THE EFFECTS OF OCEAN VERSUS LAND INFLUENCES ON BARRIER REEFS AROUND A CARIBBEAN ISLAND

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Abstract: Coral reef health is rapidly declining worldwide as ocean temperatures increase and negative land influences on these marine systems intensify. It is difficult to observe declines in coral health directly because mortality often occurs immediately after episodic disturbance events. Little Cayman Island offers a special opportunity to evaluate some factors influencing coral health. Overfishing, pollution and sedimentation are minimal or absent, and the geologic structure of the island creates a clear spatial gradient of land vs ocean influences. We predicted that measures of coral health would decrease along a gradient of increasing land influence. We studied three sites across that gradient, sampling each at three scales: 20-m transects for substrate composition (sand vs coral), 1-m^2 quadrats on coral heads for health and diversity of corals, and individual colonies of selected species for more detailed coral health assessment. The gradient of land vs ocean influence strongly affected coral health on all three scales, and the effects differed among species. Coral cover, healthy tissue on coral heads, and species richness were all lower at sites with greater land influence. The effects of land influences on coral health were greater in *Diploria strigosa* and *Siderastrea siderea* than in *Porites porites*.

Key Words: coral reef health, Little Cayman Island, land influences, ocean influences

INTRODUCTION

Coral reef health is declining rapidly worldwide as ocean temperatures increase and terrestrial influences on coastal systems intensify. Many studies have focused on declines of coral reef health after episodic disturbances such as hurricanes (Woodley et al. 1981; Harmelin-Vivien and Laboute 1986), extreme water temperatures (Goreau 1992; Marshall and Baird 2000), outbreaks of coral disease (Bruckner and Bruckner 1997; Porter et al. 2001), and oil spills (Guzman et al. 1994). These disturbances can lead to reef coral mortality rates as high as 90% in one week (Glynn 1990). Some authors have argued that even natural disturbances, which have previously maintained high coral reef diversity via intermediate disturbance, have increased in severity and can now cause irreversible declines in coral reef health (Williams and Bunkley-Williams 1990; Rogers and Miller 2006). Others maintain that these disturbance regimes will lead instead to a shift in coral community structure, as a few species have already shown resilience to extreme episodic disturbances (Wilkinson

1999; Hughes et al. 2003). However, many of these studies are limited, in that they only look at single disturbance events without taking into account how future coral reef degradation may magnify the effects of episodic disturbance.

Few studies have examined the effects of chronic disturbance on coral reefs. These effects, classified here as "land influences," include a suite of factors that have negative impacts on coral growth: nutrient-loading from runoff, increased sedimentation, and higher surface temperatures (Nystrom et al. 2000). "Ocean influences," in contrast, positively affect coral health through upwellings of cooler pelagic water to shallow barrier reefs, which buffers against coral bleaching (West and Salm 2003). Chronic, land-based disturbance can strongly influence the future health of coral reefs (Pastorok and Bilyard 1985, Gates 1990). There is increasing awareness that humans can alter the frequency and intensity of these subtler disturbance regimes (Wilkinson 1999). Global warming amplifies the negative effects of land influences.

The Marine Conservation Law of 1979 established marine parks and other protected areas around Little Cayman Island in an attempt to slow the coral degradation that was apparent around the Caribbean. However, Little Cayman's barrier reefs lost 40% of their coral cover from 1997 to 2005 (Brown et al. 2006) and in 2003 a research group found that there was no difference in coral health between protected and unprotected sites on Little Cayman (Manfrino et al. 2003). The group postulated that coral health was correlated with large-scale ocean (positive) and land (negative) influences rather than localized human impact.

To test this hypothesis, we compared coral health between sites likely to have different levels of land and ocean influence. We predicted that in sites with a greater predominance of ocean influences, there would be higher coral cover, more healthy corals among living colonies, and higher coral species richness. We also predicted that the impact of land influences on coral health would differ among coral species.

METHODS

We studied reefs and corals at three sites on Little Cayman Island, along the island's southern coast, from 3 - 7 March, 2007. Our sites were located on the back barrier reef along Owen Island, South Sound (west of the beach resorts), and in Preston Bay (Fig. 1). Based on our knowledge of reef geology and prevailing currents, we assumed these sites would provide a gradient of ocean and land influences. Preston Bay, the closest to the outer reef wall and farthest from developed areas,

was our least land-influenced site, with a reef exposed to pelagic water. Owen Island lies in a shallow sound with several resorts and docks; we assumed it would have the most land influence and lowest ocean influence. We assumed the South Sound site, which was outside the main sound and was close to the channel leading to the ocean, would be intermediate between the two others. We reasoned that South Sound, being closer to the ocean than Owen Island, would receive a mix of land and ocean influences, while receiving more land-based run-off and higher temperatures than Preston Bay.

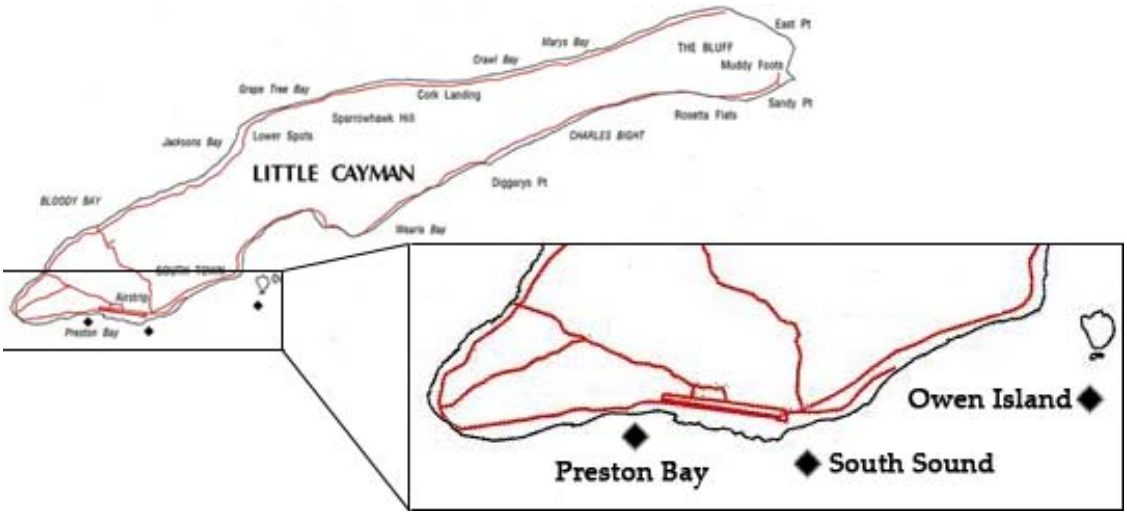

Figure 1: Our three sample sites were on the southern back barrier reef of Little Cayman Island. We expected a gradient of increasing ocean influences and decreasing land influences on the back reef from east to west. Land influences include warm water from the shallows around Owen Island and runoff from resorts around Owen Island and South Sound. Ocean influences include cold, nutrient-poor upwellings from the steep, 1,000-meter wall associated with Little Cayman Island. Preston Bay is closest to the edge of this wall, while South Sound is more removed, and a shallow, warm bay separates Owen Island from the wall.

We sampled at three spatial scales, focusing on four metrics of coral community health - total coral cover, percent live coral, percent healthy coral, and coral species richness. At each site, we first sampled five 20-m transects parallel to the back reef and recorded the substrate type or coral species (single point assessment) at 1 m intervals. If a point fell over coral, we noted species and condition (healthy or unhealthy). We also sampled 40 1 m x 1 m quadrats haphazardly placed on coral heads along the back reef at each site. Within each quadrat, we recorded the percentage cover of healthy coral (normal coloration), unhealthy coral (discolored or bleached), dead coral, and sand, as well as the species of stony and fire corals encountered.

To assess coral health at the species level, we took measurements of individual colonies of the three most abundant stony coral species in our sites: massive starlet coral (*Siderastrea siderea*), symmetrical brain coral (*Diploria strigosa*), and finger coral (*Porites porites*). We sampled 10 colonies of each species per site, using colonies that fell within our quadrats and haphazardly selecting additional colonies as needed. We calculated surface area by noting the geometric shape that most accurately matched the colony (sphere, hemisphere, cube or cylinder) and taking diameter, length, width, and height as needed. We reported the health of each colony using six descriptive categories: healthy, bare coral skeleton (BCS), BCS with low algal turf, BCS with dense algae, discolored, and bleached.

Statistical analysis: In back reef transects, we compared the percent sand and percent coral (alive and dead combined) between sites using a chi-squared test. To test for difference in percent healthy coral and percent dead coral among the three sites in our coral head quadrats, we used ANOVA tests. We compared species richness among sites using an ANOVA and then a Tukey-Kramer HSD test (alpha = 0.05).

RESULTS

Along 20-m transects, Owen Island had significantly more sand and less coral cover (live and dead combined) than South Sound or Preston Bay ($X^2_{df=2,297}$ = 16.752, P=.0002, Fig. 2). Furthermore, we found that the percent of dead coral per quadrat declined from Owen Island to South Sound to Preston Bay (ANOVA, $F_{df = 2,117}$ = 31.97, P = 0.001; Fig. 4), while the percent of healthy coral increased across the same sites (ANOVA, $F_{df = 2,117}$ = 31.97, P = 0.001; Fig. 4).

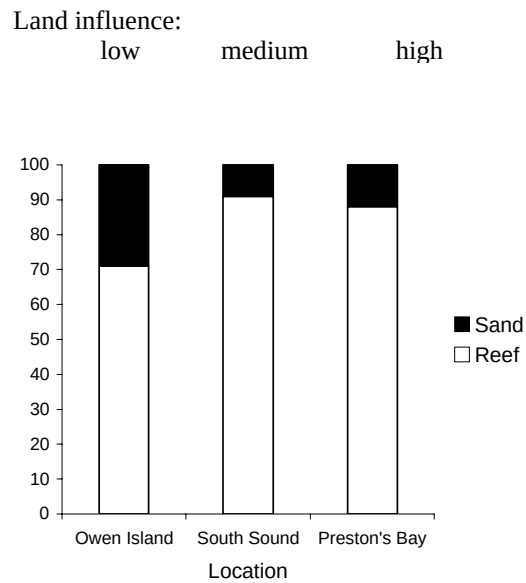

Figure 2: Mean percent cover of sand and coral (live or dead) on five 20-meter transects at three sites along a gradient of land vs ocean influences (gradient from left to right in the figure; see Fig. 1 for details) on Little Cayman Island. South Sound and Preston Bay had significantly more coral cover than Owen Island, but South Sound was not significantly different from Preston Bay.

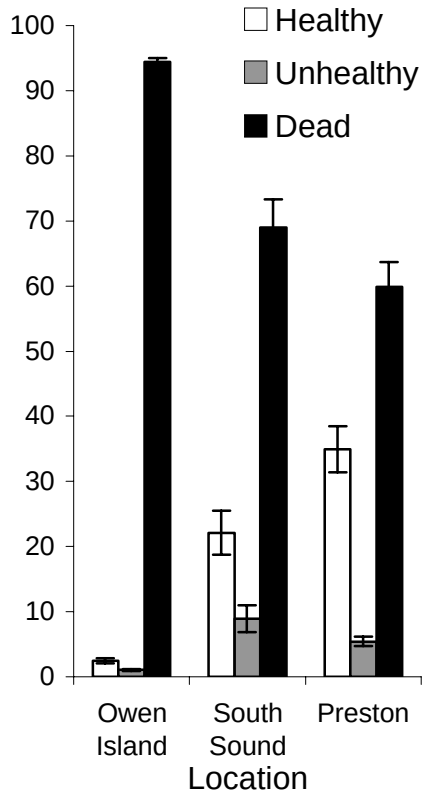

Figure 4: Coral health along a gradient of land vs ocean influence (gradient from left to right in figure; see Fig. 1 for details), on Little Cayman Island. Living coral was classified as unhealthy if it was discolored or bleached. Healthy coral tissue cover increased significantly along this gradient, while percent dead coral decreased. n = 40 quadrats sampled for each site.

In our coral head quadrats, Preston Bay had significantly higher coral species richness per quadrat (3.55 ± 0.24271, mean ± 1 SE), than both South Sound (1.575 ± 0.14272), and Owen Island (1.425 ± 0.10674), but there was no significant difference between South Sound and Owen Island.

Our individual colony samples indicated that the health and abundance of *Siderastrea* and *Diploria* colonies changed with the land-ocean gradient, while *Porites* did not.

For *Siderastrea*, we found the highest percentage of healthy tissue in Preston Bay (67% ± 5.4; ANOVA, $F_{df=2,27}$=17.02, P <0.0001), the highest percentage of unhealthy tissue in South sound (20% ± 3.61; ANOVA, $F_{df=2,27}$=2.32, P =0.12), and the highest percentage of dead tissue in Owen Island (76% ± 8.43 ANOVA, $F_{df=2,27}$=16.90, P <0.001) (Fig. 5). In coral head quadrats, *Siderastrea* was most abundant at South Sound (Fig. 3).

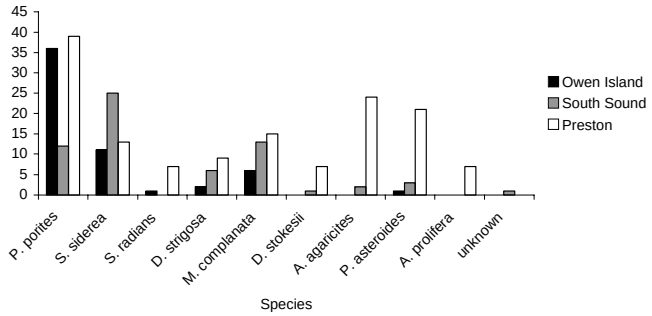

Figure 3: Abundance of ten species of coral in 40 quadrats (each 1 m x 1 m) on three sites over a gradient of land vs ocean influences (gradient from top to bottom in key; see Fig. 1 for details), on Little Cayman Island. For six species, abundance increased along this gradient. *P. porites* and *S. siderea* were the most abundant species across the three sites.

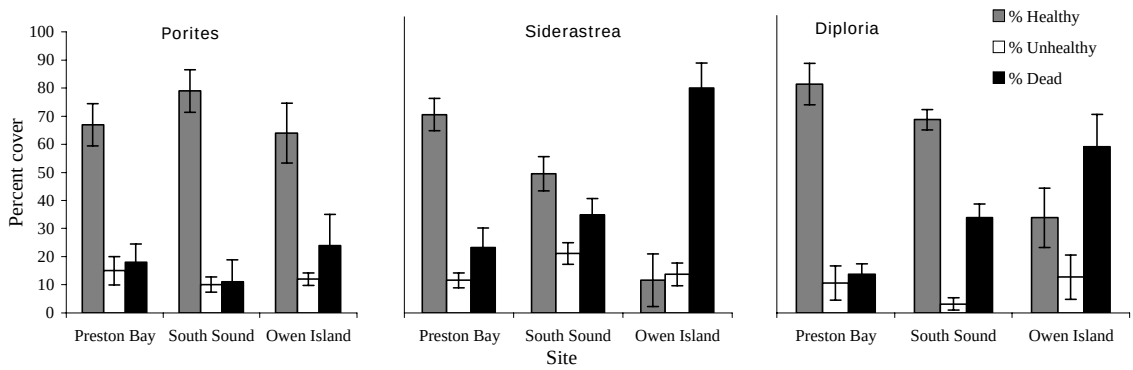

Figure 5. Health of individual coral colonies (percent healthy, unhealthy and dead tissue – 1 S.E.), for the three most abundant species across a gradient of land vs ocean influences (left to right in figure; see Fig. 1 for details) on the barrier reefs of Little Cayman Island. n = 10 colonies for each species for each site. *Porites* health did not differ significantly among sites, while *Siderastrea* and *Diploria* colonies were healthier at Preston Bay.

For *Diploria*, we found the highest percentage of healthy tissue in Preston Bay (77% ± 8.66; ANOVA, $F_{df=2,30}$=8.49, P =0.0012) and the highest percentage of both unhealthy (12 ± 7.46; ANOVA, $F_{df=2,30}$ =0.61, P =0.55) and dead tissue in South Sound (56 ±10.86; ANOVA, $F_{df=2,30}$=8.56, P =0.001) (Fig. 5). In coral head quadrats, *Diploria* was most abundant at Preston Bay (Fig. 3).

For *Porites*, we found no difference among sites for healthy tissue (ANOVA, $F_{df=2,27}$=0.78, P =0.47), unhealthy tissue (ANOVA, $F_{df=2,27}$=0.32, P =0.73), or dead tissue (ANOVA, $F_{df=2,27}$=.60, P =0.56), indicating that the health of this species is less responsive to land and ocean influences (Fig. 5). In coral head quadrats, *Porites* was most abundant at Preston Bay (Fig. 3).

DISCUSSION

Total coral cover, percent live coral, percent healthy coral, and coral species richness – our four metrics of coral community health – were all higher at Preston Bay, the site with the least land influence. These findings are consistent with the hypothesis that coral reefs are healthier at sites where ocean influences are greater than land influences.

Along broad-scale transects, there was significantly more sand and significantly less total coral cover (alive and dead combined) at Owen Island than at either South Sound or Preston Bay. Coral skeletons, whether live or dead, provide the structural living space for many other reef organisms (Clark and Edwards 1999); therefore, total

coral coverage is a measure of the quality of a reef as habitat to other organisms. Live coral has more structural integrity than dead coral, as evidenced by the destruction caused by storms on reefs that experienced previous coral mortality (Manfrino et al. 2003). Therefore, reefs containing more live coral should provide habitat that is superior to reefs with less live coral. As we predicted, Owen Island had significantly less live coral than either South Sound or Preston Bay, although there was no significant difference in percent live coral between South Sound and Preston Bay. Finally, the health of existing live coral can be an indicator of the future health of a reef, allowing for projections of structural and habitat quality on the reef (Manfrino et al. 2003). Preston Bay had the most healthy coral, followed by South Sound, with Owen Island having the least.

Preston Bay's reef supported more coral species than South Sound and Owen Island, upholding our predictions. Coral diversity is critical to the maintenance of suitable habitat for the rest of the reef community; thus, factors affecting coral diversity have indirect effects on the diversity of the entire reef (Connell et al. 1997). Coral species differ in their tolerance to adverse environmental conditions (Meesters et al. 1997). *P. porites* appears to be a resilient species. It was the most frequently encountered species at two of the three sites and had the most healthy coral across all three sites (Fig. 5). *S. siderea* and *D. strigosa* were somewhat less prevalent and less healthy overall than *P. porites*, and *A. palmata* was entirely absent from all sites but Preston Bay, where land-based influences are least.

Based on previous studies of coral reef degradation (Wilkinson 1999) and the logic of our predictions, we expect that monitoring land influences such as pollution, suspended sediment, salinity, temperature, and pH would reveal correlations between these variables and coral health at Little Cayman Island. Future studies of the aquatic abiotic conditions at Little Cayman would be especially valuable given the recent establishment of a long-term coral monitoring program along the island's northern coast (*personal communication, Carrie Manfrino LCRC*), under the direction of the Little Cayman Research Center. In conjunction with seawater data, such knowledge of the temporal change in coral health could reveal important connections between oceanic conditions and the status of the reef. Taken as a whole, such a program would contribute immensely to our understanding of the relative importance of land and ocean influences, a modified ocean environment, and global climate change for coral reef health.

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