observations longer than 30 s.

We equalized variances with a log<sub>10</sub> transformation of bite rate and ran two, two-way ANOVAs for the effects of grouping and damselfish territory on feeding rates; one for adults, one for juveniles. We did not include interactions between the two factors because we had no a priori hypotheses about the effect of damselfish territory on grouping. We were also unable to include the interaction term in the model since we observed no solitary juveniles feeding in damselfish territories.

We tested for the specific hypothesized differences in feeding rate using linear contrasts. We compared feeding rates of solitary individuals and individuals in heterospecific and conspecifics groups ( $\mu_H + \mu_C - \mu_S = 0$ ), and of individuals in

heterospecific and conspecific groups ( $\mu_H + \mu_C = 0$ ).

## RESULTS

We observed a total of 38 adult and 48 juvenile Ocean Surgeonfish over the period of 3 days. Fourteen focal adults and 36 juveniles foraged in groups. On average, conspecific groups contained  $2.12 \pm 0.08$  fish (mean  $\pm$  SE), while heterospecific groups contained  $6.88 \pm 0.52$  fish. Of the 20 fish species observed foraging with Ocean Surgeonfish in heterospecific groups, juvenile Blueheaded Wrasse, juvenile Striped Parrotfish, and adult Striped Parrotfish were the most common (Table 1).

Schooling behavior affected feeding rate of juveniles and adults differently (Table 2, Figure 1). Feeding rate of individuals in con- and heterospecific groups differed for juveniles (linear contrast  $F_{1,44} = 10.11$ ,  $P = 0.003$ ) but not adults (linear contrast  $F_{1,33} = 1.33$ ,  $P = 0.23$ ). When combined, feeding rate of individuals in conspecific and heterospecific groups did not differ from those of solitary foragers, for either adults (linear contrast  $F_{1,33} = 1.17$ ,  $P = 0.29$ ) or juveniles (linear contrast  $F_{1,44} = 2.64$ ,  $P = 0.11$ ). Juveniles in heterospecific groups fed the fastest (Figure 1).

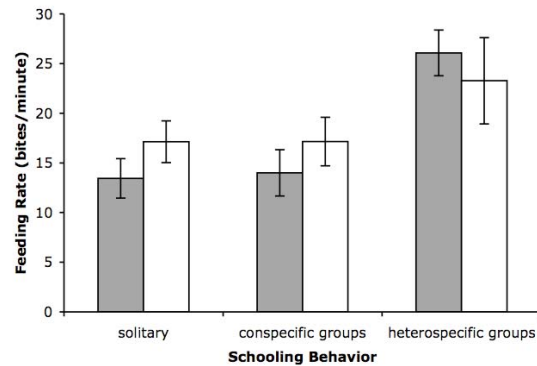


Figure 1. Feeding rate (mean  $\pm$  SE) of adult and juvenile Ocean Surgeonfish (*Acanthurus bahianus*) with different schooling behaviors in a back reef of Grape Tree Bay, Little Cayman Island. Gray bars = juvenile (N=48), white bars = adults (N=38).

Feeding rate of adults and juveniles did not differ significantly ( $t = 0.74$ ,  $df = 85$ ,  $P = 0.46$ ). Feeding rates also did not differ in and out of damselfish territories for adults or juveniles (Table 2). Although neither adults nor juveniles foraged extensively in damselfish territory, adults and juveniles did spend similar percentages of foraging time in damselfish territories (22.9% and 16.2% of observations respectively; Pearson's  $\chi^2 = 0.59$ ,  $P = 0.44$ ). Adults, which mainly fed alone (57.9%), differed from juveniles, which fed mostly in heterospecific groups (59.2%; Pearson's  $\chi^2 = 15.75$ ,  $P = 0.0004$ ). Although heterospecific groups were larger (mean  $\pm$  SE,  $6.88 \pm 0.52$ ) than conspecific groups ( $2.12 \pm 0.08$ ;  $F = 80.43$ ,  $df = 1$ ,  $P < 0.0001$ ), the mean number of Ocean Surgeonfish in conspecific (mean  $\pm$  SE,  $2.7 \pm 0.27$ ) and heterospecific groups ( $2.1 \pm 0.21$ )

did not differ ( $df = 1, 47, t = 3.14, P = 0.08$ ).

## DISCUSSION

Adult feeding rate was unaffected by schooling behavior, whereas juveniles fed faster when associated with heterospecifics. Larger, mixed-species groups increase predator detection and allow individuals to spend more time foraging (Lukoschek and McCormick 2000). If predator detection is more important for juveniles than adults, and juveniles can feed faster in heterospecific groups, juveniles should forage in groups whenever possible.

The significantly lower feeding rate of juveniles in conspecific vs. heterospecific groups may be due to difference in behavior influenced by species composition of groups, or by group size. Since heterospecific groups were always larger than conspecific groups, we were unable to isolate the effect of group composition vs. group size on feeding rate.

Previous studies suggest that juvenile Ocean Surgeonfish avoid conspecifics in favor of mixed-species schools to minimize the cost of direct competition, while still benefiting from schooling (Debrot et al. 1988, Overholtzer et al. 2000). We found no evidence of conspecific avoidance, as both conspecific and heterospecific groups contained the same number of Ocean Surgeonfish. Assuming intraspecific competition in con- and het-

erospecific groups is equal, juveniles' tendency to school in heterospecific groups must be explained by mechanisms other than competition avoidance (i.e. increased predator detection or improved foraging efficiency).

By estimating the proportion of damselfish territory in potential foraging areas, it would be possible to test whether Ocean Surgeonfish feed in damselfish territories more than by chance alone (suggesting they do so to gain access to higher quality food), or less than by chance (suggesting active avoidance).

Insights into how schooling affects individual behavior could be gained by measuring the time individuals spend schooling vs. alone, and evaluating the potential costs of schooling, e.g. within group aggression and resource competition, and how these differ between con- and heterospecific groups.

The benefits of heterospecific schooling for juvenile Ocean Surgeonfish seem clear and unequivocal. Literature on schooling behavior in fish focuses on two main components of fish fitness, feeding rate and predation risk. While there may be tradeoffs between these in some cases, no such tradeoffs are apparent here. Our findings indicate a substantial advantage in feeding rate. The extensive literature on how schooling reduces predation risk (Lukoschek and McCormick 2000, Morse 1977) makes it implausible that predation risk would be increased by joining a large, het-

erospecific group, especially for these relatively small juveniles, who could be vulnerable to a wide range of predatory fish on the reef.

Indeed, the benefits of reduced predation risk may contribute strongly to the feeding benefits of heterospecific group membership that we demonstrated. High juvenile feeding rates in these groups may be largely due to the reduced need to spend time on predator vigilance. Further, large heterospecific groups may be able to forage in areas rich in resources but relatively exposed to predators.

In summary, our findings lead to the prediction that juvenile Ocean Surgeonfish should associate with heterospecific schools wherever possible. Individual juveniles that tend to associate with the smaller, conspecific groups, or forage alone, should have lower fitness, and this behavior selected against. It is possible that these benefits of heterospecific schooling differ across the range of the species; in that case gene flow could maintain some variance in individual juvenile behavior.

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Table 1. Abundance and frequencies of species observed in foraging groups (N=50) containing Ocean Surgeonfish (*Acanthurus bahianus*) in a back reef on Little Cayman Island. Bold captions indicate most common species observed in heterospecific groups.

Common Name	Scientific Name	Lifestage	Total Number of Individuals Observed	Number of Groups containing each Species
Blue Tang	<i>Acanthurus coeruleus</i>	Adult	2	2
		Juvenile	1	1
Bucktooth Parrotfish	<i>Sparisoma radians</i>	Adult	2	1
		Juvenile	2	2
Doctorfish	<i>Acanthurus bahianus</i>	Adult	1	1
		Juvenile	2	2
Foureye Butterflyfish	<i>Chaetodon capistratus</i>	Adult	1	1
French Grunt	<i>Haemulon flavolineatum</i>	Adult	33	4
<b>Blueheaded Wrasse</b>	<b><i>Thalassoma bifasciatum</i></b>	<b>Juvenile</b>	<b>18</b>	<b>11</b>
Bluelip Parrotfish	<i>Cryptotomus roseus</i>	Juvenile	1	1
Slippery Dick	<i>Halichoeres bivittatus</i>	Juvenile	6	5
Spotfin Butterflyfish	<i>Chaetodon ocellatus</i>	Juvenile	1	1
Stoplight Parrotfish	<i>Sparisoma viride</i>	Juvenile	6	6
Redtail Parrotfish	<i>Sparisoma chrysopteron</i>	Juvenile	3	1
Mutton Snapper	<i>Lutjanus analis</i>	Adult	4	2
Princess Parrotfish	<i>Scarus taenipoterus</i>	Adult	2	2
		Juvenile	2	1
Rainbow Wrasse	<i>Halichoeres pictus</i>	Adult	4	2
Sergeant Major	<i>Abudefduf saxatilis</i> <i>spelling?</i>	Adult	2	1
Slippery Dick	<i>Halichoeres bivittatus</i>	Juvenile	16	6
Spotted Goatfish	<i>Pseudupeneus maculatus</i>	Adult	1	1
<b>Striped Parrotfish</b>	<b><i>Scarus criucensis</i></b>	<b>Adult</b>	<b>24</b>	<b>10</b>
		<b>Juvenile</b>	<b>20</b>	<b>10</b>
Yellowtail Snapper	<i>Ocyurus chrysurus</i>	Adult	3	1
Yellowtail Goatfish	<i>Mulloidichthys martinicus</i>	Adult	2	1
		Juvenile	2	1

Table 2. Two-way ANOVA of effects of schooling behavior and damselfish territories on feeding rate of adult and juvenile Ocean Surgeonfish on a back reef at Little Cayman Island.

<b>Source</b>	<b>Adults</b>			<b>Juveniles</b>		
	<b>df</b>	<b>F</b>	<b>P</b>	<b>df</b>	<b>F</b>	<b>P</b>
<b>Damselfish Territory</b>	1	0.01	0.92	1	0.11	0.74
<b>Schooling Behavior</b>	2	1.14	0.33	2	9.01	0.0005
<b>Error</b>	34			44		

# INITIAL RECRUITMENT OF CORAL REEF FISH TO SMALL-SCALE ARTIFICIAL, COMPLEX STRUCTURES

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Faculty editor: David R. Peart

*Abstract:* With continuing coral decline, artificial reefs are being considered more often in reef conservation and management. We studied the effects of small-scale PVC artificial reef structures, of three levels of complexity, on fish recruitment in Grape Tree Bay, Little Cayman Island. Based on previous research, we hypothesized that fish abundance and percent juveniles recruited would be greater on structures of high complexity than those of low complexity. We also predicted that more fish and juveniles would recruit to artificial structures than control plots, and that abundance and richness would increase over time on structures of each complexity level. The presence of artificial structures increased the abundance, percent juveniles, and composition of initial fish recruitment, relative to control plots, but level of complexity had no detectable effect on recruitment.

*Keywords:* Fish recruitment, artificial coral reefs, diversity, back reef

## INTRODUCTION

Maximizing the suitable habitat for juvenile fish may be critical in increasing the overall carrying capacity of juveniles in a patch reef area (Sale 1997; Leis et al. 2002; Gratwicke & Speight 2005). Habitat complexity is important for survival and recruitment of juvenile fish in natural habitats (Beukers & Jones 1998), juvenile fish in artificial reefs made from natural materials (Isbey & Gorbatskin 2007), and overall abundance and richness in artificial reefs made from synthetic materials (Charbonnel et al. 2002).

Over time, percent juveniles, richness, diversity, and/or abundance of recruited fish increased on artificial reef structures

(Isbey & Gorbatskin 2007). Time scales of recruitment may vary for artificial reef structures constructed of synthetic materials vs. natural materials. We tested how the presence and degree of structural complexity of synthetic structures influence initial recruitment over several days post-placement to artificial structures in Grape Tree Bay, Little Cayman.

If juvenile fish are at higher predation risk than adults (Connell & Jones 1991), more juveniles should colonize complex habitats than adults, as recruited juveniles suffer high mortality in low complexity habitats (Connell & Jones 1991).

Based on the idea that the most suitable natural habitats are complex (Beukers & Jones 1998), and that the number of refuges within a

coral reef limits fish abundance and juvenile survival, we predicted that fish abundance of new recruits, and percent juveniles, would increase from low to high complexity structures. Small-scale structures may also attract younger or smaller fish since small refuge size prevents larger, adult fish from recruitment. We also predicted that more fish would recruit to artificial structures than control plots, and that overall abundance and richness would increase over time in each reef type.

## METHODS

On 6 - 10 March, 2008, we monitored initial recruitment on artificial structures along a ca. 225 m stretch of back reef in Grape Tree Bay, directly behind the Little Cayman Research Centre. Fifteen artificial structures (five replicates of each of three structure types) were placed 15 m apart and 2 m away from any coral heads. We expected a spatial gradient in fish assemblages along the back reef, so we blocked the structures when placing them. Each was anchored in place with two 2 lb weights. All substrate that provided additional shelter (rocks, algae, shells) was removed from under the structures. Descriptions and photos of structures are in Appendix A.

We monitored two control plots per block ( $n = 10$ ) placed 7 m from any artificial structure and 2 m

from any coral heads. Each control was 0.33 m x 0.30 m, covering ca. the same area as artificial structures. Within each block, we used one modified control (algae removed) and one unmodified control (unmanipulated substrate) to assess the effect of substrate manipulation on fish recruitment.

We placed artificial structures on the seabed floor on the morning of 6 March (day 1). The structures were placed on sandy sections of the seabed floor ca. 1.22 m - 1.52 m deep. We collected data from the afternoon of 6 March through the afternoon of 8 March (day 3). Each day, we observed each structure and controls for 3 - 5 minutes in the morning (ca. 10:00) and the afternoon (ca. 16:00). We recorded number, species, and lifestage (adult or juvenile) of recruited fish for each of the 15 artificial structures and 10 control plots.

Based on our predictions, we tested for the effect of structures on initial fish recruitment using linear contrasts testing for several response values (% juveniles, richness, Shannon-Weiner diversity index, and abundance of recruited fish). We tested for differences between structures and control plots, as well as between high and low complexity, and reported mean  $\pm$  SE results for each of these.

We ran two repeated measures ANOVAs for the effect of time and reef type on abundance,

one including all controls (Day 2-3), and one excluding all controls (Days 1-3); we did the same for species richness. Because we met the assumption of sphericity, we report F-test values for all analyses. We were unable to include the controls to test for the effect of complexity for all 3 days because we began taking data on the un-manipulated controls on the morning of Day 2, and the manipulated controls on the afternoon of Day 2.

## RESULTS

Over the course of the experiment, we made 137 fish observations across 23 species. We observed a total of 39 fish and 8 species at our last sampling period (day 3). Gobies and blennies were the most common fish found in low and medium complexity reef structures over 3 days ( $90.8 \pm 3.8\%$ ,  $78.1 \pm 9.5\%$ ), while high complexity structures contained the same number of gobies and blennies ( $50 \pm 18.4\%$ ) as other fish. We observed very few gobies and blennies in both control plots on day 3 ( $C_u = 1$ ,  $C_m = 0$ ). The Goldspot Goby was the most common species observed in artificial structures over the course of the experiment (low complexity = 19, medium complexity = 13, high complexity = 7).

Over the time period in which we had controls, neither time nor its interaction with reef type were

significant predictors of species richness or abundance of fish (Table 1, Figures 1, Figure 2). However, when we considered our full time period, excluding controls, richness but not abundance increased over time (Table 1). Thus we present mean values  $\pm$  SE and contrasts from our last observation period (afternoon of Day 3).

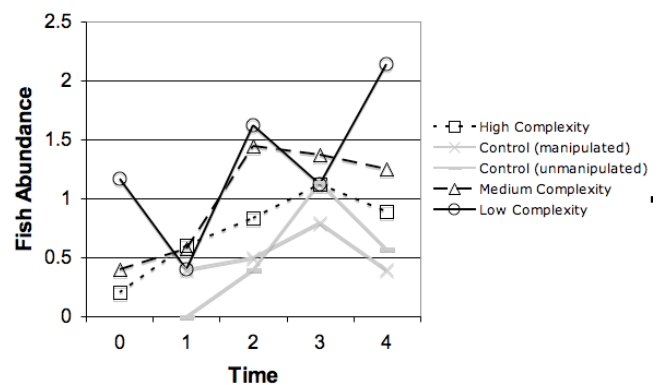


Figure 1. Abundance of fish recruited to artificial structures of varying complexity and control plots over 3 days on the back reef of Grape Tree Bay, Little Cayman Island. Time is categorized by morning and afternoon of each day of data collection (0 = afternoon Day 1, 1 = morning Day 2, 2 = afternoon Day 2, 3 = morning Day 3, 4 = afternoon Day 4).

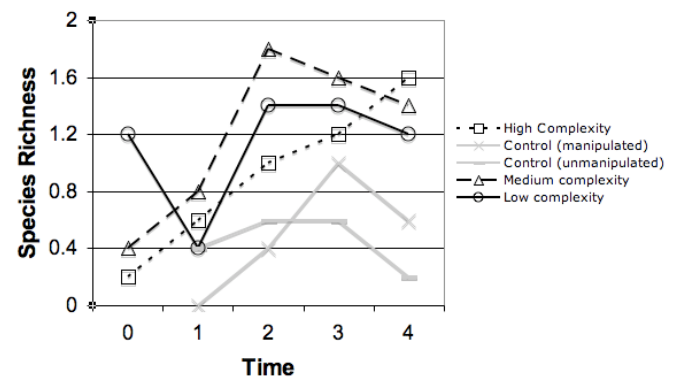


Figure 2. Species richness of fish recruited to artificial structures of varying complexity and control plots over 3 days on the back reef of

Grape Tree Bay, Little Cayman Island. Time is categorized by morning and afternoon of each day of data collection (0 = afternoon Day 1, 1 = morning Day 2, 2 = afternoon Day 2, 3 = morning Day 3, 4 = afternoon Day 4).

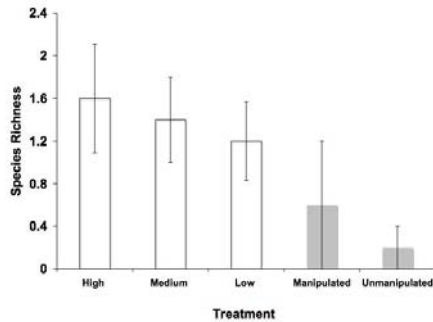


Figure 3. Species richness (mean  $\pm$  SE) of fish recruited to artificial structures of varying complexity (high, medium and low) and control plots (manipulated and unmanipulated) on day three since placement in the back reef of Grape Tree Bay, Little Cayman Island. White bars = artificial structures (N=15), grey bars = control plots (N=10).

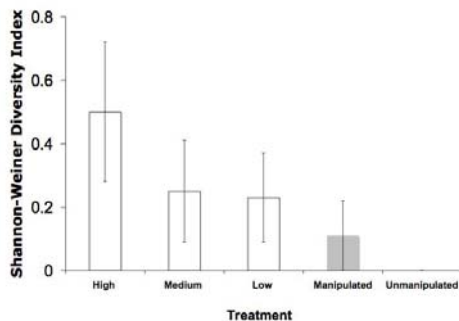


Figure 4. Diversity (mean  $\pm$  SE) of fish species recruited to artificial structures of varying complexity (high, medium and low) and control plots (manipulated and unmanipulated) on day three since placement in the back reef of Grape Tree Bay, Little Cayman Island. White bars = artificial structures (N=15), grey bars = control plots (N=10).

Reef structures had greater fish abundance, richness, diversity and percent juveniles than controls

(contrasts: abundance:  $F_{1,20} = 6.67$ ,  $P = 0.02$ , richness:  $F_{1,20} = 6.25$ ,  $P = 0.02$ , diversity:  $F_{1,20} = 4.20$ ,  $P = 0.05$ , juveniles:  $F_{1,20} = 5.18$ ,  $P = 0.03$ ), but effects of complexity varied. The number of fish recruited to high complexity reef structures differed from low complexity structures (linear contrast,  $F_{1,20} = 4.29$ ,  $P = 0.05$ ). On average, low complexity structures contained more fish ( $2.14 \pm 0.59$ ) than medium complexity ( $1.25 \pm 0.31$ ) and high complexity structures ( $0.89 \pm 0.11$ ). For richness and diversity, artificial structures did not differ between high and low complexity (richness: linear contrast,  $F_{1,20} = 0.42$ ,  $P = 0.53$ ; diversity: linear contrast,  $F_{1,20} = 1.76$ ,  $P = 0.20$ ). Percent juveniles recruited did not differ between high complexity and low complexity structures (linear contrast,  $F_{1,20} = 0.45$ ,  $P = 0.51$ ).

## DISCUSSION

The presence of artificial structures increased the abundance and composition of initial fish recruitment relative to exposed control plots, whereas complexity had no apparent effect on recruitment. Though more complex artificial structures offered more potential resting areas in and outside of an overhang, we saw no increase in abundance with increasing complexity. The presence or absence of shelter may play a greater role in initial recruitment than its

complexity (which increase the number of potential refugia within a shelter). Alternatively, the kinds of artificial structures that offer the best shelter to fish may be different than the ones we designed.

Juveniles used artificial structures more than adults, suggesting that resting and hiding habitat are limiting for juveniles, or that the size of artificial structures and refugia favored juvenile recruitment. Our artificial structures were too small to provide space for most species of adult fish, which may explain why adult gobies and blennies were more commonly recruited than adults of other larger, pelagic families.

Overall, time was not a significant predictor of abundance or richness of fish recruited to artificial structures. It may be that the time scale of our study was not relevant to synthetic artificial structures, as the modification of synthetic surfaces may be necessary for recruitment. Weathering or colonization by primary producers creates more suitable habitat for recruitment by making artificial structures resemble natural ones (Carr et al. 1997). If recruitment to synthetic surfaces is a function of such modification, then fish recruitment to synthetic artificial structures may increase over longer time scales.

As habitats within coral reefs become increasingly degraded due

to climatic changes and anthropogenic effects (Rilov and Benayahu 1997; Golani and Diamant 1999; Strelcheck et al. 2005), artificial structures could play a key role in maintaining species richness and abundance in recovering reef systems (Clark et al. 1994, 1999). Understanding the factors affecting the habitat suitability and fish colonization of artificial structures is central to improving the contributions of artificial reefs.

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Table 1. Repeated measure ANOVAs testing the effect of time and reef type on the abundance and richness of fish recruited to artificial structures of increasing complexity (low, medium, high), with exposed control plots included (afternoon of day 2 - afternoon of day 3) and excluded (afternoon of day 1 - afternoon of day 3), on the back reef of Grape Tree Bay, Little Cayman Island.

	<b>Abundance with controls</b>			<b>Abundance without controls</b>		
<b>Effect Tests</b>	<b>df</b>	<b>F</b>	<b>P</b>	<b>df</b>	<b>F</b>	<b>P</b>
<u>Between treatments</u>						
Reef Type	4	3.275	0.032	4	0.8789	0.5101
Error	21			11		
<u>Within Subjects</u>						
Time	2	0.0885	0.9157	4	2.033	0.1939
Time * Reef Type	8	1.1332	0.364	16	0.5443	0.8922
Error	36			22		
	<b>Richness with controls</b>			<b>Richness without controls</b>		
<b>Effect Tests</b>	<b>df</b>	<b>F</b>	<b>P</b>	<b>df</b>	<b>F</b>	<b>P</b>
<u>Between subjects</u>						
Reef Type	4	2.754	0.0566	2	0.398	0.6802
Error	21			12		
<u>Within subjects</u>						
Time	2	0.3587	0.7032	8	0.9254	0.5191
Time * Reef Type	8	0.5316	0.8252	4	7.2957	0.007
Error	38			18		

## APPENDIX A. ARTIFICIAL STRUCTURE DESCRIPTIONS

We created three types of artificial structures from PVC pipe, each one being approx. 0.3048 m (1') long. Each of the three artificial structures represented a different stage of complexity. We cut the 8" PVC pipe sections using a skillsaw and drilled 1/8" holes using a drill and a hole cutter. We tied each of the PVC connections to the 8" PVC pipe base using nylon string. The 8" PVC pipe was notched so as to keep each of the smaller PVC joints in place when tied with the nylon string. The three types of structures were:

**Simple complexity structure** – Very simple and smooth with no holes. 8"

thin PVC pipe cut in half with a 1 ¼" strip of blue netting wrapped around it (Figure 5).

**Medium complexity structure** – 8" thin PVC pipe cut in half. Five, 1/8" holes and two, 1¼" strips of blue netting wrapped around ends of PVC pipe. Two sets of four different PVC structures (described below) connected to the 8" thin PVC pipe base (Figure 6).

**Most complexity structure** – 8" thin PVC pipe cut in half. Ten, 1/8" holes and four, 1¼" strip of blue netting wrapped around it. Four sets of four different PVC structures connected

to the 8" thin PVC pipe base (Figure 7).

**Four Different PVC Structures:**

1" 90° bend w/ 3/4" coupler for

separation

3/4" 90° bend,

1" T joint w/ 3/4" coupler for separation,

3/4" T joint



Figure 5. Up-close photograph of simple Complexity Structure. Photo: Yiran Gu



Figure 6. Up-close photograph of medium Complexity Structure. Photo: Yiran Gu

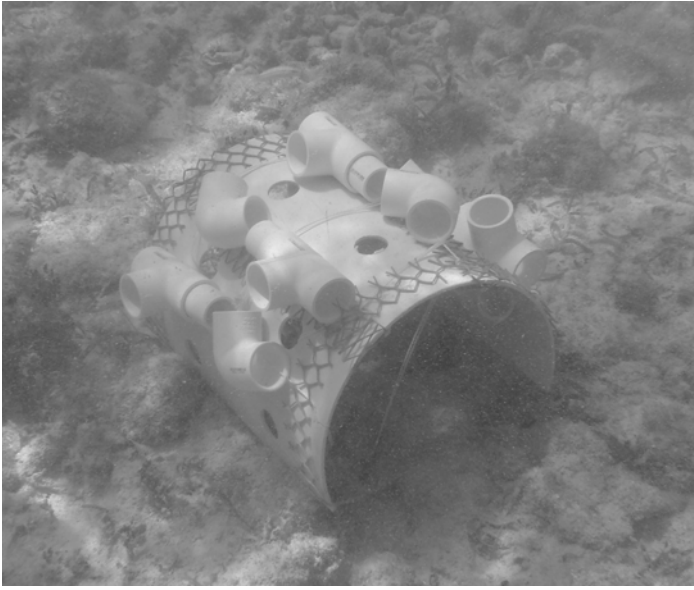


Figure 7. Up-close photograph of most Complex Structure. Photo: Yiran Gu

# SHARKNOSE GOBY AND PEDERSON SHRIMP PROVIDE DISTINCT CLEANING SERVICES TO CLIENT FISH

BRIAN M. LAPPAS, SAMANTHA R. KAPLAN, JENNA M. SULLIVAN, AND THOMAS J. LOBBEN

Faculty editor: David R. Peart

**Abstract:** Several species of fish and shrimp act as cleaners for fish in tropical reef systems. Cleaners remove harmful ectoparasites from clients and in turn gain safe and reliable access to food resources. This mutualism has been extensively studied, but differences in the services provided by cleaner species remain unclear. We examined the cleaning behaviors of Pederson shrimp and Sharknose gobies at Bloody Bay, Little Cayman Island. We predicted that morphological and behavioral differences between shrimp and gobies would result in specialized cleaning behaviors that provide different services to clients. As expected, Pederson shrimp and gobies cleaned different areas of clients.

*Key Words:* Little Cayman, cleaner fish, cleaner shrimp, *Periclimenes pedersoni*, *Gobiosoma genie*

## INTRODUCTION

In the mutualism between cleaners and their clients, the cleaners gain access to food while clients benefit from removal of harmful parasites (Trivers 1971). This mutualism is well known (Wiksten 1995); however, few studies compare specific cleaning behaviors between shrimp and fish.

Pederson shrimp (*Periclimenes pedersoni*) and Sharknose gobies (*Gobiosoma genie*) provide similar services to client fish in coral reefs at Little Cayman Island. Both clean the same spectrum of client species, occupy similar habitats around coral heads and sponges, and often clean the same client simultaneously (Wiksten 1995; personal observations). However, shrimp and gobies are very different

morphologically. Shrimp are dexterous and slow-moving, while gobies have larger mouths and are more mobile. We hypothesized that these differences determine different cleaning behaviors. We predicted that cleaner shrimp and gobies would specialize on certain areas of clients. We also expected the morphological differences between fish and shrimp would influence the time taken to clean their clients.

## METHODS

From 6 March to 8 March 2008 we observed cleaning behavior by gobies and Pederson shrimp at the Cumber's Cave diving location in Bloody Bay, Little Cayman Island. Using SCUBA we conducted six 60-minute dives in pairs at a depth of ca. 10 m, and surveyed 50 m to each

of the east and west, from the permanent buoy marker at Cumber's cave dive site. We opportunistically located active cleaning stations and monitored cleaning behaviors at each for 10 minutes, or until the client fish swam away.

We measured the duration of each cleaning event from the time of discovery. While this underestimates time spent cleaning, it is unbiased with respect to cleaner type. We noted client and cleaner species, and each area where the cleaner came in contact with the client (head, eye, side, back, gills, mouth, and fins). From these data we calculated an index of 'total area covered' by counting the number of areas covered by cleaners and averaging by station. We excluded cleaning observations that appeared to have been terminated due to diver presence.

## RESULTS

We observed a total of 42 cleaning events at 23 cleaning stations in Cumber's Cave. Nineteen events occurred at 11 Sharknose Goby stations, 11 events occurred at 7 Pederson Shrimp stations, and 12 events occurred at 5 stations with both gobies and shrimp ("gobies/shrimp stations"). We tallied 34 gobies at goby-specific stations, and 35 shrimp at shrimp-specific stations.

Shrimp and gobies cleaned different areas of client fish (Table 1). Shrimp cleaned eyes and gills more than gobies, while gobies cleaned the sides of client fish more than shrimp. As the number of cleaners increased, so did the total number of areas covered by the cleaner (regression:  $F = 6.27$ ,  $df = 1,28$ ,  $P = 0.018$ ). However, the number of areas covered by the cleaner did not differ between shrimp and gobies (one-way ANOVA:  $F = 0.43$ ,  $df = 1,15$ ,  $P = 0.52$ ). Shrimp cleaning thoroughness (number of areas cleaned) did not differ between shrimp specific stations and gobies/shrimp stations (2 tailed t-test;  $t = 0.618$ ,  $df = 17$ ,  $p = 0.054$ ). At stations with both species of cleaners present, gobies covered more areas on a client than did gobies at goby-specific stations (2 tailed t-test;  $t = 3.03$ ,  $df = 26$ ,  $p = 0.005$ ).

Cleaning event durations ranged from 5 s to 600 s (mean  $\pm$  SE =  $142 \pm 21$  s). Shrimp and gobies at their respective stations cleaned each client for approximately the same amount of time ( $74 \pm 36$  and;  $86 \pm 26$  s client<sup>-1</sup>, respectively), but when clients visited stations occupied by gobies and shrimp, they stayed significantly longer (one-way ANOVA;  $F = 5.13$ ,  $df = 2, 19$ ,  $P = 0.017$ ;  $223$  s client<sup>-1</sup>  $\pm$  39). Interestingly, there was no relationship between the time spent at the cleaning station and the overall number of fish or gobies

actively cleaning (one-way ANOVA;  $F = 0.064$ ,  $df = 1,45$ ,  $P = 0.80$ ).

TABLE 1: The percentage of cleaning events by each type of cleaning station (rows) that resulted in cleaning specific areas of the client (columns).  $X^2$ ,  $R^2$ , and p-values shown for each of the different chi-squared tests. Data collected 6-8 March 2008 at 10 m depth, 50 m East and West of the Cumber's Caves dive site permanent mooring ball.

	Head	Eye	Side	Back	Gills	Mouth	Fins
Gobies/ shrimp	100%	60%	100%	100%	100%	60%	100%
Gobies	55%	9%	82%	64%	45%	18%	72%
Shrimp	57%	57%	29%	43%	86%	71%	57%
$X^2$	3.42	6.15	8.52	4.22	6.07	5.65	2.79
$R^2$	0.168	0.226	0.335	0.193	0.261	0.189	0.149
p	0.181	<b>0.046</b>	<b>0.014</b>	0.121	<b>0.048</b>	0.059	0.247

## DISCUSSION

As predicted, there were subtle differences between the behaviors of Pederson shrimp and Sharknose gobies at cleaning stations. Although cleaners at these stations spent the same amount of time cleaning, shrimp appeared to clean gills and eyes preferentially, while gobies were more likely to clean the side of the client. Different morphologies of shrimp and gobies may maximize foraging efficiency in these different areas; perhaps the longer and more agile appendages of shrimp allow easier reach into gill crevices and a more delicate cleaning of the eyes, whereas the larger mouths and quicker movement of gobies allow them to clean larger areas, such as the side. In addition to providing distinct services to clients by cleaning different areas, fish and shrimp may be accessing different resources in different areas of client fish. The provision of different

services to clients may indicate niche partitioning, which is one possible mechanism to explain how these species co-occur.

We also found a high incidence (23%) of stations containing both shrimp and goby cleaners. Goby and shrimp stations did not differ in time spent cleaning a client, but clients spent more time at stations containing both shrimp and fish. Gobies cleaned significantly more areas at goby/shrimp stations than at goby stations, but shrimp cleaned similar numbers of areas, whether at shrimp stations or goby/shrimp stations. Shrimp may be more specialized cleaners than gobies, because even in the longer cleaning events that occurred at goby/shrimp stations, shrimp focused on the same areas, while gobies cleaned additional areas, not covered at goby stations.

Gobies and shrimp clearly provide different services to clients. To explore the implications of these

differences, each type of cleaner could be experimentally removed, and the consequences for fish health, growth and survival evaluated.

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# DISTRIBUTION AND POLYP BEHAVIOR OF THREE PHENOTYPES OF *MONTASTREA* ACROSS TWO MICROHABITATS

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*Abstract:* *Montastrea* is a common Caribbean hard coral genus that grows in several different morphotypes (which may or may not represent different species), over a range of depths. We investigated the distribution of *Montastrea* morphotypes (boulder, lobed, encrusting) and whether the percent polyp openness during the middle of the day varied among morphotypes and across microhabitats. In Jackson Bay, Little Cayman, encrusting corals were more abundant on the sloping fore-reef face (5-10 m depth) while lobed and boulder corals were more abundant on the almost flat reef top (3-8 m depth). Boulder corals had the greatest polyp openness, and polyp openness decreased with depth for all morphotypes. Differences in habitat associations and polyp openness between morphotypes indicate distinct ecological roles, whether or not morphotypes are genetically isolated.

## INTRODUCTION

*Montastrea* is a common Caribbean reef-building coral that grows as several morphotypes, which commonly occur between 5-23 m depth (Veghel and Back 1993). Currently, it is unclear whether the different morphotypes represent several related species (Humann 1993, Amral 1994, Szmant et al. 1997). If they represent a single species, they may be the result of genetic polymorphism or phenotypic plasticity.

We focused on differences in habitat associations and polyp openness (zooplankton feeding) between *Montastrea* morphotypes.

Morphotypes clearly co-exist locally within a coral reef, but different morphotypes may survive and grow better in different habitats.

Morphotypes may also differ in polyp openness. This could occur if, for example, some morphotypes provide better fish habitat, resulting in greater localized water disturbance from the swimming fish, causing polyps to close. Polyp openness might also differ among habitats. For example, in habitats with high turbulence, the encounter rate between polyps and zooplankton may be high, and polyps may open more as a result. Finally, polyp openness might depend on an interaction between morphotype and habitat. For example, a morphotype that tends to have open polyps in areas of low sedimentation may tend to close its polyps if sedimentation rate is high.

We examined the distribution and percent polyp openness of the major coral morphotypes (lobed,



boulder, and encrusting) within two adjacent environments, the almost flat reef top and the sloping reef face, at the "Sarah's Set" diving location in Jackson Bay, Little Cayman Island. The reef top contains more horizontal surface area with greater water movement from nearby wave action, while the deeper reef face contains more sloped or vertical substrate, with calmer water. The shallow reef top also allows greater direct light penetration to corals, while light is more diffuse on the sloped reef face.

We hypothesized that the different morphotypes of *Montastrea* would be associated with habitat conditions. We predicted that the encrusting morphotype would predominate on the sloping reef face, since its encrusting structure allows greater exposure to diffuse light. Since all corals are subject to bioerosion and undercutting, we also predicted that the more massive lobed and boulder morphotypes would be less common on the sloping reef face where they may be less stable.

## METHODS

We measured *Montastrea* morphotype distribution and polyp openness during four 60 minute periods, at 1400 on March 6 and at 0800, 1000 and 1400 on March 7, 2008 at the Sarah's Set dive site in Grape Tree Bay, Little Cayman Island.

The reef top was defined as the fairly flat hard coral area within 2 m of the drop off, and the reef faced was defined as the sharply sloping (60-90°) area between the reef top and the flat sandy bottom below. Using SCUBA, we swam along the reef top and reef face at all depths between 10 and 30 m, and located all *Montastrea* colonies > 0.25 m diameter within 2 m of the reef face. For each colony, we noted morphology (lobed, boulder, encrusting), microhabitat (reef top or reef face), depth, and estimated percent open polyps in 10% intervals.

We defined lobed morphotypes as colonies with multiple-column structures, with living polyps on their dome-like tops and algae that is often bioeroded in the lower crevices. We defined boulder morphotypes as colonies with a single mound. Encrusting morphotypes were colonies with a single plate, which could have complex shape and microtopography, depending on substrate morphology. Both encrusting and boulder morphotypes ranged from smooth to lumpy in surface texture.

We recorded fish abundance near each colony by counting all fish visible within 10 cm of the coral head.

To satisfy assumptions of normality, we square-root transformed data for fish abundance

and percent open coral polyps per coral head. We used a linear regression to examine the relationship between percent open coral polyps and depth. We examined the effect of microhabitat and morphology on percent open coral polyps per coral head and on fish abundance, using two full-factorial two-way ANOVAs. By plotting microhabitat and morphology against the residuals of a regression of percent open coral polyps versus depth, we corrected for variance in coral polyp openness due to depth.

## RESULTS

Coral morphotypes were distributed non-randomly among habitats ( $\chi^2 = 20.65$ ,  $r^2 = 0.67$ ,  $P < 0.0001$ ). Lobed and boulder morphotypes were more abundant on the reef top, while the encrusting morphotype was more abundant on the reef face (Figure 1).

Percent open polyps decreased with increasing depth ( $df = 1$ ,  $160$ ,  $P < 0.0001$ ), but depth explained little of the variation in polyp openness ( $r^2 = 0.10$ ). Percent open polyps also differed by morphology (two-way ANOVA,  $df = 2, 156$ ,  $F = 47.39$ ,  $P < 0.0001$ ), but not microhabitat ( $df = 1$ ,  $156$ ,  $F = 0.84$ ,  $P = 0.36$ ) when the effect of depth had been removed (by analyzing residuals; see Methods). Boulder corals opened their polyps more

than lobed or encrusting morphotypes (Figure 2).

Fish abundance varied with morphology (two-way ANOVA,  $df = 2, 156$ ,  $F = 12.54$ ,  $P < 0.0001$ ) but not microhabitat (two-way ANOVA,  $df = 1, 156$ ,  $F = 1.02$ ,  $P = 0.31$ ) or depth ( $r^2 = 0.0004$ ,  $df = 1$ ,  $160$ ,  $P = 0.81$ ). Fish were more abundant on lobed than on boulder or encrusting coral (Tukey's HSD  $\alpha = 0.05$ ).

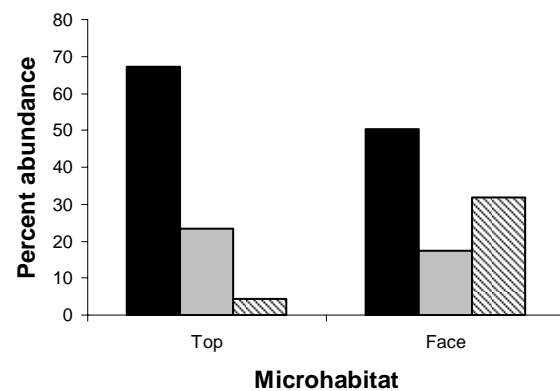


Figure 1. Percent of total *Montastrea* colonies contributed by the boulder (black), lobed (gray) and encrusting (hatched) morphotypes on the reef top and reef face at Sarah's Set dive site in Jackson Bay, Little Cayman Island. Data from 163 colonies sampled between 3-10 m depth.

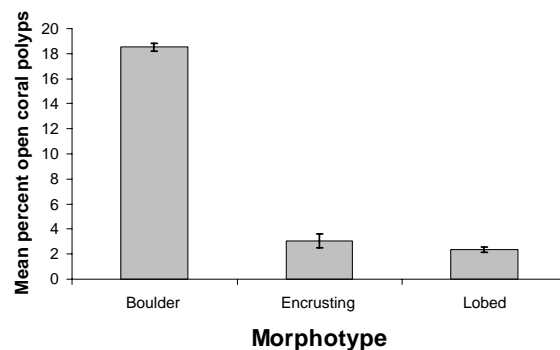


Figure 2. Mean percent open coral polyps ( $\pm 1$  SE) by morphology of the coral *Montastrea* at Sarah's Set in Jackson Bay, Little Cayman Island. Letters indicate differences as calculated by Tukeys HSD ( $\alpha = 0.05$ ). Data from 163 colonies sampled between 3-10 m.

## DISCUSSION

*Montastrea* morphotypes had clear habitat associations. Lobed and boulder morphotypes dominated the reef top, where the horizontal substrate may better support these heavy upward-growing corals. Compared to the reef top, the steeply sloping (and sometimes vertical or overhanging) reef faces may provide better habitat for the encrusting morphotype. Here, there is less chance of being shaded by taller corals, given the more diffuse light at the greater depth of the reef face.

Polyp openness decreased with increasing depth. Corals may open their polyps more in shallow water since greater water activity increases zooplankton movement across the coral's surface, increasing encounter rates and potential prey capture (Sebens et al. 1998).

Greater fish abundance around lobed corals suggests that their greater rugosity compared to boulder or encrusting morphotypes provides a daytime habitat for many fish. These fish may cause greater localized water disturbance, which may reduce polyp openness in lobed corals even though they are distributed more in shallow waters where polyp openness is greater overall.

*Montastrea* morphotypes differed in distribution across habitats, polyp opening behavior and response to depth. If

morphotypes represent phenotypic plasticity, *Montastrea* shows remarkable capacity to adjust to local environments during colony development. If the morphotypes represent a genetic polymorphism, our results suggest that different genotypes are favored in different habitats, perhaps maintaining a stable polymorphism in the species. Finally, if the morphotypes are distinct species, our findings indicate how small-scale variations in environmental conditions and depth can contribute to the species diversity of corals.

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# TIME BUDGETS FOR NASSAU GROUPEL (*EPINEPHELUS STRIATUS*) ON LITTLE CAYMAN ISLAND

ROBERT H. YANKER III

Faculty editor: David R. Peart

*Abstract:* All animals must budget their time to maximize fitness. I studied Nassau Grouper behavior and time budgets in Jackson Bay, Little Cayman. I found that Nassau Grouper use their time differently throughout the day. Near dusk they spend most of their time searching for crustaceans, compared to morning and afternoon when they mostly hunt using a “sit-and-wait” strategy.

*Keywords:* territoriality, fish and crustacean predation

## INTRODUCTION

Effective time allocation is important to all animals and involves balancing energy use with energy intake. Those individuals that are more effective at budgeting their time will likely have higher fitness, passing these traits on to future generations. Often efficiency varies by time of day. Unlike many reef fish which may modify activities to avoid predation, adult Nassau Grouper (*Epinephelus striatus*) are one of the top predators and can generally move freely with little risk other than intraspecific aggression related to territoriality. Nassau Groupers are generalist predators with a diet of ca. 54% fish, with the remainder mostly crustaceans (Randall 1967). They feed throughout the day but mostly in the early morning and at dusk (Sadovy et al. 1999). Little Cayman has one of the last viable populations

of Nassau Grouper in the Caribbean, thus making Little Cayman an ideal area for research on the species.

I predicted that Nassau Grouper would allocate their time differently throughout the day, spending morning and dusk mostly searching and midday sitting and waiting (see definitions of behaviors in Methods, below).

## METHODS

I measured Nassau Grouper time budgets on 6-8 March 2008 at 8:00, 11:00, 16:30 in Jackson Bay, Little Cayman. At each sampling period, I located a single adult Nassau Grouper and recorded its behaviors for one hour. For each sample I followed a separate individual, identified by the patterning on its body, especially the spotting within the stripes. I grouped behaviors into five categories:

swimming, drifting, searching, sitting, and cleaning. Only sustained, directed swimming events used to change location were recorded as "swimming" (short swims were disregarded). I defined drifting as slow movement among sea fans or other objects with little or no tail movement, staying in one location only briefly. Searching was defined as actively looking underneath various rocks, caves, or crevices. I defined sitting as remaining stationary for more than several minutes, apparently in the classic 'sit-and-wait' behavior of many predatory fish. Cleaning was defined as waiting or being actively cleaned at a cleaning station. Behaviors were recorded only if they occurred in periods of one minute or longer. I also collected detailed observational data documenting predation events, territorial displays, approximate fish size, repeated sightings, and total distance moved. The frequency of each behavior was tested with chi-squared tests, comparing to a null model assuming no temporal partitioning.

## RESULTS

Grouper behaviors varied by time of day ( $X^2 = 50.9$ ,  $df = 8$ ,  $P < 0.001$ ). The differences were driven primarily by the dusk measurements; there was no significant difference between morning and midday in time spent

sitting ( $X^2 = 0.996$ ,  $df = 1$ ,  $P = 0.32$ ) or searching ( $X^2 = 1.88$ ,  $df = 1$ ,  $P = 0.17$ ). Searching was significantly more frequent at dusk ( $X^2 = 24.3$ ,  $df = 2$ ,  $P < 0.001$ ). While there were no significant differences between fish behavior at midday and morning, groupers spent 53% of their time sitting at midday and only 41% sitting during the morning. In contrast to the morning, 63% of dusk samples were spent searching (Table 1). Little time was spent swimming, being cleaned, or drifting in any time period.

Table 1. Proportion of time spent on various activities for Nassau Grouper in Jackson Bay, Little Cayman. Data from seven one-hour sampling periods and one 30 min. sample.

Activity	Morning	Midday	Dusk
Cleaning	24%	17%	12%
Drifting	3%	10%	13%
Searching	24%	13%	63%
Sitting	41%	53%	7%
Swimming	8%	7%	5%
<b>Totals</b>	100%	100%	100%

I noted six predation events during the 7.5 hours of observation; four were successful. During searching behavior at dusk, groupers consumed one crab and part of one spiny lobster. There was one successful attack on a fish, while sitting at midday. Additionally one cleaner fish was consumed after being cleaned at a cleaning station during a midday sample. While drifting, two unsuccessful attacks occurred; the first on a large parrotfish in the morning and the

other on a small barracuda at midday.

Most groupers moved < 100m during a the observation period, but the largest fish sampled moved hundreds of meters along the reef parallel to the shore during the hour of monitoring. There were also many territorial displays with the larger fish always winning the dispute.

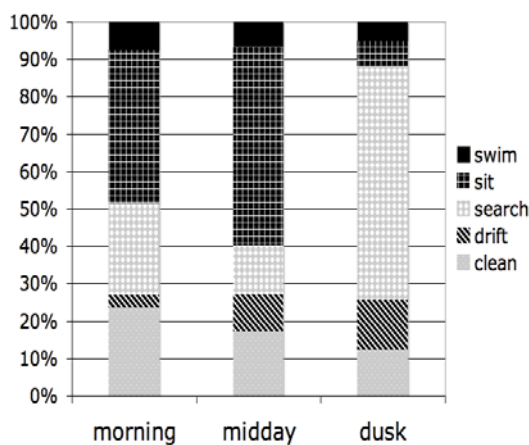


Figure 1. Time budgets for Nassau Groupers at Jackson Bay, Little Cayman Data from seven one-hour bouts and one 30 min. bout.

## DISCUSSION

Nassau groupers allocate their time differently throughout the day, possibly to maximize foraging efficiency. It appears they take advantage of dusk to hunt nocturnal crustaceans such as spiny lobsters as they emerge from hiding.

I was unable to assess behavior in the early morning hours; possibly dawn and dusk behaviors may be similar, though based on my

data morning behaviors do not differ from those at midday. Nassau groupers may be acquiring nearly half of their food in the hour or two before sunset, leaving the rest of the day to hunt for fish, etc.

It is likely that the energy expended searching for crustaceans has the greatest payoff at dusk. Since searching is likely more energetically costly than sitting and drifting, the net energy gain of crustacean and fish predation may be similar.

While searching and sitting make up the majority of their time swimming, drifting and cleaning are also major uses of time. Swimming may be costly and thus only used when it is necessary to move to another area. Drifting appeared to be used opportunistically as a passive hunting strategy while the individuals were moving around the reef, essentially resting. Cleaning seemed to be relatively similar at all times of day.

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# TO FISH OR NOT TO FISH: SCIENCE, POLICY, PUBLIC OPINION, AND THE MANAGEMENT OF NASSAU GROUPER

LIA M. CHEEK AND YIRAN GU

Faculty editor: David R. Peart

“Closing the aggregation to fishing? That’s perfect! Keep it that way,” said a local fisherman from Little Cayman, Cayman Islands.

Another local fisherman, however, wanted the government to re-open the aggregation for fishing, but with a limit on the number of fish caught.

The debate is about whether people should be allowed to fish the Nassau Grouper when they aggregate to spawn near the west end of Little Cayman Island, at a spot locally known as the Grouper Hole.

Like all other natural resources management decisions, the establishment of a new Grouper Hole fishing regulation will depend on inputs from scientists, local residents, fishermen, businessmen and politicians. To better understand the diversity and strength of these opinions on Little Cayman, we interviewed three local fishermen, two marine park officers, one long-term fishing guide, and one research scientist. Because tourism contributes substantially to the island’s economy, we also

interviewed a group of fourteen diving tourists (Appendix I).

Nassau Grouper, *Epinephelus striatus*, is an IUCN-declared endangered species occurring naturally in the Caribbean basin. Although fish are not usually described as charismatic, the term seems appropriate for Nassau Groupers. Each fish appears to have distinct behavioral patterns<sup>1</sup>, and individuals often gain the affection of divers and angler fishermen alike. However, because they are tasty, easy to catch, and aggregate predictably in the thousands to spawn every year at the same place and time, Nassau Groupers have suffered severely from intense fishing pressure throughout their range. The island of Little Cayman is home to one of the last few remaining large, healthy, and actively spawning aggregations in the world. This population has persisted because there has never been large-scale commercial fishing around the island.

Prior to 2001, the spawning aggregation was known to only a

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<sup>1</sup> Long-term seasonal fishing guide from Wyoming.



few local fishermen, who never took more than 10 groupers per person per season<sup>2</sup>. Unfortunately, in 2001, and again in 2002, a few fishermen from a nearby island found the spawning aggregation, and, using just two boats<sup>3</sup>, line-fished ca. 70% of the 7000 Nassau Grouper aggregation in just a couple of days<sup>4</sup>. Unable to sell their large catch rapidly, thousands of fish rotted in storage, prompting a public outcry. In response, the Caymanian government quickly passed legislation, banning the fishing of Nassau Grouper at the Grouper Hole, starting in 2003. As this legislative moratorium approaches its end in January 2011, decisions regarding future management of Grouper Hole become important once again.

Most of the tourists that come to Little Cayman are environmentally-conscious individuals looking for reefs in near-pristine condition, rather than luxurious beach resorts<sup>5</sup>. They expect good reef habitat--all of the

fourteen visitors we interviewed said that if fish populations were decimated, they would not come back again. These responses suggest that even if economic benefits were the only important factor in this management decision, the benefits of fishing and reef conservation need to be balanced. The tourists appreciate and support the efforts that the Caymanian government devotes to protecting the reefs. Some even said they would be happy to contribute funds to reef protection, perhaps by purchasing fishing licenses, or paying entrance fees to marine parks. According to a long-time fishing guide we interviewed, "if [visiting recreational angler fishermen] can afford the plane ticket to get down here, they won't mind paying a bit extra for a fishing license". It seems that visitors to Little Cayman are willing to contribute financially to conservation efforts.

Apart from the tourists, all seven of the other interviewees agreed that the Nassau Grouper aggregation should be protected to some extent. Six of the seven believe that the aggregation should be kept closed, because that would ensure the continued survival of Nassau Grouper in the future.

"If you don't take care of what you've got, you'll have it no more soon," said a born-and-raised Little Caymanian who is also a local

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<sup>2</sup> Local fisherman from Little Cayman island.

<sup>3</sup> Jon Clamp, manager of Little Cayman Research Institute.

<sup>4</sup> Whaylen, L., P. Bush, B. Johnson, K.E. Luke, C. McCoy, S. Heppell, B. Semmens, and M. Boardman. Aggregation dynamics and lessons learned from five years of monitoring at a Nassau grouper (*Epinephelus striatus*) spawning aggregation in Little Cayman, Cayman Islands, BWI. Gulf and Caribbean Fisheries Institute Proceedings, 1.

<sup>5</sup> Diving tourist group interview.

fisherman. "Of course you'll have to protect it."

One of the research scientists working on the Nassau project explained that "keeping the aggregation closed during the spawning season would protect the sexually mature adults, ensure a healthy sex-ratio, and maintain the reproductive potential of the population."

But not everybody believes that the Grouper Hole should be closed completely. One local fisherman who has fished the aggregation since the 1980s said that to some of the older people, "it matters a lot if the aggregation is closed." According to him, many people rely on the aggregation for a large and easy catch each year "...to help feed their family and make some extra pocket-money. As long as you put a limit [on the amount you can take from the aggregation], people will get used to it. Most people abide by the law."

Of course most fishing in the waters around Little Cayman has no direct impact on the Nassau Grouper aggregations that are so localized in space and time. Harvesting fish from the sea is a long-standing tradition amongst Caymanians. Many of the older generation started fishing when they were five or six years old. Fishing for meals was part of daily routine.

"When I was little, we ate fish everyday. Except Sundays. My

mother refused to cook fish on Sundays," said an older local fisherman.

"You'll never see a complete ban on fishing here. Never," he said, "people should be allowed to fish for food, and with the right limits, you can't destroy that."

"Our heritage is to use the waters," said another older fisherman. "They tell us that they're protecting our heritage. But if you take our fishing ground away, we can no longer practice our heritage. How's that protecting our heritage?"

Clearly, being able to fish is very important to the local community, and none of the people we interviewed suggested banning fishing around the island. However, as Marine Parks Officers Robert Walin and Hank Blagen told us, more and more people are beginning to understand the need to protect the Nassau aggregation.

"Most people fish them out of ignorance. They don't understand the mating system and how they aggregate," said Walin. "Sometimes, people don't know where the exact limits [of the Grouper Hole] are," said Blagen, "but once you tell them, they usually move right away."

While keeping the aggregation closed would allow the Nassau population to recover, opening it up would present the major challenges of determining the right harvest limits, and enforcing those limits.

Although scientists are busy studying the Nassau population, our knowledge is still limited. According to the scientist we interviewed, “we don’t know anything about the recruitment of this Nassau grouper population as of now.” And without knowing the number of larvae that settle on the reefs at Little Cayman, scientists cannot estimate the population growth rate, and therefore, the number of fish that can be harvested sustainably.

Even if a fishing limit can be determined accurately, it’s likely that scientists and fishery management officials may still perceive the risk of opening the Nassau Grouper aggregation to be too high. Experiences from 2001 and 2002 have shown that as few as two individuals fishing over a few days can severely damage the spawning population. To avoid a repetition of that huge setback, regulations will need to be extremely strict, which might demand more time and effort than Marine Parks Officers can manage. As Blagen puts it, “we simply can’t sit there and wait 24/7 to check every boat.”

Without the strong enforcement of a fishing limit, it could be too risky to open up the aggregation for fishing. This may force the government to keep it closed. Although a few older fishermen who believe strongly in their right to fish may oppose such a decision, all locals interviewed

appear to understand the importance of protecting the aggregation, and will likely accept strong regulations made to benefit Nassau Groupers.

In the world at large, traditional, scientific, industry and conservation interests often clash unproductively. Little Cayman provides an exceptional example of a community where perspectives and broad goals seem to be shared across people with different backgrounds and in different walks of life. These shared values should help build a broad consensus when the time comes to make this difficult decision: just how stringent will the regulations have to be if we are to keep the charismatic Nassau Groupers abundant in the reefs of Little Cayman?

#### APPENDIX I. DESCRIPTION OF INTERVIEWEES AND SUMMARY OF VIEWS EXPRESSED

Seven individuals and a group of fourteen diving tourists were interviewed between March 6<sup>th</sup> and March 10<sup>th</sup>, 2008. The seven individuals were recommended by Mr. John Clamp, manager of Little Cayman Research Institute, and consisted of three local fisherman, two Little Cayman Marine park officers, a seasonal fishing guide, and a scientist studying the Nassau grouper. The group of diving tourists was from the Southern Cross resort; they came to the research

station for a tour of the facilities. Interviews lasted between 30 and 60 minutes. We posed a set of core questions to all individuals, together with a few specialized questions to take advantage of the particular knowledge and experience of each individual. Our core questions included:

“What is your opinion on fishing laws and management on Little Cayman”?

“How much are fish populations affected by the amount of fishing that occurs on Little Cayman”?

“What influences do incoming tourists and expatriates, have on fish populations and management decisions”?

We asked individuals to discuss their opinions on the fishing of the Nassau Grouper aggregation in 2001 and 2002, as well as how they felt about the ban, and what they believed future management decisions should be. We asked if their opinion would change if scientists showed that larvae produced from the aggregation were not stocking the Cayman Islands. We asked what were some of the important things could be done to improve the situation with Nassau groupers, as well as general background questions about the interviewees and their experience. As we only interviewed seven out of the 150 people living on Little Cayman, our responses are not representative of the entire

population; however we did find some variation in opinions.

All individuals said that the ban that was placed upon the grouper aggregation in 2003 was positive and necessary. One out of seven individuals suggested that fishing of the aggregation should be reinstated at some point in the future with limits upon the amount of fish taken. Another stated that fishing with limits is likely to occur as the population recovers, though he personally thinks the aggregation should remain closed. Six out of seven interviewed stated that fishing in general should be allowed, as it is culturally important on Little Cayman. All individuals said that the aggregation should still be protected even if scientists found no local recruitment (though all local fishermen were skeptical of the possibility that there might be no local recruitment). All tourists, the long-term fishing guide from Wyoming, the research scientist from Oregon, and one local fisherman, said that the Caymanian government should use fishing licenses and marine park entrance fees to increase resources devoted to reef conservation, reef research, and marine law enforcement. All those interviewed agreed that the Nassau Grouper spawning aggregation should be protected, and that education and enforcement should be improved.

# HOST PREFERENCE OF FLAMINGO TONGUES, *CYPHOMA GIBBOSUM*, AMONG TWO GORGONIANS ON LITTLE CAYMAN ISLAND

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*Abstract:* Grazers are important to many marine benthic systems for the role they play in controlling the abundance and distribution of algae and some benthic invertebrates. However, it remains unclear how much coral grazers influence the structure of coral communities. For the gastropod coral grazer, the Flamingo Tongue snail, *Cyphoma gibbosum*, I evaluated preference for different gorgonian corals. I tested the distribution of *Cyphoma* among two gorgonian taxa, *Eunicea* spp. and *Briareum asbestinum* on the back reef near Jackson's Point on the north side of Little Cayman Island. I used both surveys and reciprocal transplants of *Cyphoma* to test host species preference. *Cyphoma* were more common on the much rarer *Eunicea* spp. However manipulation trials suggested a preference for the Corky Sea Finger, *B. asbestinum*.

*Keywords:* back reef, gorgonian community, Little Cayman Research Center, Corky Sea Finger, Knobby Sea Rod

## INTRODUCTION

Grazers are important to many marine benthic systems for the role they play in controlling the abundance and distribution of algae and invertebrates (Ogden *et al.* 1973; Hay 1981). Many animals consume and damage corals, but their influence on coral community structure is not well understood. Species that graze randomly among the available coral hosts would have a different effect than those that feed preferentially on one or a few corals.

I studied the distribution of the small, gorgonian-grazing Flamingo Tongue snail (*Cyphoma gibbosum*) among two taxa of gorgonian (Knobby Sea Rods, *Eunicea* spp. and Corky Sea Fingers,

*Briareum asbestinum*) on the back reef near Jackson's Point on the north side of Little Cayman Island. In previous observations I had seen *Cyphoma* occupying and grazing on colonies of *Eunicea* spp. I hypothesized that *Cyphoma* would feed preferentially on *Eunicea* spp., predicting there would be more *Cyphoma* on *Eunicea* spp. colonies than on *B. asbestinum* colonies, when corrected for the relative abundance of the two gorgonians. I also used reciprocal transplants to test for host preference and nonrandom feeding patterns in *Cyphoma*.

## METHODS

On Mar 6 - 10 on the back reef of Grape Tree Bay outside the Little Cayman Research Center on the north side of Little Cayman Island, I estimated the densities of *Eunicea* spp. (Knobby Sea Rods) and *B. asbestinum* (Corky Sea Finger) using ten 3 x 2 m plots by counting and measuring colonies of each. I could not identify *Eunicea* to species since most members of this genus can only be distinguished microscopically. I grouped each colony into one of five size categories: 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm and 40-50 cm by height. I summed the length of colonies within each taxon (using midpoints of the size ranges), and took the mean for all plots, as a measure of abundance.

I estimated *Cyphoma* abundance in the study area using a belt transect of ca. 220 x 5 m, running east-west along the back reef. I searched for two hours, counting *Cyphoma* individuals and aggregations and identifying host to species or genus.

I tested host preference using reciprocal transplants of *Cyphoma* individuals. I moved individuals between gorgonian colonies of the same taxon ("conspecific"), and also between gorgonians of different taxa ("heterospecific"). I controlled for disturbance by removing and replacing individuals on the same colonies ("controls").

## RESULTS

*Briareum* dominated the gorgonian community of the back reef, making up  $84.2 \pm 0.04$  % (mean  $\pm$  1 SE) of colonies of the two gorgonian taxa observed. There was a mean of  $3.73 \pm 0.54$  *B. asbestinum* colonies m<sup>-2</sup> and  $0.65 \pm 0.15$  *Eunicea* spp. colonies m<sup>-2</sup>. Mean length was  $14.71 \pm 1.35$  cm m<sup>-2</sup> for *B. asbestinum*, and  $22.92 \pm 1.85$  cm m<sup>-2</sup> for *Eunicea* spp.

On the first sampling date, I found 46 *Cyphoma* on four different gorgonian taxa (Table 1; density = 0.042 individuals m<sup>-2</sup>). *Pseudoplexaura* and *Plexaura homomalla* both had a very low abundance and very few observations of snail grazers, so I did not consider them further. *B. asbestinum* represented 53.6% of the colonies hosting *Cyphoma*.

Table 1. Gorgonian corals hosting *Cyphoma gibbosum* on the back reef of Grape Tree Bay on the north side of Little Cayman Island. The table gives the number of colonies of each gorgonian occupied by *Cyphoma*, and the number of *Cyphoma* found on each taxonomic group.

Gorgonian	Common Name	No. Colonies	No. <i>Cyphoma</i>
<i>Briareum asbestinum</i>	Corky Sea Finger	16	24
<i>Eunicea</i> sp.	Knobby Sea Rod	15	17
<i>Pseudoplexaura</i> sp.	Porous Sea Rod	2	4
<i>Plexaura homomalla</i>	Black Sea Rod	1	1
Total		34	46

Excluding individuals on *Pseudoplexaura* sp. and *P. homomalla* colonies, 58.5% of *Cyphoma* from the transect sampling were found on *B. asbestinum*. Under a null model with no host preferences, we would expect *Cyphoma* to be found on each suitable gorgonian species in abundances proportional to the relative densities of each. *Cyphoma* were found significantly less than expected on the common *B. asbestinum* when considering both the number of colonies ( $t = 6.06$ ,  $df = 9$ ,  $P = 0.0002$ ) and the summed maximum height  $m^{-2}$  ( $t = 2.60$ ,  $df = 9$ ,  $P = 0.029$ ).

*Cyphoma* rejected the new host in 17% of the transplant controls, and response was identical for the two gorgonian taxa. Response did not differ between host taxa in the conspecific transplants ( $\chi^2 = 0.29$ ,  $df = 1$ ,  $P = 0.59$ ); there was 25% rejection of *B. asbestinum* and 37.5% rejection of *Eunicea* spp. However, *Cyphoma* were significantly more likely to leave a *Eunicea* spp. colony (83% rejection) than a *B. asbestinum* colony (16.67%) when transplanted across gorgonian taxa in the heterospecific manipulations ( $\chi^2 = 4.41$ ,  $df = 1$ ,  $P = 0.036$ ).

## DISCUSSION

*Cyphoma* were more abundant on the rarer *Eunicea* spp. than on *B. asbestinum*, supporting the hypothesis that *Cyphoma* prefer

*Eunicea* spp. as a host. There are three possible explanations: 1) *Eunicea* spp. are better hosts for *Cyphoma*, but their abundance is controlled by some unrelated factor; 2) *Cyphoma* prefer *Eunicea* spp. and exert top-down pressure on the gorgonians that limits their abundance; or 3) *Cyphoma* actively seeks out *Eunicea* spp. because they are rare, possibly as a result of some tolerance threshold for secondary compounds produced by other gorgonian hosts. There have been many studies on secondary compounds in gorgonians (e.g. Fenical *et al.* 1981 and La Barre *et al.* 1986), but no evidence that *Cyphoma* choose their host or alter their feeding rates to avoid toxins (Lasker *et al.* 1988).

In contrast, the cross-host transplants suggest preference among *Cyphoma* for *B. asbestinum*. *Cyphoma* may become canalized to a particular host once they commence feeding, although this only holds for those originally feeding on *B. asbestinum*. It is also possible that there are different genotypes that preferentially feed on each gorgonian type, with differing tolerances for the other. While more *Cyphoma* apparently seek out *Eunicea* spp., these individuals are more tolerant of both gorgonian taxa. Individuals that feed on *B. asbestinum* seem to have little tolerance for the alternative. This difference in flexibility may be linked to the relative abundances of

the gorgonians; those that prefer the rarer *Eunicea* spp. would have an advantage if they could easily switch to the more readily available *B. asbestinum*.

If there was some genetic basis for host preference, large changes in gene frequency among *Cyphoma* could have heavy impacts on the structure of the gorgonian community. However, it appears that *Cyphoma* graze on and kill polyps, with little effect on the colony as a whole. Inferences about *Cyphoma*'s impact on community structure require more information on the damage that *Cyphoma* inflict on gorgonians as they feed.

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