

**Factors Affecting the Distribution and Health of the
Intertidal Coral *Goniastrea aspera* on the Reef Flat in
Geoffrey Bay, Magnetic Island**



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Abstract

The intertidal zone can be a harsh environment, presenting many challenges to the organisms inhabiting it. Given its dynamic nature, it is surprising that it is sometimes able to sustain systems as delicate and sensitive as coral reefs. Many organisms have adapted to life on the intertidal reef flat, and one of the most prominent on the northeastern coast of Australia is the massive coral *Goniastrea aspera*. The mechanisms driving the distribution of this species are not entirely understood; this study investigated the potential role of microhabitat, as well as that of actual physical characteristics of the colonies, in the distribution of *G. aspera* on a distinctly zoned intertidal reef flat on Magnetic Island.

General distribution was determined using transects, and data was collected about the distance from shore, size, morphology, substrate attachment, and health of each individual colony. Quadrats were used to estimate the percent cover of different substrate types within the individual microhabitat. *G. aspera* was found to occur in highest densities in the coral-rubble zone, with an apparent preference for certain substrate types; however, selection of these microhabitats did not have a significant effect on the health of the colonies. Zone was found to influence the amount of bleaching in individuals, while distance from shore was the most important factor influencing substrate attachment, and in turn, substrate attachment had the most influence on the percentage of living coral tissue in each individual colony. The distribution and health of the colonies was found to be influenced by many different factors of both the environment and the coral itself. Microhabitat and competition are hypothesized to play key roles in density and health of *G. aspera* on the reef flat, with physical characteristics also having an influence, but further research into these interactions is needed to verify the exact role each one plays.

Keywords: intertidal, zonation, coral, *Goniastrea*, Magnetic Island

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Introduction

The intertidal zone is often referred to as the meeting place of the land and the sea, a unique environment that possesses components of both marine and terrestrial ecosystems. Life in the intertidal is both dictated by and dependent upon the tides, and the organisms that dwell there have developed amazing adaptations to deal with the stresses of living in such a dynamic, ever-changing environment. Survival in the intertidal means coping with a wide array of challenges, including extreme temperature variation, drying winds and desiccation, and flooding by freshwater after heavy rains (Bennett 1974). Depending on vertical distribution and tidal regime, some organisms in the intertidal may be only occasionally exposed to the air for short periods of time, while others may withstand up to 12 hours of exposure daily (Bennett 1974). Tidal levels are considered to be critical factors determining the vertical distribution of marine organisms (Carefoot 1985). In fact, studies have shown that there are certain tidal heights, often referred to as 'critical tidal levels', that mark the upper and lower distribution boundaries for different intertidal species, and between these various critical levels, different groups of species or sub-communities exist because they have similarly adapted to a regime of emersion and submersion (Underwood 1978). Beyond the seaward boundary of the critical tidal levels, one moves out of the intertidal and into an entirely marine environment whose composition is dependent upon the latitude, geology, and environmental conditions of the location. In tropical locations, one marine system that commonly follows, and occasionally merges with, the intertidal is that of the coral reef.

Coral reefs are among the most diverse ecosystems in the world, but they are also among the most environmentally sensitive (Nanette et al. 2000). Coral reefs have very specific set environmental requirements for survival, and only a narrow range of tolerance for deviations in these conditions. All coral reefs require ample sunlight, a

specific range of warm water temperatures, full marine salinity (over 20 parts per thousand), relatively sediment-free water, and a hard, stable bottom for substrate attachment (Lieske et al. 1994). In addition to being vulnerable to slight changes in environmental conditions, reefs are also susceptible to damage from fishing, sedimentation, invasive species, predator outbreaks, endemic disease, coastal development, waste disposal, anchor damage, and trampling in shallow areas (Nanette et al. 2000). Given all of the above environmental requirements and vulnerabilities, it is not surprising that the distribution of reefs worldwide is fairly limited; however, what is surprising is that in some places, these delicate ecosystems have managed to adapt to life in the intertidal.

Most reefs with an intertidal component are nearshore fringing reefs that can be divided into three distinct regions: the reef slope, which exists on the most seaward edge of the reef; followed by the reef crest, where live coral cover is the highest; and finally the reef flat, a shallow area at the back of the reef that extends shoreward on a very gradual gradient (Bennett 1974, Mapstone et al. 1992). The shallowest parts of the reef—the reef flat and occasionally the reef crest—are the areas of the reef that exist within the bounds of the intertidal zone. Although not considered intertidal in the sense of regularly exposed temperate shores, shallow reef flats are often referred to as ‘semi-tidal’ environments and may have many of the same features as rocky shore intertidal communities, but are only exposed during the largest spring tidal range (Brown et al. 2002a). Extreme low tide, which maximizes the stresses of desiccation and overheating, as well as maximum isolation, which inhibits settlement of new recruits, are the main limiting factors to coral growth in the intertidal (Ditler 1978). Extreme water temperature and light have also been proven to overstress corals, and there have been numerous documented cases of coral bleaching caused by high irradiance from the sun, a phenomenon commonly known as ‘solar bleaching’

(Ditler 1978, Brown et al. 2002*b*). The responses of corals to these physical rigors generally result in a reduction of diversity on intertidal reefs (Brown et al. 2002*a*). Nevertheless, a number of species of coral have managed to adapt to life in the intertidal, somehow coping with the added stresses of exposure, desiccation, and great variations in temperature and salinity, all in an environment that by any definition would be less-than-ideal for coral growth (Bennett 1974).

Corals that do grow on the reef flat are not randomly distributed; the zonation of coral assemblages on reefs is one of the systems' most prominent features, and almost every intertidal reef exhibits some kind of physical or biological zonation pattern (Baird et al. 2003). This zonation has been attributed to many different factors, including light, water movement, and competition (Baird et al. 2003), but the most commonly cited factors influencing coral density patterns on the reef flat are emersion and sedimentation, with corals on the shoreward, inner reef flat possessing a greater tolerance of both factors (Morrissey 1980). In fact, some studies have suggested that emersion alone determines the absolute vertical upper limit of coral distribution; however, horizontal distribution across the reef flat remains affected by many physical and biological factors, whose specific interactions are not yet entirely understood (Morrissey 1980). In terms of shallow intertidal reefs, the species composition of reef flats tend to be dominated by massive corals, most often of the families Faviidae and Poritidae, which are physiologically and morphologically well adapted to desiccation and stress from light intensity (Brown et al. 2002*a*). Massive coral species tend to be the most able to physically adapt to life in the intertidal, and many are actually found in greater densities on the intertidal reef flats than they are on the reef crests—where the highest density of almost every other coral occurs (Brown et al. 2002*a*).

Among the suite of massive intertidal corals, the Indo-Pacific coral *Goniastrea aspera* (family Faviidae) is one of the most common species on most intertidal reef flats along the seashores of far northeastern Australia (Brown et al. 2002b). *G. aspera* tends to form scattered communities rather than expansive, continuous reefs and is characteristic of nearshore fringing reefs and rocky shores (Babcock 1983). The rounded colonies grow in either massive or encrusting morphology, with a tendency toward massive growth, and produce relatively large corallites (Vernon et al. 1997, Nanette et al. 2000). Individual colonies of *G. aspera* display high fecundity and have relatively long life spans, with reproduction taking place between 5-15 years of age (Babcock 1991). The corals are broadcast spawners, producing small, buoyant eggs that have a minimum planktonic period of 2-4 days, usually resulting in the widespread dispersal of larvae away from the original parent colony (Baird et al. 2003, Babcock 1983). *G. aspera* is most common in shallow, turbid water—found normally between 0-3 meters depth—and is almost always restricted in distribution to the reef flat (Bull 1997, Babcock 1983), able to withstand up to several hours of emersion daily (Vernon et al. 1977).

A previous study by Babcock (1983), conducted on the reproductive strategies of *Goniastrea aspera*, found that the distribution of individual colonies on the reef flat could not be explained by the coral's reproductive behavior. He suggested that variability in microhabitat might be more important than reproductive behavior in determining adult distribution patterns of *G. aspera*. Microhabitat has been shown to be incredibly important for niche separation in many systems, and the diversity of a habitat can often be a function of the heterogeneity of the microhabitats it supports (Crowe 1998). Another study of *G. aspera* (Baird et al. 2003) proved that larvae settle at four times greater densities in shallow waters, suggesting that even as early as in the larval stage, *G. aspera* may be deliberately selecting certain microhabitats and

settlement sites from cues during dispersal or at settlement, as opposed to carrying out non-directional, random colonization attempts in any available habitats. However, the influence of microhabitat on the distribution and health of adult *G. aspera* colonies—measured as a factor both of percent bleaching and percent living coral tissue in each colony—has never been directly studied.

This study aims to determine the role of microhabitat, as well as the role of physical attributes—including size, morphology, distance from shore, and substrate attachment—in the distribution and health of *Goniastrea aspera* on an intertidal reef flat. By observing the characteristics and habitats of individual colonies, this study hopes to shed light on some of the larger-scale mechanisms possibly influencing the distribution of *G. aspera* in these unique environments.

Methodology

Study Site

Magnetic Island (19°9'S, 146°50'E) is a large granitic island approximately 8km offshore of Townsville in Northern Queensland, Australia. The island is situated in the shallow waters of Cleveland Bay and is home to numerous small bays, many of which support not only diverse intertidal communities, but also near shore fringing coral reefs (Figure 1). This study was conducted in Geoffrey Bay, one of the larger bays and home to one of the more expansive fringing reefs on the island. The bay itself is approximately 1.5km long, and the reef flat extends anywhere from 120-150m from shore. The reef in Geoffrey Bay has developed through the accumulation of non-biogenic sediment from the surrounding environment, which over time has provided foundation for substrate attachment of numerous corals and algae (Mapstone et al. 1992). This bay also contains the most extensive and accessible intertidal reef flat, formed from the same sediments accumulated under the coral-dominated fringing reef crest. The reef flat can generally be defined as a 'semi-tidal' habitat (Brown et al. 2002a), completely exposed during spring low tides but not at all during neap tides.

Refer to: *ISP_ASE_SP06_Jsmith_MagneticIslandMap.doc*

Figure 1: *Map of the immediate Townsville area, including Cleveland Bay and Magnetic Island*

Environmental Influences

Magnetic Island experiences diurnal tidal fluctuations, with the spring tides ranging from 0.8m-2.5m (mean sea level: 1.59m) (Morrissey 1980). There is also a suggested hydrodynamic link between the northwest corner of Geoffrey Bay and the adjacent northeast corner of Nelly Bay, in the form of a tidal eddy sweeping north around Brighton Point, the rocky outcropping that physically separates the two bays (Mapstone et al. 1980). The end of Nelly Bay adjacent to Geoffrey Bay is home to a large ferry terminal—the major transportation from Townsville—and construction of this port involved the dredging of channels in the surrounding shallow waters. Sediments resuspended by the dredging and any sediment that is continually stirred up by the daily passages of the ferry may be carried via the tidal eddy into the northwest end of Geoffrey Bay, possibly decreasing water clarity and increasing sedimentation rates (Mapstone et al. 1980).

The most dominant wind pattern in northeastern Australia is the southeast trade winds (Mapstone et al. 1980). Due to the south-southeast aspect of Geoffrey Bay and a fetch of approximately 100km from the east (Bull 1977), it is almost completely exposed to the prevailing southeasterly and the turbid swells that these winds create in the surrounding waters (Babcock 1983). Due to the orientation of the reef, the swell front is often parallel to the reef edge, creating fairly rough water conditions across the reef that can stir up a lot of sediment from the surrounding shallow waters. Because of this, organisms on the reef in Geoffrey Bay, as well as in other bays around Magnetic Island, have adapted to withstand at least short periods of high sediment movement; however, they don't necessarily need to endure extended periods of sedimentation because the same turbid water that brings in the suspended particles also prevents them from settling (Mapstone et al. 1980).

Zonation

The intertidal reef flat of Geoffrey Bay can be divided into three distinct zones based on substrate type: mudflat, rubble, and coral rubble. These zones have been shown to be related to a number of environmental factors, including strength of water movement, substrate nature and type, sediments and sedimentation, and exposure by tides and the resulting variations in temperature and salinity (Babcock 1983). The mudflat zone is characterized mostly by sand and seagrass, with some sparse patches of rubble. The rubble zone is overwhelmingly composed of rubble, with macroalgae and sand the only other obvious substrate types. The coral rubble zone is dominated by *Sargassum* spp. and other algae, in addition to patches of rubble, with stands of live coral and individual massive coral colonies (Babcock 1983, S. Jennings, unpubl.). During preliminary studies, the study species *Goniastrea aspera* was found to be completely absent from the mudflat zone, and this was confirmed by a previous study of the coral, which showed it to be unable to survive in this zone due to the accumulations of fine, sandy sediment (Babcock 1983).

The mudflat zone is narrowest in the northwestern end of the bay, an area also known to have significantly greater hard coral cover compared to the other end of the bay, which is dominated mainly by algae (Mapstone et al. 1992). Because the only zones that were to be surveyed for this study were the rubble and coral rubble, the northwest end of the bay, where these two zones dominate the intertidal, was chosen as the study site. A section of shore was measured 100m from the rocky end of the beach, and from that point, a transect was laid stretching from the shore 125m out to the reef crest. These two boundaries defined the study area as well as the distances of the zones from shore. As previously mentioned, the mudflat zone in the study area was almost non-existent, extending only 5-10m from shore, while the rubble zone

reached from 10-75m,, and the coral rubble zone existed between 75-125m, where it then merged with the reef crest (Figure 2).

Refer to *ISP_ASE_SP06_Jsmith_GeoffreyBayMap.doc*

Figure 2: *The northwestern end of Geoffrey Bay, showing the zones of the intertidal and the study area*

Data Collection

Three types of data were collected for this study: general distribution, physical parameters and characteristics, and microhabitat description. To get a picture of the overall distribution of the coral, transects of measuring tape were laid perpendicular to shore, ranging anywhere from 120-125m in length, depending on the distance from shore of the reef crest. As one walked along the transect from shore, every *Goniastrea aspera* colony within 0.5m on either side of the transect, regardless of size or morphology, was counted. A total of eight transects were performed, resulting in a survey of a combined 867 corals distributed over the reef flat.

For the physical characteristics, similar transects were used in attempt to ensure random sampling, but an entire transect was not completed every day. For every coral along the transect, the zone it was found in (rubble or coral rubble), the distance from shore (measured from the start of the mudflat zone—the beginning of the intertidal) and the size (measured by circumference) were noted, along with morphology (massive or encrusting) and if it was attached to the bottom substrate (if it could be picked up [unattached] or not [attached]). The general state of health of the coral was measured by estimating the percent living, percent dead, and percent bleached of each individual colony.

To obtain microhabitat data, one-meter-squared quadrats were laid down around each coral measured along the transect. Within the quadrat, the percent composition of all the different substrate types was estimated and grouped into general categories, such as rubble, sand, and seagrass. For the algae species, numerous previous studies had shown that *Sargassum* spp. is by far the most dominant algae on the reef flat of Geoffrey Bay, and consequently plays a large ecological role in the functioning of the intertidal, especially in the rubble and coral rubble zone (Morrissey 1980). For this reason, *Sargassum* spp. was separated out from the general “algae” category and recorded as its own substrate type. All other algae species were recorded as “other algae”. Coral species were identified by morphological type, and by family and genus where applicable. A total of 200 *Goniastrea aspera* individuals were measured and recorded, along with their microhabitat, in the 1450m² area of reef flat (not representative of density) between the dates of 15-30 April 2006.

Data Analysis

Data was analysed first in Microsoft Excel, and later in SPSS. The substrate types for microhabitat were divided into the following categories: rubble, sand,

Sargassum spp. algae, other algae, other *Goniastrea aspera*, *Porites* spp., and short branching corals. All other substrate types (sponge, seagrass, *Acropora* spp., *Montipora* spp., other Faviidae, soft coral, encrusting coral, and anemone) were fairly uncommon, so they were placed in a general substrate category of “other” for analysis. For one specific analysis that focused only on the corals, a new substrate category was created named “other corals”, which included any corals found in the habitat that were not *Goniastrea aspera* (*Porites* spp., *Acropora* spp., *Montipora* spp., other Faviidae, short branching coral, soft coral, and encrusting coral). For all other tests, the eight general categories originally mentioned were used for analysis.

In order to test the potential microhabitat preference by *Goniastrea aspera*, data from another study—one conducted concurrently with this one—was analysed. Jennings (2006) conducted a study in the northwestern half of Geoffrey Bay mapping the different zones in the intertidal. She used 25m line-intercept transects, taking data every 0.5m and performing 15 transects in each of the three zones. I used her data from the rubble and coral rubble zones to generate a picture of the “overall habitat” of these zones. I placed her substrate data into the categories defined above and calculated average percent cover for each of her 30 transects, 15 from the rubble zone and 15 from the coral rubble zone. I then compared her average percents, which from this point on will be referred to as the ‘overall habitat’, to the average percent of the substrate cover for *Goniastrea aspera* habitat.

Numerous comparisons between the variables of physical characteristics were performed as well, separating the original data either by zone, substrate attachment, or morphology. Statistical tests done in SPSS included Univariate and Multivariate ANOVA ($p_{crit}=0.05$) and Linear Regressions. Microsoft Excel was used to generate the graphs as well as the standard error (S.E.) values.

Results

The density of *Goniastrea aspera* on the reef flat increased with distance from shore, peaking at approximately 100-115m from shore (Figure 3). The individual coral colonies were not found in the mudflat zone (0-15m), but were found in both rubble (15-75m) and coral rubble (75-125m) zones, with the highest density existing in the coral rubble zone.

Refer to: *Figure3-Density in ISP_ASE_SP06_Jsmith_Figures.exe*

Figure 3: *Density of Goniastrea aspera* (n=867) on the reef flat in Geoffrey Bay, Magnetic Island

The average percent of each individual *Goniastrea aspera* colony bleaching was significantly higher in the rubble zone than in the coral rubble zone (average percent bleaching in the rubble zone was 1.49%, whereas it was only 0.30% in the coral rubble zone; $p < 0.05$, Figure 4).

Refer to: *Figure 4-Bleaching by Zone in ISP_ASE_SP06_Jsmith_Figures.exe*

Figure 4: Average percent of individual *Goniastrea aspera* colonies bleaching (+ S.E.) as a factor of zone. *G. aspera* colonies in the rubble zone (n=69) experienced significantly more bleaching than those in the coral rubble zone (n=131, ANOVA, $p < 0.05$)

The overall habitat of the intertidal rubble and coral rubble zones differed significantly from the microhabitat in which *Goniastrea aspera* was found in those zones (Figure 5). *G. aspera* occurred in parts of the zones that contained a significantly higher percentage of rubble (39.63% in overall habitat as opposed to 55.03% in *G. aspera* habitat; $p < 0.05$) and a significantly lower percentage of *Sargassum* spp. (24.87% in overall habitat; 14.15% in *G. aspera* habitat; $p < 0.05$) and other algae (17.20% in overall habitat; 8.71% in *G. aspera* habitat; $p < 0.05$).

Refer to: *Figure 5-Habitat Comparison* in *ISP_ASE_SP06_Jsmith_Figures.exe*

Figure 5: Comparison of the microhabitat of *Goniastrea aspera* (average % cover + S.E.; n=200) with that of the overall habitat of the rubble and coral rubble zones (average % cover + S.E.; n=30) on the reef flat in Geoffrey Bay, Magnetic Island. *G. aspera* existed in microhabitats with significantly more rubble and less *Sargassum* spp. and other algae (ANOVA, p<0.05)

Even though the corals seemed to prefer specific microhabitats within the different zones, there was no significant correlation of percent cover of rubble, *Sargassum* spp., or other algae to the actual percent of living coral in the colonies or the incidence of bleaching among individuals (all p>0.05, Table 1).

Table 1: Statistical results for the correlation of significant microhabitats to the percent living and bleaching of *Goniastrea aspera* colonies on the reef flat in Geoffrey Bay, Magnetic Island

Regression Test	R² Value	P-Value
Rubble Cover vs. % Living	0.0002	>0.05
Rubble Cover vs. % Bleached	0.0012	>0.05
<i>Sargassum</i> spp. Cover vs. % Living	0.0132	>0.05
<i>Sargassum</i> spp. Cover vs. % Bleached	0.0003	>0.05
Other Algae Cover vs. % Living	0.0127	>0.05
Other Algae Cover vs. % Bleached	0.0157	>0.05

In the coral rubble zone, the average percent cover of other corals in *Goniastrea aspera* habitat was significantly less compared to the overall habitat of the intertidal zones (6.8% in the overall habitat compared to 3.24% in *G. aspera* habitat; $p < 0.05$), even though the percent cover of other *G. aspera* individuals was not significantly different between the two ($p > 0.05$, Figure 6). However, a lower percent cover of other corals in the microhabitat did not correlate with increased health of the individual colonies ($R^2 = 0.001$; $p > 0.05$).

Refer to: *Figure 6-Coral Habitat* in *ISP_ASE_SP06_Jsmith_Figures.exe*

Figure 6: Comparison of the presence of *Goniastrea aspera* (ANOVA, $p > 0.05$) and other corals (ANOVA, $p < 0.05$) in both *G. aspera* microhabitat (average % cover + S.E.; $n = 131$) and the overall habitat of the zone (average % cover + S.E.; $n = 15$) in the coral rubble zone on the reef flat in Geoffrey Bay, Magnetic Island

There were also significant differences in the distribution and health of *Goniastrea aspera* colonies based on physical characteristics. The average distance from shore of attached *Goniastrea aspera* colonies was significantly greater than that of unattached colonies (average distance of attached colonies was 81.61m, whereas average distance of unattached colonies was 63.35m; $p < 0.05$, Figure 7). However, average distance from shore did not differ significantly between massive and encrusting colonies ($p > 0.05$).

Refer to: *Figure 7-Distance From Shore* in *ISP_ASE_SP06_Jsmith_Figures.exe*

Figure 7: Average distance from shore (+ S.E.) of different morphologies of *Goniastrea aspera* colonies on the reef flat in Geoffrey Bay, Magnetic Island. Both massive attached (n=116) and encrusting attached (n=41) colonies grew significantly farther from shore than massive unattached (n=15) and encrusting unattached (n=28) colonies (ANOVA, $p < 0.05$)

The average percentage of living coral tissue in attached colonies was significantly greater than that of unattached colonies (average percent living of attached colonies was 84.77%, compared to 61.21% for unattached colonies; $p < 0.05$); however, there was no significant difference in average health between the two different morphologies ($p > 0.05$) (Figure 8).

Refer to: *Figure 8-Percent Living* in *ISP_ASE_SP06_Jsmith_Figures.exe*

Figure 8: Average percentage of living coral tissue (+ S.E.) on *Goniastrea aspera* colonies on the reef flat in Geoffrey Bay, Magnetic Island. The average percent living of massive (n=116) and encrusting (n=41) attached colonies was significantly greater than that of massive (n=15) and encrusting (n=28) unattached colonies (ANOVA, $p < 0.05$).

Discussion

From the results of this study, it is obvious that there is no one, single factor determining the distribution of *Goniastrea aspera* on the reef flat; rather, there are a number of important factors that all seem to play a role in influencing the density, as well as the physical characteristics and health, of the colonies. The overall density distribution of the coral over the reef flat in Geoffrey Bay coincides with what one would expect to find given the environmental conditions. Studies have shown that effects of physical stresses are much greater on the inner parts reef flats (shoreward) than they are on outer reef flats (Brown et al. 2002a). Although Faviidae corals such as *G. aspera* have the capacity to occupy a maximum diversity of biotypes (Vernon et al. 1977), the conditions become too harsh and the substrate becomes too inadequate closer to shore, causing the density of *G. aspera* to decrease with decreasing distance from shore. In addition, research on the reef flat of Geoffrey Bay has indicated that water movement decreases and sedimentation increases as one moves from the crest to the flat (Babcock 1983, Morrissey 1980), which would tend to decrease larval recruitment and limit growth in areas farther from the reef crest.

The increased incidence of bleaching in *Goniastrea aspera* colonies in the rubble zone, compared with lower incidence in the coral rubble zone, provides an interesting insight into which environmental factors may actually be influencing disease in the corals, as well as indirectly determining the distribution patterns by stressing corals in certain zones more than others. Because the rubble zone is closer to shore, more often exposed and for longer periods of time, increased levels of solar irradiation may be a possible cause for the increased occurrence of bleaching in this zone, meaning that the bleaching observed may be classified as ‘solar bleaching’ (Brown et al. 1994). However, past studies of bleaching in *G. aspera* have shown that colonies that are subjected to higher levels of UV radiation throughout the year

became acclimated to those increased levels, and the corals in these conditions actually became more resistant to bleaching (Nanette et al. 2000). So while sun exposure may be one factor affecting bleaching patterns, it is likely that it is acting in conjunction with other environmental stresses, such as heating and desiccation, which have also been previously cited as causes of bleaching in corals (Brown et al. 1994). The stresses of these conditions may be restricting adult coral growth and preventing any larvae that may settle in the area from developing further, therefore causing the patterns observed in the density of *G. aspera* on the reef flat in Geoffrey Bay.

Microhabitat proved to be at least partially responsible for distribution, with the habitat of *Goniastrea aspera* being significantly different in more than one way compared to the overall habitat of the zones. The differences in microhabitat suggest that *G. aspera* is selecting sites of higher rubble and lower algae cover for growth. One possible explanation for this trend involves the competition between coral and algae. Competition between hard corals and benthic algae is one of the most important ecological interactions in determining the structure of a coral reef (McCook 2001). Corals compete with algae for both space and light, and in instances of decreased herbivory or increased nutrient levels, it is not uncommon for a reef once dominated by scleractinian corals to become dominated by macroalgae (McCook 2001). Macroalgae not only takes valuable substrate area from the coral, but increased presence of macroalgae may shade corals. Both of these strategies could be classified as overgrowth, which has proven to be one of the most widespread mechanisms of competition on reefs (Underwood 2006, McCook 2001).

Even in instances where algae are not directly inhibiting the growth of coral, they may still be damaging the population by acting as recruitment inhibitors, preventing new corals from settling (McCook 2001). Considering the established competitive interactions between corals and algae, it appears that *G. aspera* on the

reef flat in Geoffrey Bay is either out competed for space and light in areas of higher algae cover, with corals that settled outside of these areas having an increased survival rate, or that the *Sargassum* spp. and other algae in the coral rubble and rubble zones actually directly inhibits *G. aspera* larvae from settling in the areas directly around the algae. However, this hypothesis fails to explain the high density of *G. aspera* in the coral rubble zone, where the presence of macroalgae is highest (Jennings, unpubl). If colonies are seeking out areas of higher rubble and lower algal cover, then it would make sense for them to settle at higher rates in the rubble zone. A possible explanation for this is that the vertical distribution—between zones—of *G. aspera* on the reef flat in Geoffrey Bay is determined by environmental factors such as tidal height and dessication, while microhabitat is more important in determining the horizontal distribution—within zones—across the reef flat parallel to shore. *G. aspera* is more common in the coral rubble zone due to more favorable tidal conditions, but within that zone, distribution is more influenced by the microhabitats resulting from competition.

Another interesting feature of the microhabitat of *Goniastrea aspera* is the decreased presence of other species of corals in the immediate surroundings. This observation coincides with previous research showing that the distribution of *G. aspera* on intertidal reef flats tends to be clumped, with many colonies growing within close proximity of other individuals of the same species (Babcock 1983). This clumped distribution pattern is supported by the findings of this study as well; the percent cover of other *G. aspera* individuals was more than twice as high as that of all other coral species combined in the microhabitat of *G. aspera*. Diversity on a reef tends to be the highest on the reef crest and slope, with higher numbers of confamilial species present on the outer reef flat, and higher numbers of congeneric species found on the inner reef flat, which basically means that the species present on the reef flat

become more closely related as one moves away from the crest toward shore, regardless of the actual number of species present (Brown et al. 2002a). Therefore, the presence of many closely related species, and even many individuals of the same species, on the reef flat of Geoffrey Bay is not unusual, and may be the result of external environmental factors limiting the type, or even the family or genus, of species that are able to survive. However, other previous studies of massive intertidal corals found that colonies were evenly spaced, and that the nearest neighbors were rarely of the same species (Endean 1997). Apparent deviation from this distribution pattern may be due to competitive strategies developed by *G. aspera* in order to secure habitat and fend off other corals. One common competitive strategy of corals is the use of sweeper tentacles, an induced morphological response that serves to attack and sting invaders of habitat in close proximity (Chornesky 1989). *G. aspera*, along with most members of the family Faviidae, have relatively large polyps, and this feature has been attributed to better defense via mechanisms such as sweeper tentacles (McCook 2001). If this kind of competition is in play, then it is possible that the lack of other corals in the microhabitat of *G. aspera* may be due to the competitive success of the individuals of that species.

In addition to tidal cycles and microhabitat preferences, certain physical characteristics of the environment were shown to influence the distribution and health of the corals. The higher incidence of live coral cover on attached colonies compared with unattached colonies coincides with the basic ecological idea that one of the requirements for coral reef growth is a hard, stable bottom for substrate attachment (Lieske et al. 1994). If corals are not firmly attached to the benthic substrate, or the benthic substrate itself is unstable, the probability of damage or displacement by waves, which may completely overturn the colony and prevent any photosynthesis, is greatly increased. Bioerosion of the substratum or skeleton of the coral at the

attachment point may increase over time, also resulting of dislodgement of the colonies (Babcock 1991). The increased occurrence of attached colonies farther from shore can be seen as an indication of harsher environmental conditions—such as increased wave action and water movement—that may dislodge unstable communities and deposit them closer to shore as unattached colonies. These dislodged colonies tend to suffer increased mortality, having a significantly less percentage of living coral tissue than the attached colonies farther from shore. This influences the distribution of *G. aspera* on the reef flat, because if the only colonies that occur close to shore are mostly unattached individuals, then they will have a harder time surviving environmental stresses than the more stable, attached colonies, resulting in more successful survival of colonies farther from shore.

Although this study only investigated the immediate physical and environmental conditions influencing the distribution of *Goniastrea aspera*, there are other, more broad-scale environmental factors and changes that may be influencing the distribution and health of corals, both now and in the future. Because reefs are already sensitive environments, reef flats that exist in intertidal zones are among the most sensitive environments on earth to even minute changes in sea level (Lieske et al. 1994). In one instance, slight changes in sea level change at an intertidal reef in Thailand caused dramatic declines in coral cover and species diversity across the entire reef flat, resulting from the breakdown of zonation and an increase in the distributional range of some species that were previously confined to distinct sections of the reef (Brown et al. 2002a). If changes like these occurred on the reef flat in Geoffrey Bay, it would no doubt have a huge impact on both the distribution and survival of *G. aspera*. While it is important to understand the small-scale factors and details of distribution and health, larger-scale influences should also be kept in mind,

especially since it is changes in those kinds of environmental characteristics that will have the greatest impact on both intertidal coral reef systems in the future.

Conclusion

The distribution and health of the intertidal coral *Goniastrea aspera* is influenced by many environmental and physical factors that are all related to each other in a complex web of biological, physical, and ecological interactions. While more obvious factors such as tidal height and sedimentation rates were shown to be the most likely candidates influencing the vertical distribution of *G. aspera* on the reef flat, less apparent and more complex factors such as microhabitat and intra-specific competition appeared to be more important in determining the horizontal distribution of the coral within the different zones of the reef flat. The physical characteristics, particularly substrate attachment of individual colonies, proved to be influential in both distribution and health of *G. aspera* on the reef flat as well.

Despite the work of this and other previous studies, many gaps of information and understanding still exist that could potentially be filled by well-directed further studies. A study of the different factors that are suspected to cause bleaching in corals could be examined in the *G. aspera* colonies in Geoffrey Bay, perhaps shedding more light on environmental conditions at work in the reef flat that may not be obvious or quantifiably measurable. A study of the competition between macroalgae and massive intertidal corals, as well as a study of competition between coral species in the intertidal, would be useful in better defining the microhabitat preferences and distribution of those organisms. And while it is important to understand the small-scale, intricate factors influencing localized distribution and health, a better understanding of the role of global conditions and processes in intertidal coral habitats is incredibly important for the future because changes in these factors have the potential to produce dramatic shifts in both the structure and diversity of these sensitive systems.

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Appendix A: Tide Tables

Approximate time and height of tides in Cleveland Bay during data collection

Red = Low Tides

Source: Australian Government Bureau of Meteorology

Date	Time	Height	Date	Time	Height
14 April 2006	02:49	1.30	24 April 2006	13:30	0.64
14 April 2006	08:38	2.95	24 April 2006	18:50	3.16
14 April 2006	14:47	0.89	25 April 2006	01:00	0.73
14 April 2006	21:22	3.06	25 April 2006	07:02	3.66
15 April 2006	03:11	1.43	25 April 2006	13:43	0.50
15 April 2006	08:59	2.80	25 April 2006	19:30	3.39
15 April 2006	15:07	0.89	26 April 2006	01:40	0.72
15 April 2006	21:56	3.03	26 April 2006	07:35	3.59
16 April 2006	03:37	1.61	26 April 2006	14:12	0.42
16 April 2006	09:23	2.60	26 April 2006	20:14	3.55
16 April 2006	15:31	0.96	27 April 2006	02:24	0.82
16 April 2006	22:38	2.95	27 April 2006	08:10	3.41
17 April 2006	04:19	1.82	27 April 2006	14:42	0.42
17 April 2006	09:53	2.37	27 April 2006	20:58	3.60
17 April 2006	16:02	1.10	28 April 2006	03:12	1.02
17 April 2006	23:31	2.82	28 April 2006	08:45	3.13
18 April 2006	7:09	1.93	28 April 2006	15:13	0.51
18 April 2006	10:33	2.10	28 April 2006	21:43	3.54
18 April 2006	16:48	1.29	29 April 2006	04:08	1.28
18 April 2006	--	--	29 April 2006	09:21	2.78
23 April 2006	05:58	3.46	29 April 2006	15:45	0.69
23 April 2006	12:42	0.82	29 April 2006	22:30	3.39
23 April 2006	18:11	2.86	30 April 2006	05:15	1.53
23 April 2006	--	--	30 April 2006	09:59	2.41
24 April 2006	00:17	0.84	30 April 2006	16:19	0.94
24 April 2006	6:30	3.61	30 April 2006	23:22	3.16

Appendix B: Physical Characteristics Data Collection Sheet

#	Zone	Distance From Shore	Circumference	Morphology	Substrate Attachment	% Living	% Dead	% Bleached
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Appendix C: Microhabitat Assessment Data Collection Sheet

#	% Rubble	% Sand	% <i>Sargassum</i> spp.	% Other Algae	% Other <i>Goniastrea aspera</i>	% <i>Porites</i> spp.	% Short Branching Coral	% Other	Notes / Descriptions
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