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# Effects of herbivore grazing on juvenile coral growth in the Gulf of Mexico

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**Abstract.** This study demonstrates how herbivore grazing and substrate variations influence coral recruitment patterns at the Flower Garden Banks, Gulf of Mexico, for two brooding corals, *Agaricia spp.* and *Porites spp.* Three herbivore treatments and two tile textures and orientations were tested. Herbivore grazing significantly affected coral growth for *Agaricia,* but had no effect on *Porites*. Data suggest that grazing of *Diadema antillarum* and *Cerithium litteratum* negatively affected growth of juvenile *Agaricia* since smaller colonies were observed in herbivore treatments (p=0.0034). *Agaricia* recruits were larger on rough textured tiles (p=0.0054), but tile texture did not affect *Porites* size. Tile orientation preference differed between species, with *Agaricia* having larger and more colonies on vertical tiles (p<0.0001) whereas *Porites* colonies were larger and more numerous on horizontal tiles (p=0.0053). Our findings suggest that recruitment and growth of corals varies considerably between species and that this needs to be considered when developing reef conservation strategies.

**Keywords:** Herbivory*,* coral recruitment, *Diadema antillarum,* phase shifts

## Introduction

Competition for primary space plays a major structuring role on coral reefs (Lang and Chornesky 1990) and phase shifts from coral to algal dominated communities highlight the importance of this competition. Reports of declining reef resilience and phase shifts towards algal dominated communities appear to be increasing at an accelerated rate (Done 1991; McCook et al. 2001; Hughes et al. 2003, 2007; Aronson and Precht 2006). Caribbean reefs have experienced an average of 40% coral loss since the 1970's (Gardner et al. 2003) and exhibit little recovery as recruitment rates decrease. Many factors affect coral recruitment, however algal competition appears to play a significant role in inhibiting recruitment and growth (McCook et al. 2001; Lirman 2001; Jomba and McCook 2002; Birrell et al. 2005; Vermeij 2006).

Grazing has been suggested as a tool to mitigate coral recruitment since herbivore exclusion experiments have demonstrated that reduced grazing causes declines in coral cover (e.g. Lirman 2001) and increasing grazing creates more suitable substrate on which corals can recruit (Omori *et al*. 2006). Caribbean reef communities appear to be highly influenced by the echinoid species, *Diadema antillarum* (Sammarco 1980; Carpenter 1988, Carpenter and Edmunds 2006), which was profoundly demonstrated in 1982 when a natural, species-specific pathogen induced a mass mortality of *D. antillarum* across the entire Caribbean. Mortality rates reaching 99% were observed (Lessios et al. 1984) and reefs were taken over by robust algal species, which caused a decrease in coral recruitment (Hughes et al. 1989). The recovery of *D. antillarum* has been remarkably slow; however, an increase in juvenile coral recruitment has been associated with urchin resurgence in Jamaica suggesting that these herbivores are a keystone species for coral growth (Carpenter and Edmunds 2006).

The Flower Garden Banks National Marine Sanctuary (FGB) (Fig.1) is an ideal area to study coral recruitment and competition, not only for its pristine conditions, but also for its relatively low species diversity (Gittings, 1992), which offers a simpler approach to understanding the ecology of the system. This study investigates how herbivores influence early coral recruitment and growth in the Gulf of Mexico.

Figure 1: Map the Gulf of Mexico showing the location of the Flower Garden Banks National Marine Sanctuary, 115 miles south of the Texas/ Louisiana border.

Recruitment rate variations can have profound repercussions on the management of coral reefs and low coral recruitment rates currently being observed on Caribbean reefs are likely to result in slow reef recovery after natural or anthropogenic disturbances (Hughes et al. 1999). Using herbivorous species to promote recruitment has been suggested as a solution to reduce the long-term decline of coral communities (Hughes et al. 2005; McCook et al. 2001).

**Material and Methods**

*Experimental setup*

A 6m x 6m x 0.6m galvanized steel platform was constructed in June 2007 on a sand patch at 24m depth on the East FGB (27º54'33.0"N, 93º35'59.7"W, Fig.2) to provide a controlled environment to test the effects of herbivores and tile texture and orientation on coral recruitment and growth. Nine fiberglass bins (117cm x 36cm x 25cm), each randomly assigned to one of three treatments (1. *Diadema antillarum*; 2. *Cerithium litteratum*; 3. No herbivore control), were attached. Twelve quarry tiles (15cm x 15cm) were suspended within each bin and served as settlement substrata. Tiles had one smooth side and one grooved side (Smooth, Rough) and two orientations (Vertical, Horizontal) were tested. Herbivore densities within treatments were determined by conducting herbivore censuses of the surrounding reef area and two *Diadema antillarum* and 50 *Cerithium litteratum* per bin were used. All animals were collected at night using SCUBA and retained within bins using 1.3cm$^2$ wire mesh.

Figure 2: Coral recruitment platform constructed on a sand patch on the East Flower Garden Banks at 24m depth.

*Data analysis:*

In April 2008, after nine months of natural recruitment, four tiles from each bin were photographed using a high-resolution digital underwater camera with strobe. All recruits (live and dead) were divided by genus (*Porites, Agaricia*) and total polyp/colony area (mm$^2$) was directly measured in ImageJ 10.2 and compared between herbivore treatments, tile textures and tile orientations. Coral size data were log-transformed to satisfy the assumptions of normality (Shapiro-Wilk) and equal variances for parametric statistical tests. Only main effects are presented here as no significance was observed for interaction terms. All statistics and graphics were performed in JMP 7.0.2.

**Results**

*Herbivore treatment*

Herbivory significantly affected colony size for *Agaricia* (p=0.0034) but not *Porites* (p=0.4445, Fig.3B) (Table 1). *Agaricia* recruits were the smallest in the sea urchin treatment, larger in the mollusk treatment and the control treatment had the largest recruits (Table 2, Fig.3A).

Table 1: Analysis of variance (ANOVA) table indicating variation coral size (mm$^2$) (log-transformed) for *Agaricia spp.* and *Porites spp.*

| Source | DF | F Ratio | P |
|---|---|---|---|
| ***Agaricia spp.*** | | | |
| Treatment | 2 | 15.46 | 0.0034* |
| Orientation | 1 | 42.16 | <.0001* |
| Texture | 1 | 7.82 | 0.0054* |
| ***Porites spp.*** | | | |
| Treatment | 2 | 0.82 | 0.4445 |
| Orientation | 1 | 8.32 | 0.0053* |
| Texture | 1 | 0.42 | 0.8393 |

*Indicates significant difference α=0.05

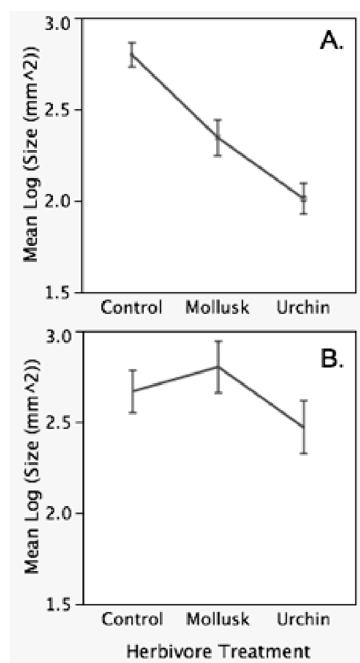


Figure 3: Variations in mean coral size (mm$^2$) between three herbivore treatments. A. *Agaricia spp.* (n=489) B. *Porites spp.* (n=76) Figure represents log-transformed data and standard error bars.

Table 2: Tukey's Studentized Range (HSD) test for significant differences in coral size (mm$^2$) (log-transformed) between different herbivore treatments.

| | Tukey Grouping* | Least Sq Mean | Std Error | n |
|---|---|---|---|---|
| ***Agaricia*** α=0.05 | | | | **489** |
| Control | A | 2.56 | 0.10 | 175 |
| Mollusk | B | 2.03 | 0.11 | 149 |
| Urchin | C | 1.77 | 0.10 | 165 |
| ***Porites*** α=0.05 | | | | **78** |
| Control | A | 2.33 | 0.20 | 29 |
| Mollusk | A | 2.65 | 0.20 | 31 |
| Urchin | A | 2.31 | 0.32 | 18 |

*Levels not connected by the same letter are significantly different

*Tile texture*

Tile texture had a significant effect on coral size for *Agaricia* ($p=0.0054$), however there was no texture effect for *Porites* ($p=0.8393$, Fig.4B) (Table 1). Student's t-tests demonstrated that *Agaricia* recruits on rough surfaces were significantly larger than those growing on smooth surfaces and there were also approximately three times as many recruits on rough surfaces (Table 3, Fig.4A)

Table 3: Student's t-test results for differences in coral size (mm$^2$) (log-transformed) between different tile textures and orientations.

| | Least Sq Mean | Std Error | n |
|---|---|---|---|
| ***Agaricia*** | | | **489** |
| **TEXTURE*** | | | |
| Smooth | 1.97 | 0.10 | 127 |
| Rough | 2.29 | 0.06 | 362 |
| **ORIENTATION*** | | | |
| Horizontal | 1.74 | 0.10 | 131 |
| Vertical | 2.51 | 0.07 | 358 |
| ***Porites*** | | | **78** |
| **TEXTURE** | | | |
| Smooth | 2.46 | 0.28 | 12 |
| Rough | 2.40 | 0.11 | 66 |
| **ORIENTATION*** | | | |
| Horizontal | 2.88 | 0.12 | 63 |
| Vertical | 1.98 | 0.27 | 15 |

*Indicates significant difference α=0.05

*Orientation*

Tile orientation significantly affected colony size for both *Agaricia* ($p<0.0001$) and *Porites* ($p=0.0053$) (Table 1), however, opposite trends were observed. *Agaricia* colonies were larger on vertical tiles and were approximately 2.5 more numerous on vertical tiles (Table 3, Fig.5A). *Porites* colonies were larger and over four times more numerous on horizontal tiles (Table 3, Fig.5B).

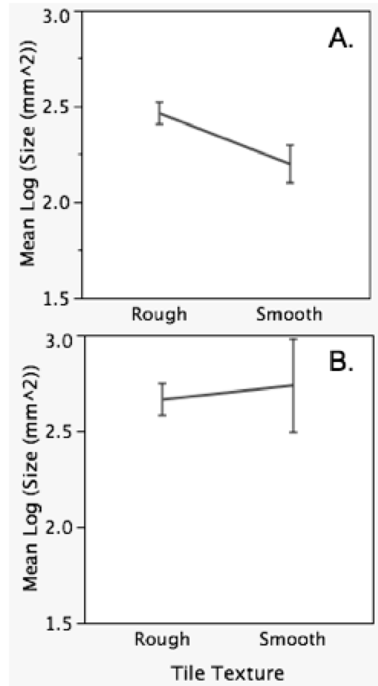


Figure 4: Variations in mean coral size (mm$^2$) between two tile textures. A. *Agaricia spp.* (n=489) B. *Porites spp.* (n=76) Figure represents log-transformed data and standard error bars.

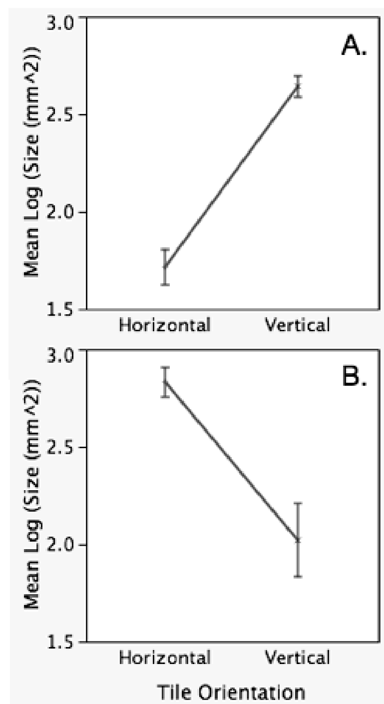


Figure 5: Variations in mean coral size (mm$^2$) between two tile orientations. A. *Agaricia spp.* (n=489) B. *Porites spp.* (n=76) Figure represents log-transformed data and standard error bars.

## Discussion

This study on juvenile coral growth at the FGB demonstrates that herbivore and substratum variations can have significant effects on recruitment and that these effects vary between coral species. Two types of corals were observed to recruit, *Agaricia* and *Porites.* Both corals are brooders, where fertilization occurs within the polyp and released larvae are competent to settle almost immediately (Harrison et al. 1984). It is important to note that although these brooding coral species observed here are common on the FGB, they are not the dominant coral species. Coral cover at the FGB is dominated by other scleractinian corals, which reproduce annually in mass spawning events. The results observed here are representative of only one site in the Gulf of Mexico and caution needs to be taken when comparing these results to other coral species and reefs.

Coral recruitment is variable and larvae actively choose suitable substrate on which to settle. Space pre-emption by other benthic organisms can therefore lead to a decrease in local coral recruitment (Vermeij 2006). Research suggests that corals have inferior competitive capabilities and slower growth rates relative to other benthic organisms such as algae, which have been shown to smother young coral recruits (Miller and Hay 1998; Connell 1997; Edmunds and Carpenter 2001; Vermeij 2006). The top-down control of herbivore grazing on algal growth has been previously demonstrated (Carpenter and Pace 1997; McCook 1999) leading to the general hypothesis that herbivores may reduce competition, thereby increasing coral growth.

In this study we found that urchin grazing negatively affected coral growth for *Agaricia* but had no significant effect on *Porites* (Fig 3AB). Birrell et al. (2005) found that coral recruits almost exclusively preferred to settle on surfaces free from sediment and algae. Although urchin grazing has been correlated with increased coral recruitment (Carpenter and Edmunds 2006), we found that coral colony growth was significantly decreased in the sea urchin treatment, indicating that our experimental sea urchin levels resulted in destructive overgrazing. Destructive overgrazing occurs when echinoid densities are high and algal grazing becomes competitive and abrasive causing a reduction in coral growth (Sammarco 1980). For *Agaricia,* coral recruits were the largest in the control, which was not expected as most herbivore exclusion experiments have shown that when algae are released from grazing pressures, algal growth and coral mortality both increase (Sammarco 1980; Tanner 1995; Lirman 2001; Jomba and McCook 2002; Birrell *et al*. 2005). These unpredicted control results are most likely due to invasive herbivores recruiting to the control bins over the winter months. Several sea urchins were observed to recruit into all experimental bins, however this recruitment is presumed to be equal across all treatments.

Substrate texture has been shown to have a strong effect on juvenile corals. Peterson et al. (2005) found corals demonstrated a strict preference towards grooves in tiles and Harrison and Wallace (1990) indicated settlement and metamorphosis were generally favored in crevices as well. In this study we demonstrated that texture preference might be species specific. *Agaricia* experienced higher growth rates on rough textured tiles while *Porites* showed no significant difference. However, both species had more recruits on rough textured tiles (Table 3) and this is most likely due to the grooves providing sanctuary for corals from overgrazing and overgrowth by other encrusting species.

Research suggests that scleractinian corals show clear preferences for substrate position. Babcock and Mundy (1996) found that coral settlement on the undersurfaces of tiles was much higher, while Vermeij (2006) found higher survival rates on vertical surfaces. In this study we found that the effect of tile orientation on coral growth was highly species specific. *Agaricia* preferred vertical tiles with almost three times as many corals on vertical tiles and significantly larger sizes as well (Fig.5A). *Porites,* however, showed a higher affinity for horizontal tiles with significantly larger individual sizes and over five times as many recruits (Fig.5B). Vermeij (2006) has suggested that variations in orientation preference may stem from differences in growth rates. Faster growing species prefer open, exposed habitats while slower growing species prefer cryptic habitats because the faster growing corals may be more dependent on the symbiotic zooxanthellae in their tissues. During storms sand accumulated on horizontal tiles, which may have affected recruitment.

The distribution and abundance of corals reflect the patterns of successful recruitment and long-term mortality. Coral settlement and growth is not random but dependent on factors such as light, water circulation, sedimentation, competition, predation and grazing (Rogers *et al.* 1984). Monitoring coral growth is important since mortality rates decrease considerably as coral recruits increase in size (Wilson and Harrison 2005). Since recruitment is crucial for coral population maintenance, any disruption in coral reproductive output will eventually lead to long-term declines (Hughes and Tanner 2000; Nozawa *et al.,* 2006). By gaining a more comprehensive understanding of coral recruitment and competition dynamics, research will offer important insights for conservation strategies and management decisions of coral reefs.

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