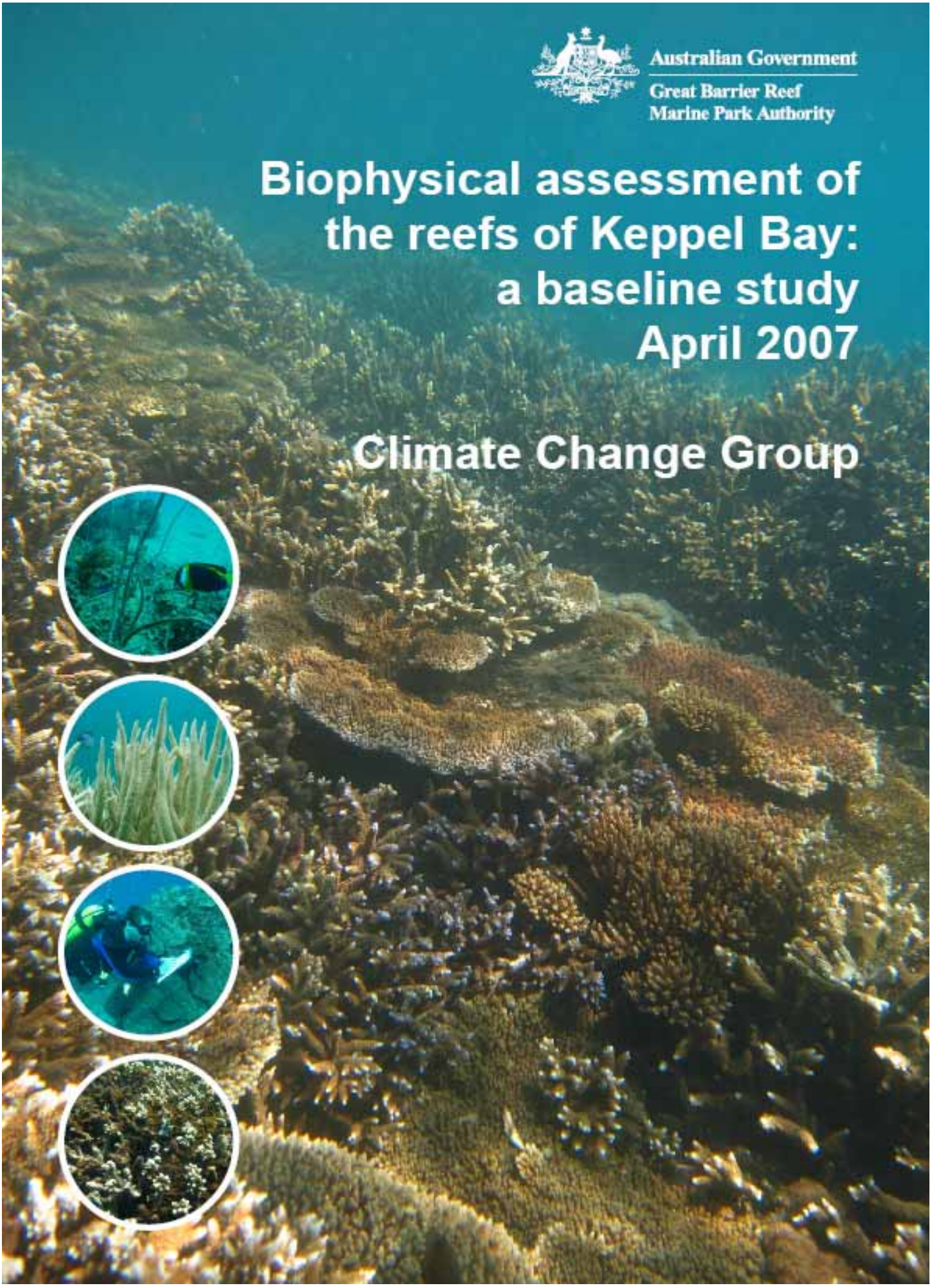


Australian Government
Great Barrier Reef
Marine Park Authority

Biophysical assessment of the reefs of Keppel Bay: a baseline study April 2007

Climate Change Group

Contents

Introduction

The Keppel Islands are a group of 16 continental islands lying 18 km off the coastal town of Yeppoon in the southern Great Barrier Reef. Located in the shallow basin to the north of Keppel Bay, the islands are host to a patchwork of fringing reefs in various forms of development. Coral communities are abundant in some locations, and coral cover is high (60 to 70%) relative to the average at sites surveyed by the Australian Institute of Marine Science's Long-Term Monitoring Program (~35%), and are often dominated by extensive stands of branching Acropora that extend into shallow water. These 'staghorn' corals are vulnerable to impacts caused by environmental stresses such as elevated sea temperature (causing coral bleaching events), degraded water quality (associated with hyposaline floods events) and physical damage (from cyclones, storms and anchoring).

The Fitzroy River, one of the largest catchments in Queensland, is about 40 km to the south of the Keppel Islands. Large flood plumes occur approximately every 10 years, and the soft riverine sediments are regularly re-suspended in the shallow bay by wind and tide action causing high turbidity. Heavy rainfall also affects the shallow reef flat habitats, with reported incidences of coral mortality caused by heavy rain at times of extreme low tides.

Over recent years, warm sea temperature anomalies have caused widespread bleaching among the fringing coral communities (1998, 2002 and 2006). In the summer of 2006, the Keppel Islands were the centre of a protracted bleaching event, where sea temperatures of 1.5–2 ºC above average summer temperatures were sustained for several weeks from December 2005 to February 2006. Almost 100% of coral communities were affected by bleaching and average coral mortality was 40%.

Climate models for the Great Barrier Reef Region project that sea temperatures and the frequency of intense storms and cyclones will increase in coming decades, and rainfall regimes will change (IPCC 2007, Johnson & Marshall 2007). Implications for the fringing reefs in the Keppel Islands include more frequent and severe coral bleaching events, storm damage and freshwater events.

The Keppel Islands and surrounding waters are a popular tourist destination, mainly focused around Great Keppel Island, with additional campsites on seven other islands. Jointly managed by the Queensland Parks and Wildlife Service (QPWS) and the Great Barrier Reef Marine Park Authority (GBRMPA), the Keppel Islands are popular with a range of users. Despite this popularity, the Keppel Islands are still a low-use area compared with major Great Barrier Reef destinations such as Cairns and the Whitsunday Islands. Importantly, there is an increasing number of residential developments along the mainland coast. There is also increasing participation in community groups, including the Capricorn Coast Local Marine Advisory Committee, that have interests in the management of local environmental issues.

This report provides baseline information on the reefs habitats of the Keppel Islands to support future planning, and management responses to the impacts of recent coral bleaching events. This summary includes an assessment of the extent to which locations have been affected by recent disturbances, and an evaluation of the vulnerability of the reefs to future bleaching events. The report presents the results of surveys done by the Climate Change Group of the GBRMPA, in association with the Queensland Parks and Wildlife Service (GBRMPA Day-to-Day Management unit) and the Capricorn Coast Local Marine Advisory Committee.

Methods

Ecological conditions

To assess the status of the Keppel Island reefs, habitat condition of 39 sites at 20 locations was surveyed using standard ecological survey methods. The rapid assessment technique that was used is a standard survey method (Great Barrier Reef Coral Bleaching Response Plan 2006-2007) that records benthic structure and condition within an area of approximately 50 m by 5 m. Three rapid assessment surveys were done at each site on the upper and lower reef slope, approximately 2 m and 5 m below Lowest Astronomical Tide. Timed surveys were used rather than fixed transects to reduce survey time, to avoid unsightly markers on the reef and to ensure independence among consecutive surveys.

Estimates of the benthic cover, using five main categories of hard coral, soft coral, algae (which includes algae growing on dead coral), other live and abiotic were made by trained observers. Impacts on benthic communities can be expressed in terms of cover change in these categories. For example, dead hard coral colonies are quickly colonised by fine filamentous turf algae or, when in very shallow water and strong sunlight, by crustose coralline algae. In contrast, soft coral colonies subject to severe bleaching stress 'dissolve' and disappear from the community. Other live cover contributing to the benthic community includes sponges, hydroids and clams. The *abiotic* category includes sand, silt, rubble and rock and, when not made up by rock, reflects the proportion of unstable substrate in the community that will be unlikely to support replenishment of hard coral cover through recruitment.

Estimates of hard coral cover target the most abundant taxa (eg *Acropora, Monitpora, Porites*, Faviidae) while noting the occurrence of less abundant taxa (eg *Turbinaria, Pachysera, Acanthastrea*). The categories for estimating percent cover and coral bleaching are standardised to enable consistent surveying by different observers. Visual assessment techniques have been shown to be a rapid and effective technique for reliably estimating habitat and benthic composition (Wilson et al. 2007).

Survey sites and habitat types

Thirty-nine sites were surveyed at 20 locations within the Keppel Islands (Figure 1). The locations included a broad range of habitat types: from extensive areas of branching corals to patches of algal-covered rocks. Each site had significant importance as benthic habitats supporting corals and fish communities. The sites can be divided into four types:

Habitat A – sites with slopes to depth, dominated by widespread distribution of *Acropora* species, including branching and tabulate forms.
Habitat B – sites with slopes restricted by shallow silt base, dominated by widespread distribution of *Acropora* species, including branching and tabulate forms. Overall low coral diversity.
Habitat C – sites with depth dependent coral communities and diverse benthic flora and fauna. Community structure influenced by high turbidity and/or high wave energy.
Habitat D – sites with rocky structural complexity and low coral cover.

These habitat types are represented conceptually in Figure 2. Their distribution among locations is given in Table 1.

Table 1. Distribution of four habitat types among survey locations. The number of sites conforming to a particular habitat type at each location is given in brackets.

Habitat A	**Habitat B**	**Habitat C**	**Habitat D**
Outer Rock (1) Man & Wife (1) Barren Is (1) Bald Rock (1) 23-032 (2)	Halfway Island (1) Observatory (2) Middle Island (3) Half tide Rocks (3) Miall Island (3) Square Rocks (3) Sloping Island (3) Humpy Island (2) Big Peninsula (1) Corroboree Island S (1)	Pelican Island (3) Big Peninsula (3)	40 Acre (2) Corroboree Passage S (1) Corroboree Is SE (1) Conical Rocks (1)

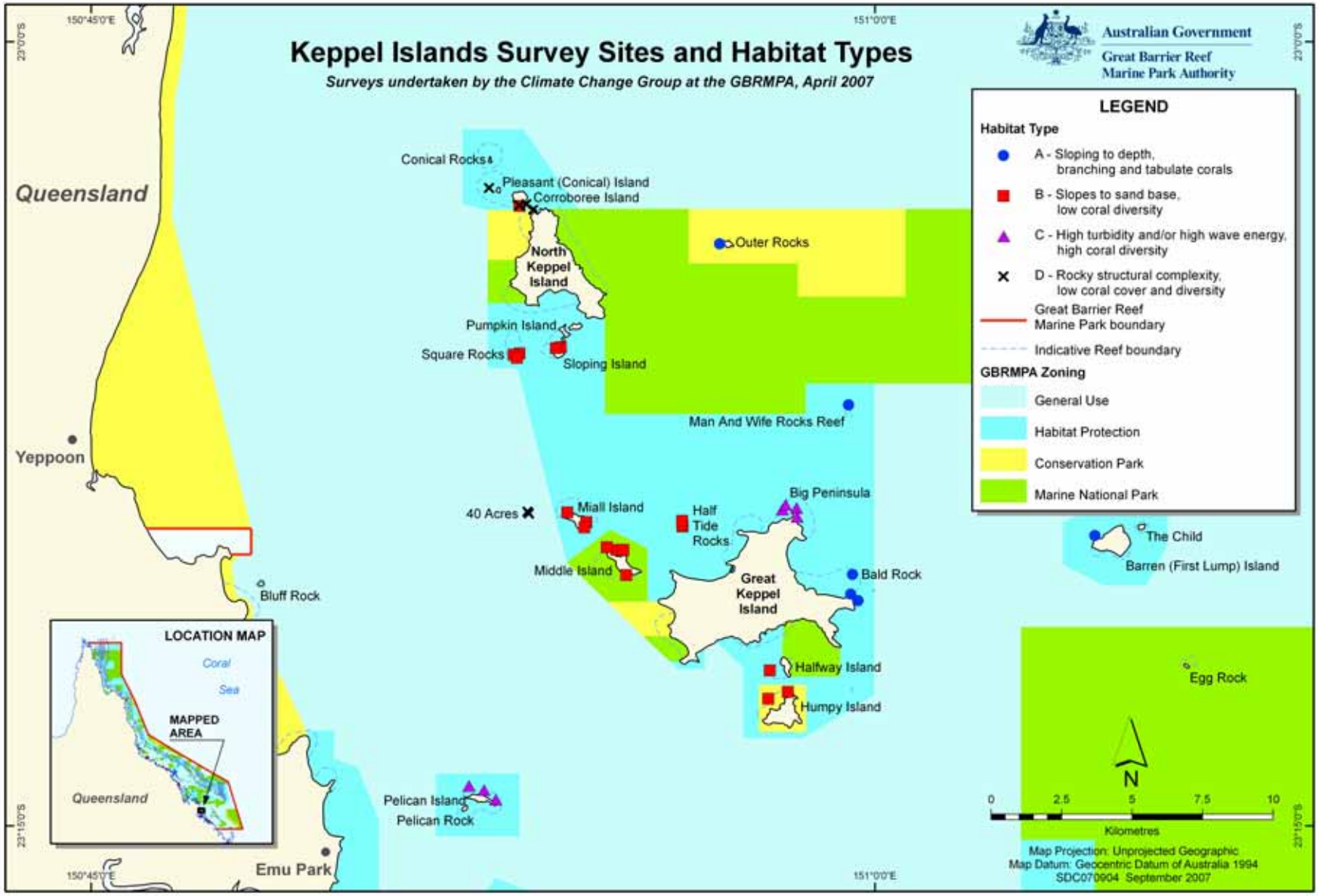


Figure 1: Map of the Keppel Islands showing survey sites and identified habitats

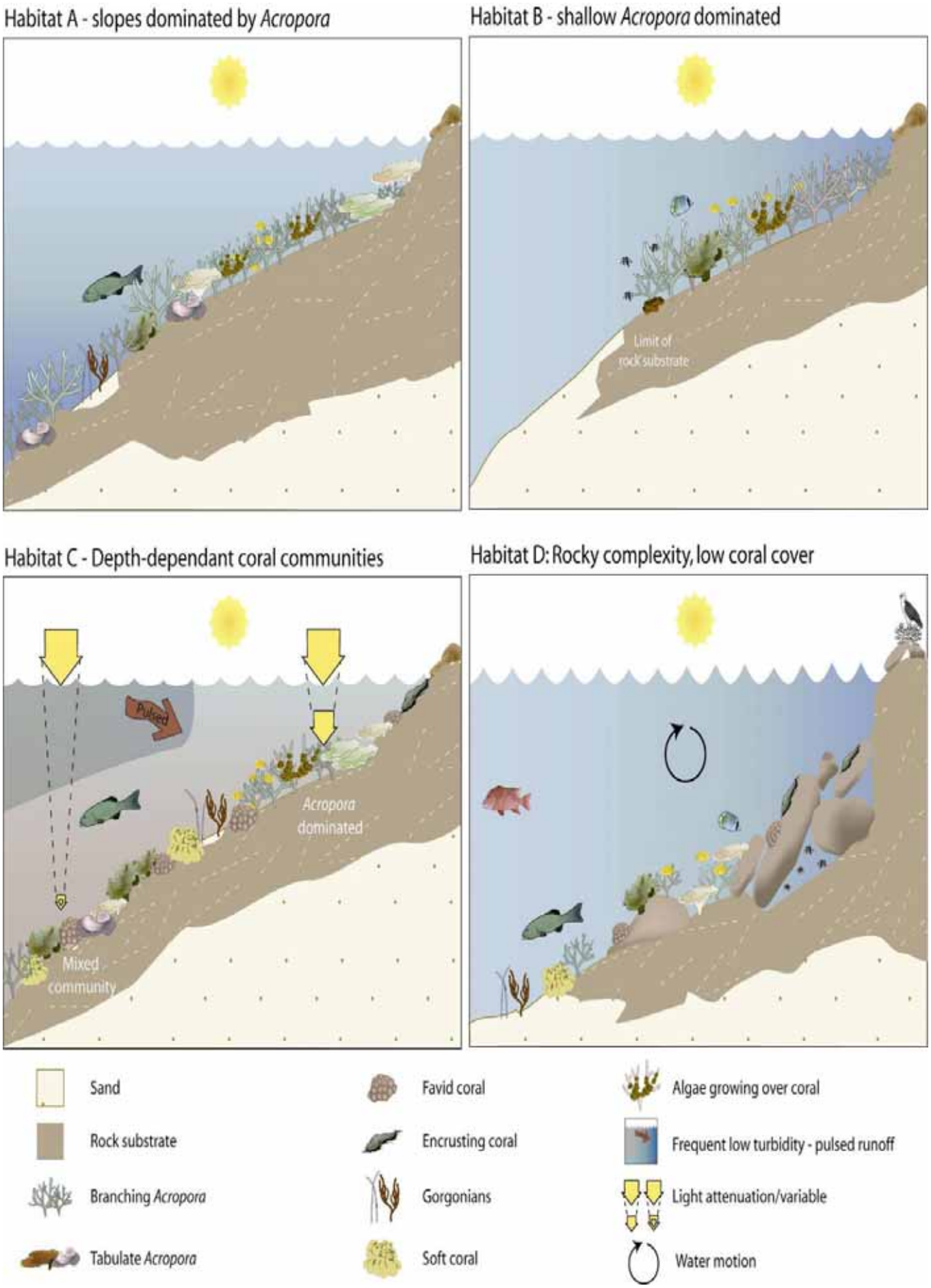


Figure 2: Four broad habitat types were identified at locations around the Keppel Islands

Survey Results

For each location a description of the benthic habitat is provided as well as the extent to which any impacts from recent disturbances can still be seen. In the 'Habitat' section, sites at a location that differed dramatically have been described individually; otherwise, sites have been grouped together and discussed in terms of upper and lower reef. Descriptions of both the physical environment and the benthic community composition have been provided. Pie charts showing the relative proportion of the bottom covered by four major categories – 'Abiotic', 'Algae', 'Soft Coral', 'Hard Coral', have also been included. The rapid assessment technique includes a fifth benthic category, 'Other Live' (sponges, gorgonians, etc). However, this category has been omitted from the results reported here as these organisms represented an insignificant proportion of the live cover at sites (less than 1% at all except 3 transects). Results from the surveys at each location are presented alongside representative photos from the survey sites. Lastly, for each location a section has been included that covers evidence of recent impacts, vulnerability to impacts like anchoring and bleaching, and a summary of the current condition of the environment.

The remainder of this section provides detailed results for each site surveyed.

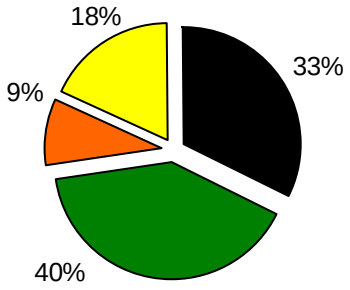
Location 1 – 40 Acre Paddock

Habitat:

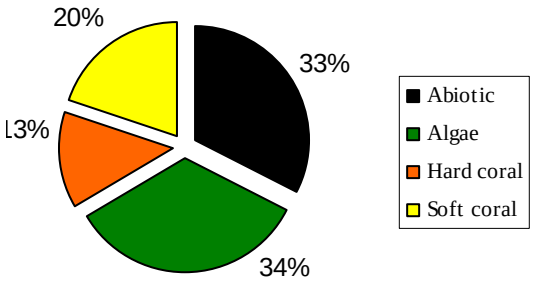
This site is made up of low-profile habitat that primarily consists of patches of solid rock emerging from a silt base that extends to a depth of 8 meters at the western edge to 12 meters along the eastern edge. The hard substrate is patchily distributed, the broadest expanse being in the southern area. The hard coral community consists of encrusting and foliose types (variety of Faviids, *Turbinaria* sp.) of small size and low abundance but high diversity. Soft corals are abundant and include *Sarcophyton, Sinularia, Klyxum* and *Lobophytum* sp. colonies, and the gorgonians *Junceella* sp. and *Ctenocella* sp. are also common. Filamentous turf algae can be found on all hard surfaces. During the 2007 surveys fish abundances were moderate but included the scribbled angel fish', a common target for aquarium collectors. Anemones and anemone fish were also moderate in abundance – average counts of anemones per 50 m transect were 2 to 3. Olive sea snakes were seen throughout the area and are known to be at higher abundance here than at other locations in the Keppel Island area.

Impacts, current condition, and summary:

40 Acre paddock was not visited during or immediately after the 2006 bleaching event. However, there was no evidence that the coral communities at this site were affected by bleaching in 2006. Most likely, this is due to the site being slightly deeper than many of the other fringing reef locations where corals extend well up into the shallows and are exposed to both high temperature and light. Because of the greater relative depth and the turbidity at this site, boaters will find it difficult to discern sandy areas from rocky substrate making the corals, gorgonians, and anemones at this site highly susceptible to anchor damage. There was evidence of minor anchor damage particularly to large plating *Turbinaria* colonies during the 2007 surveys. The coral and benthic community was in good condition during the surveys though cover is relatively low. Ecologically, this is an important site because the benthic invertebrate diversity is high, anemones and anemone fish are found here, and the location has the highest abundance of sea snakes in the area.



40 Acres Upper Slope



40 Acres Lower Slope

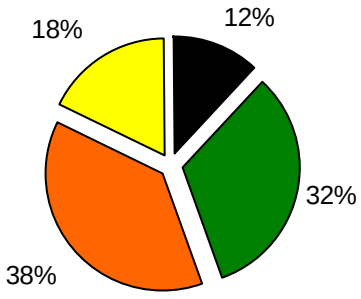
Location 2 – Square Rocks

Habitat:

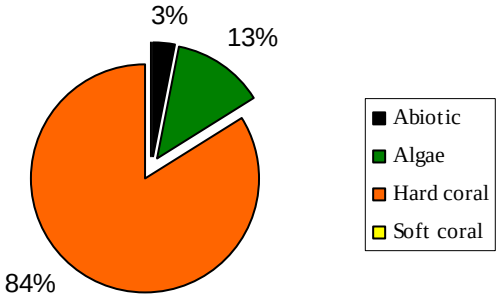
Square Rocks is an elongate series of rock outcrops orientated north to south. Fringing reef surrounds the rocks with solid substrate on the upper slope (2-3 m; dominated by hard corals) that transitions to flat rubble on sand on the lower slope (6-10 m). There is high hard coral cover on the upper slope (80%+) and low cover (15-20%) on the lower slope with higher diversity (*Acropora, Turbinaria, Goniopora, Porites* sp. and Faviids). Branching *Acropora* dominated all of the sites surveyed at Square Rocks excepting the southern tip, which has a steeper depth gradient and more vertical rock substrate. Other benthic invertebrates including soft corals, gorgonian whips and sponges are in low abundance. No anemones or anemone fish were observed in 2007. Fleshy macroalgae and seagreass were both observed among coral rubble. Abundant fish observed during the 2007 surveys included: trevally, trout, slatey bream, fusiliers, parrotfish, wrasse and angelfish.

Impacts, current condition, and summary:

At the time of the 2007 surveys there was no sign of anchor damage or recent mortality at this site. It is not likely that the benthic community found here is susceptible to anchor damage since the highest cover is found too close to the rocks to make a safe anchorage point and the depth increases rapidly with distance from the rocks. This site was not visited during or after the 2006 bleaching event. At adjacent sites, as much as 50-60% of the corals were completely bleached. The percentage of bleached corals at this site in 2006 was likely not as high. However, it is likely that a portion of the 32% of the benthos covered by algae on the upper slope is directly attributable to mortality during the 2006 event. In addition, the coral community at Square Rocks is dominated by species highly susceptible to bleaching, meaning that the site could be vulnerable to a bleaching event in the future. Ecologically, this is an important site due to the high coral cover and the abundance and diversity of reef-associated fish.



Square Rock Upper Slope



Square Rock Lower Slope

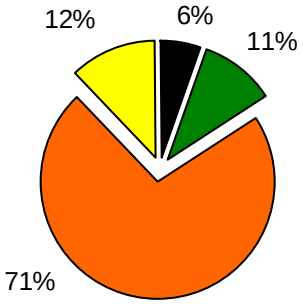
Location 3 – Sloping Island

Habitat:

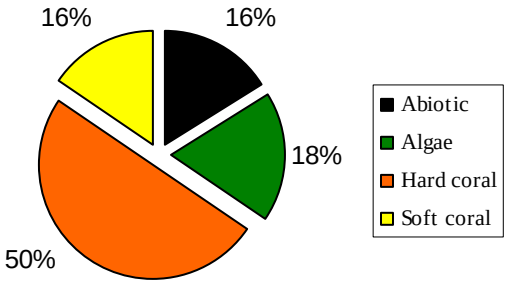
Sloping Island is surrounded by fringing reef that extends as a large patch into the channel with Pumpkin Island. Coral cover is high (>80%) on the upper slope and is dominated by *Acropora*, including many large (>1 meter in diameter) tabulate colonies while *Montipora* sp, *Pocillopora* sp, *Porites* sp and Faviids were all seen in lower abundance. The lower slope has lower coral cover (<20%) but similar diversity and is interspersed with large areas of coral rubble and sand. Soft corals including *Sinularia* and *Sarcophytum* sp. were also abundant in the fringing reefs of Sloping Island. At the time of the 2007 surveys abundant fish in the area included trout, fusiliers, parrotfish and baitfish.

Impacts, current condition and summary:

Members of the Queensland Parks and Wildlife Service reported that many corals bleached (30-40%) at this site during the 2006 bleaching event. At this site, many of the corals survived and signs of mortality from bleaching were minor. It is, however, likely that coral cover at this site was higher prior to the 2006 bleaching event and that at least some of what was counted as algae during the 2007 surveys is directly attributable to mortality during the 2006 event. The coral community at Sloping Island is dominated by species highly susceptible to bleaching, meaning that the site could be vulnerable to bleaching again in the future. There is an extensive reef flat and upper slope with a very shallow depth gradient at this site making the benthic communities at Sloping Island also highly vulnerable to anchor damage. During these surveys, there were signs of minor anchor damage in the shallows as well as fishing line entanglement. Ecologically, this is an important site due to the high coral cover in the shallows and the abundance of reef-associated fish.



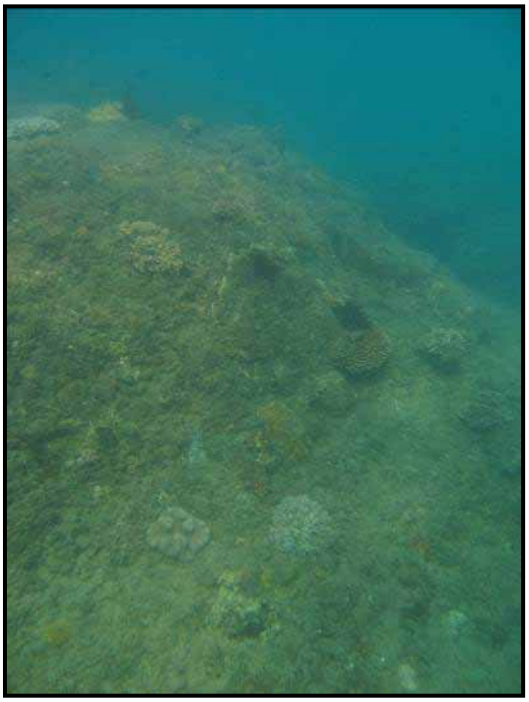
Sloping Island Upper Slope



Sloping Island Lower Slope

Location 4 – Corroboree Passage (South)

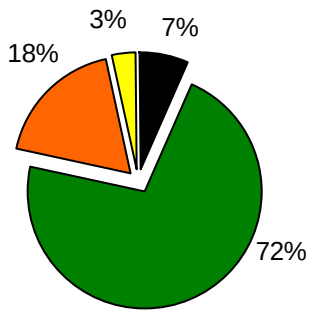
Habitat:



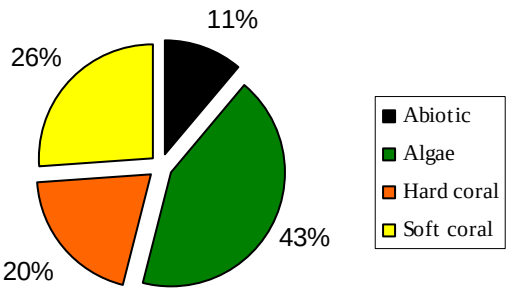
Corroboree passage is an outcrop of hard substrate that extends as a submerged ridge on the north side of North Keppel Island. The edges of the rock outcrop slope steely to sand at 5m. Hard coral cover is low (<20%), limited in diversity and patchily distributed on the slopes of the outcrop, with less cover on the topmost exposed surfaces. Relatively small (~.50 m) tabulate *Acropora* is the most common coral type. Other coral species seen include foliose *Turbinaria* sp. and sub-massive *Goniopora* sp. The seagrasses *Halophila* and *Halodule* sp. are common and are the preferred food of dugong. Despite low coral cover this site appears to be excellent fish habitat with a variety of fish observed including butterfly, rabbit, and damselfish, as well as trout and fusiliers. At the time of the 2007 surveys, the macroalgae *Sargassum* was common but this algae type is highly seasonal and is unlikely to be common year round.

Impacts, current condition, and summary:

There was no sign of anchor damage or recent bleaching mortality during the 2007 surveys. Vertical and jagged rock outcrops with steep depth gradients do not make for good anchorages and users of the site seen during the surveys were anchored well off the rocky reef. In 2006, at sites directly adjacent to this one as much as 50-60% of the corals were impacted by bleaching and 30-40% died from bleaching. It is likely that bleaching did not severely impact corals at this site. Highly exposed sites with steep depth gradients are often well mixed which can work to reduce the temperatures experienced by corals in the shallow areas of the site. Low coral cover at this site is much more likely to be a result of the depth gradient and exposure than mortality from a past disturbance. Ecologically, this is an important site due to the presence of seagrasses and the abundance and diversity of fish that are using the rock outcroppings for cover and shelter, and the strong currents in the area to bring food.



Corroboree Passage Upper Slope



Corroboree Passage Lower Slope

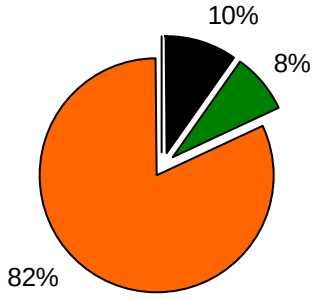
Location 5 – Corroboree Island (South)

Habitat:

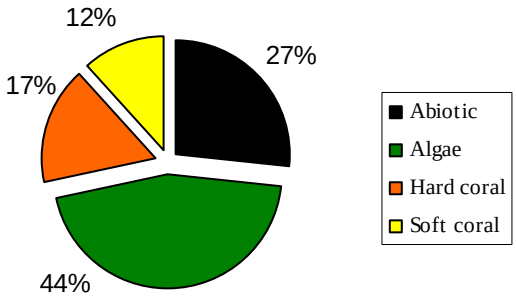
The south side of Corroboree Island is surrounded by fringing reef that extends towards Corroboree Passage. The upper reef slope is dominated by branching *Acropora* sp. with the macroalgae *Lobophora* residing between the branches and at the base of the corals. In contrast, most of the lower slope is abiotic, the majority of the benthos being covered in both sand and rubble. Coral cover is reduced on the lower slope and patches of *Halophora* seagrass are common. Types of fish observed during the 2007 surveys include angelfish, fusiliers, stripey, snapper, parrotfish, rabbitfish, trout, and sweetlip.

Impacts, current condition and summary:

At the time of the surveys the coral community was in reasonable condition. On the upper reef slope 10% of the benthos was made up of dead standing *Acropora* corals that are likely to have died following the 2006 bleaching event. In contrast, coral cover on the lower slope was much higher prior to the 2006 event (65% as opposed to 17%). During 2006 over 50% of the hard corals completely bleached at this site suggesting that the great majority of bleached corals on the upper slope survived though very few survived on the lower slope. In the extreme shallows (<0.5 meters) many of the tabulate, digitate, and branching *Acropora* colonies were dead at the time of the 2007 surveys and covered only by thin turf algaes. This suggests that these corals died when heavy rainfall coincided with an extreme low tide in mid-November 2006. Ecologically, this site is important because of the high cover of hard corals on the upper slope as well as the fish life. The site is vulnerable to future bleaching events due to there being mono-specific stands of highly-susceptible *Acropora* corals on the upper reef slope.



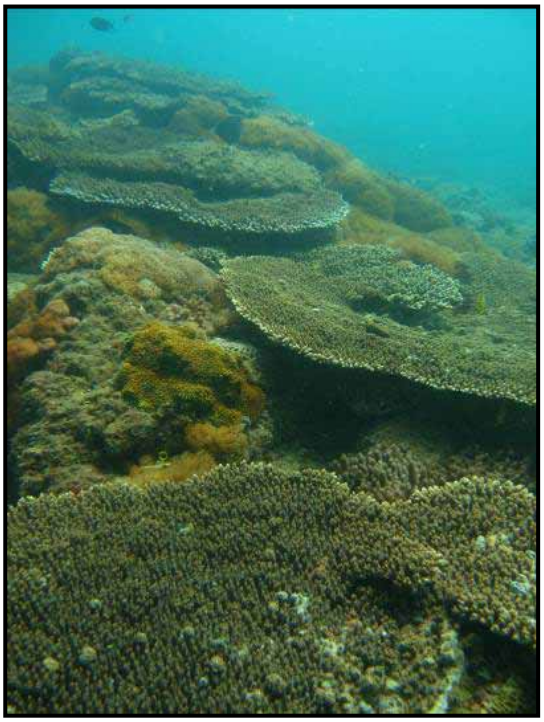
Corroboree Island Upper Slope



Corroboree Island Lower Slope

Location 6 – Corroboree Island (South-East)

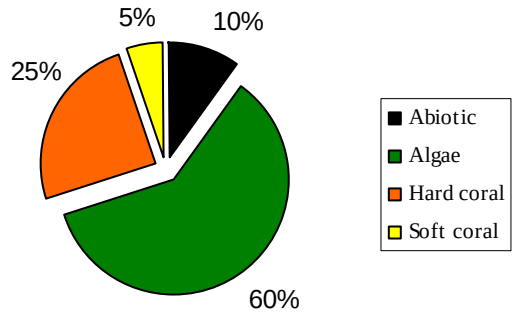
Habitat:



This site consists of a submerged boulder ridge that extends 60-70m from the shoreline into Corroboree Passage. The angular boulders that make up the ridge have numerous pockets and crevices as well as steep slopes that extend to a sand base at 4m. Overall, hard coral cover is moderate (30-40%) and is dominated by small tabulate *Acropora* corals (0.25-0.5m diameter). Other corals present were *Montipora, Pocillopora* and *Hydnophora* sp., and a range of encrusting Faviids. Anemones and anemonefish were abundant in the pockets and crevices of the ridge slope. Other fish observed during the surveys include butterflyfish, damsels, fusiliers, and trevally.

Impacts, current condition and summary:

At the time of the 2007 surveys there was no sign of anchor damage on the SE side of Corroboree Island. As per the Corroboree Passage, vertical and jagged rock outcrops with steep depth gradients do not make for good anchorages. However, the tabulate *Acropora* colonies at this site would be vulnerable to anchoring due to their fragile growth form and that they offer a far better hook-up than the turf-covered boulders at the site. In 2006, at sites directly adjacent to this site 50-60% of the corals were impacted by bleaching and 20% died from bleaching. It is likely that bleaching also impacted some corals at this site and that a portion of what was categorized as algae during these surveys is directly attributable to mortality during the 2006 event. Importantly though, adjacent sites have fringing reef that is not as exposed, has a shallower depth gradient, and is not as turbid. At Corroboree Island, however, a steep depth gradient, exposure and turbidity all work to partially protect the site from the combination of high temperatures and light that cause bleaching. Like in the Corroboree Passage, coral cover at this site is likely to be a result of the depth gradient and exposure more than mortality from a past disturbance. Ecologically, this is an important site due to the abundance of anemones, and anemonefish, as well as the abundance of other fishes and fragile coral growth forms.



Corroboree Island SE Lower Slope

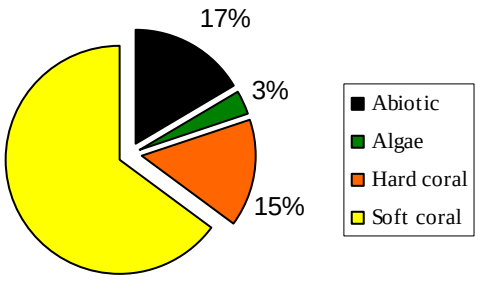
Location 7 – Conical Rocks

Habitat:

This site is made up of a highly three-dimensional *Porites* bommie field and includes some very large dead bommies. Overall, coral cover is low (<10%) despite the availability of suitable substrate and was made up entirely of *Porites* and branching *Acropora*. Macroalgae (*Lobophora* and *Sargassum* sp.) is present but not dominant probably due to the roving schools of herbivores seen. Schools of juvenile red emperor and fusiliers were also seen during the surveys.

Impacts, current condition, and summary:

At the time of the 2007 surveys the coral community was in good condition. There was no evidence of bleaching-induced mortality or anchor damage. It is unlikely that the coral community at this site is highly susceptible to anchor damage. The areas in between the large bommies are dominated by sand and rubble and the bommies are readily seen from the surface, both of which make it easy for visitors to anchor away from the corals. This site was not surveyed during or after the 2006 bleaching event. However, if the corals at Conical Rocks were affected most of them survived as no bleaching-induced mortality was observed and algae, which usually rapidly colonise corals following bleaching-induced mortality makes up less than 5% of the substrate. Ecologically, this site is important for the fish habitat provided by the topographical complexity of the bommie fields.



Conical Rocks Lower Slope

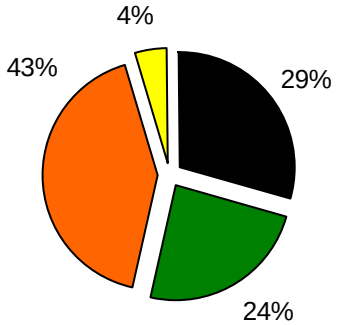
Location 8 – Pelican Island

Habitat:

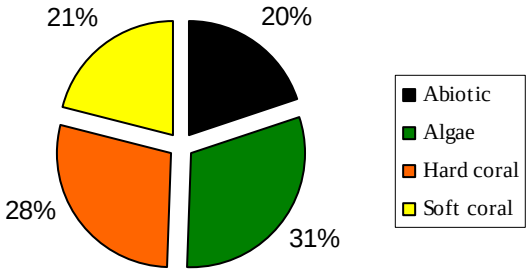
Reefs on the eastern side of Pelican Island have a gradual slope made up of rocks and small boulders that transition to a silt and sand base at 10 meters. The hard coral community extends from the shallows to the silt base with diversity dramatically increasing with depth. The hard coral community on the upper reef slope is dominated by *Acropora* sp. (branching and tabulate) which turns into a community dominated by massive and encrusting non-*Acropora* sp (*Hydnophora* sp, *Goniopora* sp, range of Faviids) on the lower reef slope. Soft corals become more numerous and varied with depth, with stalked gorgonians (*Junceella* sp) high in abundance. Soft-bodied Corallimorphs (*Discosoma* sp.) are also common on the lower slope. In the sheltered shallows the seasonal macroalgae *Sargassum* is abundant (20-30% cover) though no macroalgae were seen on the lower slope. At the time of the 2007 surveys very few fish were seen, and though a local aquarium collector was observed for over 30 minutes, he did not catch anything during that time. He did, however, anchor in the shallows.

Impacts, current condition, and summary:

At the time of the 2007 surveys the coral community was in good condition though some anchor damage was observed in the shallows. This site was not surveyed during or after the 2006 bleaching event. It is likely that bleaching impacts at this site rivalled those of adjacent sites and that coral cover was much higher here prior to the 2006 bleaching event. Dead standing Acropora colonies were observed on the upper and lower slope and it is likely that a large portion of what was categorized as algae during these surveys is directly attributable to mortality during the 2006 event. This site is also vulnerable to future bleaching events due to there being mono-specific stands of highly-susceptible *Acropora* corals on the upper reef slope. The lower slope community, however, is more diverse and made up of many species known to be among the least susceptible to bleaching. Importantly, corals in the shallower areas of this site are also vulnerable to anchor damage. The best fish habitat appears to be in the shallows and, due to the gradual slope, collectors are likely to (and were observed during the surveys) anchor in the shallows. Ecologically, this site is important because of the diversity of habitat on the reef slope as well as the great diversity of corals among the lower reef slope.



Pelican Island Upper Slope



Pelican Island Lower Slope

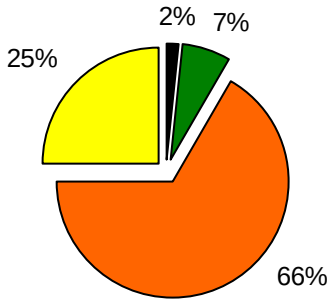
Location 9 – Man and Wife Rocks

Habitat:

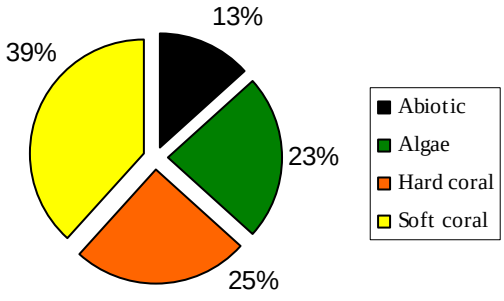
Man and Wife Rocks is a small continental island on the seaward boundary of the Keppel Islands. The sheltered northwest side of the rock slope has a steep gradient to 6 meters that extends as a shelf and then drops rapidly in depth. On the sheltered western side of Man and Wife Rocks the fringing reef on the rock base has a high cover of branching and tabulate *Acropora* (>80%). There were some former tabulate *Acropora* colonies covered with turf algae, but the majority of tabulate *Acropora* were large (1.5m diameter) and in good health. There is a shallow 'saddle' between Man and Wife rocks. Though the soft coral *Xenia* was common in the shallower depths, it was most common in the saddle between Man and Wife Rocks. Here too, tabulate *Acropora* were common in the shallow water. The fringing reef becomes a rock wall at either end of these rocky outcrops. On the lower slopes of the fringing reef area coral cover is low (<20%), and turf algae and soft corals, particularly *Briarium* sp., dominate the benthos. Fish communities were abundant and diverse and included reef-associated fish like rabbitfish and damselfish, as well as fusiliers, batfish, trout, and black-tip reef sharks.

Impacts, current condition and summary:

At the time of the 2007 surveys the coral community was in good condition. There was no evidence of bleaching-induced mortality, and very little algae, though some anchor damage was observed in the shallows. This site was not surveyed during or after the 2006 bleaching event. However, if the corals at Man and Wife Rocks were affected almost all of them survived. This site is, however, vulnerable to future bleaching events due to there being mono-specific stands of highly-susceptible *Acropora* corals on the upper reef slope. Corals in the shallower areas of this site are also vulnerable to anchor damage. The slope drops dramatically and the rocky outcrops on both sides of the saddle between the rocks do not make good anchorages. One observation of disease on a corymbose *Acropora* colony was made at 5 meters. Ecologically, this site is important because of the high cover on the relatively sheltered upper reef slope as well as the abundance and diversity of fish among the rock outcrops.



Man and Wife Rocks Upper Slope



Man and Wife Rocks Lower Slope

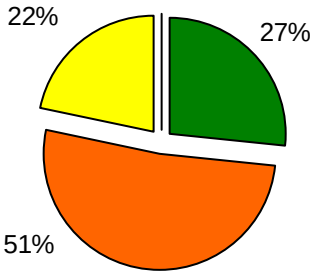
Location 10 – Barren Island

Habitat:

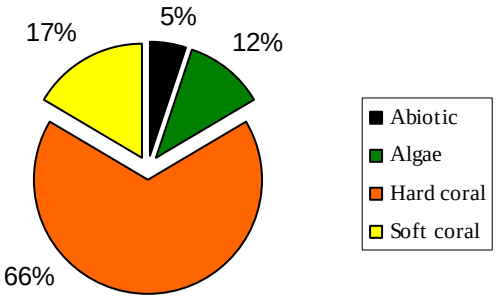
Barren Island is a rocky island supporting coral communities on the northern side. Combined soft and hard coral cover is extremely high (80%) on both the upper and lower reef slopes. Hard coral diversity is, however, limited and restricted primarily to branching and tabulate *Acropora* species with some of the tabulate corals being greater than 2 meters in diameter. A few large *Porites* and smaller Faviid colonies were observed on the lower slope. Large patches of the soft coral *Xenia* sp. are scattered on rock throughout the upper reef slope. Large roving schools of herbivores were also observed on both the upper and lower reef slope.

Impacts, current condition and summary:

At the time of the surveys the coral community was in reasonable condition. On the upper reef slope 15% of the benthos was made up of dead standing *Acropora* corals that are likely to have died following the 2006 bleaching event. Therefore, it is likely that coral cover at Barren Island was higher prior to the 2006 event and that a portion of what was classified as algae, which rapidly colonises dead corals, during these surveys is directly attributable to bleaching-induced mortality. This site is also vulnerable to anchor damage due to the extent of cover along the slopes and the fragility of the resident corals. Ecologically, this site is important because of the high cover of hard and soft corals. Importantly though, the coral cover was probably even higher here prior to the 2006 bleaching event and the site is vulnerable to future bleaching events due to there being mono-specific stands of highly-susceptible *Acropora* corals on both the upper and lower reef slopes.



Barren Island Upper Slope



Barren Island Lower Slope

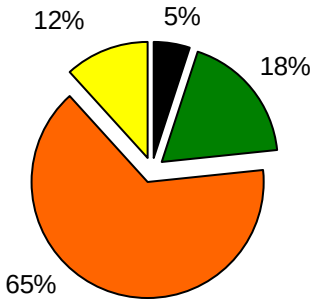
Location 11 – Bald Rock

Habitat:

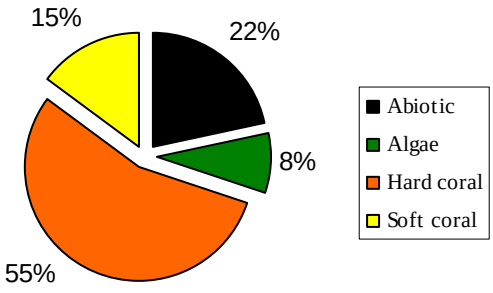
The reef edge around Bald Rock forms part of a larger fringing reef numbered 23032. The reef extends from the shallows with a moderate slope to a sand/rubble base at 10m. Hard coral communities on the upper reef slope are dominated (95%) by large stands of branching *Acropora*. Soft corals (*Xenia* and *Sarcophyton* spp) are also common. Branching *Acropora* sp. are common on the lower reef slope as well though colonies are separated by patches of sand and rubble. Schools of reef-associated fishes like damsels and butterflyfish were common on both the upper and lower reef slope during the surveys.

Impacts, current condition and summary:

There are large patches of coral mortality (20% of the benthos) among branching *Acropora* colonies on the upper reef slope, which is likely a result of the bleaching event in 2006. At adjacent sites, as much as 50% of the hard corals completely bleached during 2006. It is likely that the same percentage of corals were impacted by bleaching at Bald Rock, which indicates that many of the corals affected at this site did end up surviving though 20% died and significantly reduced the coral cover at this site. The extent of coral cover along the reef slope and the fragility of the resident corals, combined with high-visitation rates also makes the resident community highly vulnerable to anchor damage. Bald Rock is a commonly used anchorage due to the shelter from easterly winds provided by the rock outcrops. Large holes (0.5 to 1 meter in diameter) were noted among the stands of branching *Acropora* on the upper and lower reef slope, which is most likely attributable to anchoring. This extent of physical damage is often coincident with coral disease outbreak though no disease was observed during our surveys. Ecologically, this site is significant due to the high coral cover. The coral cover was higher here prior to the 2006 bleaching event and the site is vulnerable to future bleaching events due to there being mono-specific stands of highly-susceptible *Acropora* corals on both the upper and lower reef slopes.



Bald Rock Upper Slope

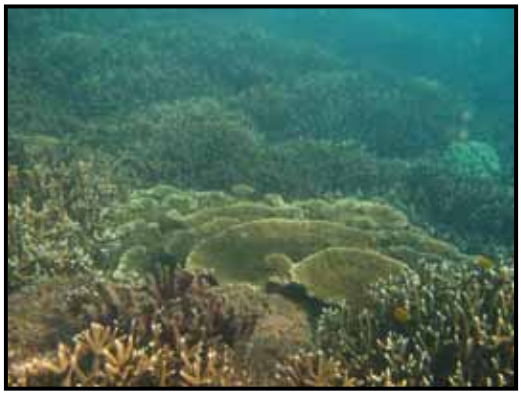


Bald Rock Lower Slope

Location 12 – Reef 23-032

Habitat:

Two sites were visited during these surveys at Reef 23032 and both were characterised by different physical environments and ecological communities.

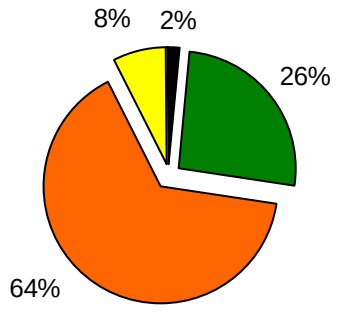


Site A, on the south-eastern side of Wreck Bay has a broad shallow reef flat and moderate reef slope. The upper reef slope is dominated by extensive stands of branching *Acropora* sp. (70% cover). Tabulate *Acropora* colonies were also common with some colonies having a diameter in excess of 2 meters. Acropora also dominates coral communities on the lower reef slope though colonies are interspersed with patches of sand and rubble. The macroalgae *Asparagopsis taxiformis*, as well as *Lobophora* sp. were common in between and among the branching *Acropora* colonies.

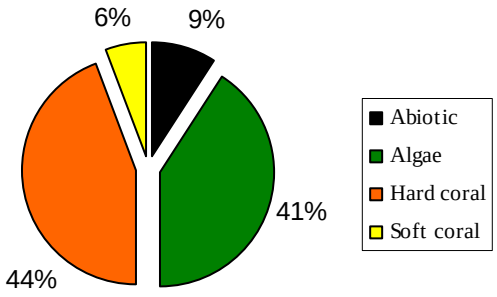
Site B, Sykes Rocks, is a constrained shallow reef slope that drops rapidly in depth around the point of a peninsula and is far more exposed to wave energy than Site A. Coral cover is high (70%) on the upper reef slope and made up primarily of branching *Acropora* that transitions, on the lower reef slope, to tabulate *Acropora*, encrusting *A. palifera* and Faviids. The soft coral *Xenia* is common, as well as the macroalgae *Lobophora* and *Chlorodesmis*.

Impacts, current condition and summary:

At both sites, 10% of the benthos on the upper and lower reef slopes was made up of dead standing branching *Acropora* colonies, which is likely due to the 2006 bleaching event. At adjacent sites, as much as 50% of the hard corals completely bleached during 2006. It is likely that the same percentage of corals were impacted by bleaching at Reef 23032, which indicates that a large portion of what was categorized as algae during these surveys is a result of bleaching-induced mortality opening up substrate. Some minor anchor damage was observed in the shallows. This site is vulnerable to anchor damage due to the extent of cover along the slopes and the fragility of the resident corals. Some minor anchor damage was observed in the shallows. Ecologically, this site is significant due to the high coral cover. Importantly, the site is vulnerable to future bleaching events due to there being mono-specific stands of highly-susceptible *Acropora* corals on both the upper and lower reef slopes.



Reef 23032 Site A



Reef 23032 Site B

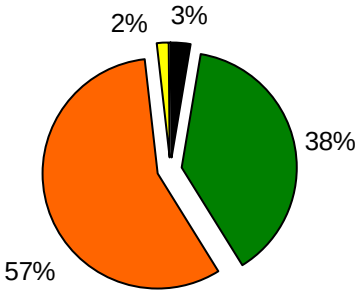
Location 13 – Middle Island – Olive Bay

Habitat:

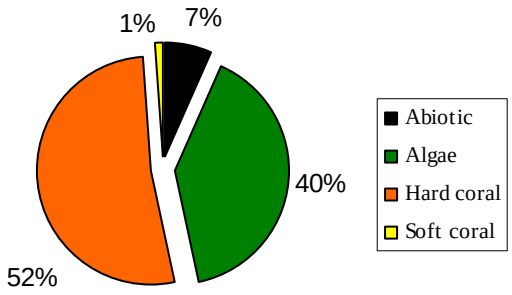
Olive Bay contains a subtidal rock that extends seaward from the northeast side of Middle Island and is of almost continuous depth (4 meters) until it dips, at the seaward border, to a sand base at 5-6 meters. The coral community is almost completely dominated (80%) by branching *Acropora*, the few other hard corals present being *Pocillopora* sp. and *Platygyra* sp. Further towards the seaward border there are large (1 meter in diameter) tabulate *Acropora* colonies as well as a few encrusting Faviid corals. Coral recruits were also common on the rocky edge. On both the upper and lower reef slope the macroalgae *Lobophora* spp was patchily distributed among the base of the branching *Acropora* colonies. Large schools of roving herbivorous fish were observed during the surveys.

Impacts, current condition and summary:

On both the upper and lower reef slope 10% of the benthos was made up by dead standing colonies of branching *Acropora*, most likely due to the bleaching event in 2006. During 2006, 60-70% of the corals at Middle Island were impacted by bleaching, most of which were completely bleached, indicating that a large portion of what was categorized as algae during these surveys was, prior to the 2006 event, live coral. This site is also vulnerable to anchor damage due to the extent of cover along the slopes and the fragility of the resident corals. Several gaps and holes in the branching *Acropora* were observed on the upper reef slope, most likely the result of anchor damage. Ecologically, this site is significant due to the high coral cover. Middle Island is vulnerable to future bleaching events due to there being mono-specific stands of highly-susceptible *Acropora* corals on both the upper and lower reef slopes.



Middle Island Upper Slope



Middle Island Lower Slope

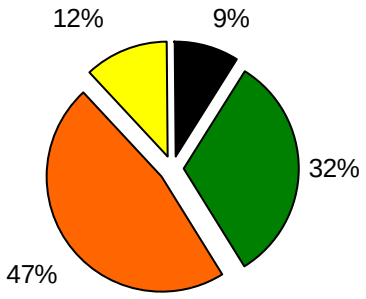
Location 14 – Big Peninsula

Habitat:

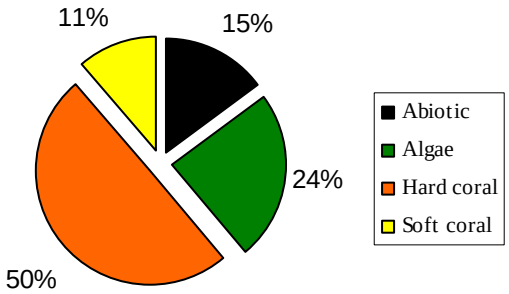
Big Peninsula contains a fringing reef on both sides of a rocky peninsula. On the western side of the peninsula hard coral communities on the upper and lower reef slopes were diverse but dominated by branching and tabulate *Acropora* sp. colonies. Towards the point, where wave energy is highest, there was a transition to more robust encrusting corals including Faviids and *Acropora palifera*. Encrusting *Acanthastrea* species were also in abundance. The eastern side of the peninsula is more exposed and contains large boulders on the upper reef slope. Fish and coral diversity during the time of surveys were both higher on the eastern side of the peninsula. The most common hard coral was the encrusting *Acropora palifera*, though branching and tabulate *Acropora* sp. were also common as well as encrusting Faviids. Schools of damselfish, fusiliers, wrasse, batfish, and parrotfish were all observed on the eastern side of the peninsula during the surveys.

Impacts, current condition and summary:

On both the upper and lower reef slope there were dead standing colonies of branching *Acropora*, most likely due to the bleaching event in 2006. During 2006, 60-70% of the corals at adjacent sites were impacted by bleaching, most of which were completely bleached. It is likely that the percentage of corals impacted at this site was similar and that a portion of what was categorized as algae during the 2007 surveys is directly attributable to mortality from the 2006 event. Ecologically, this site is significant due to the high coral cover and the abundance and diversity of the fish communities there. Big Peninsula is vulnerable to future bleaching events due to there being mono-specific stands of highly-susceptible *Acropora* corals on both the upper and lower reef slopes.



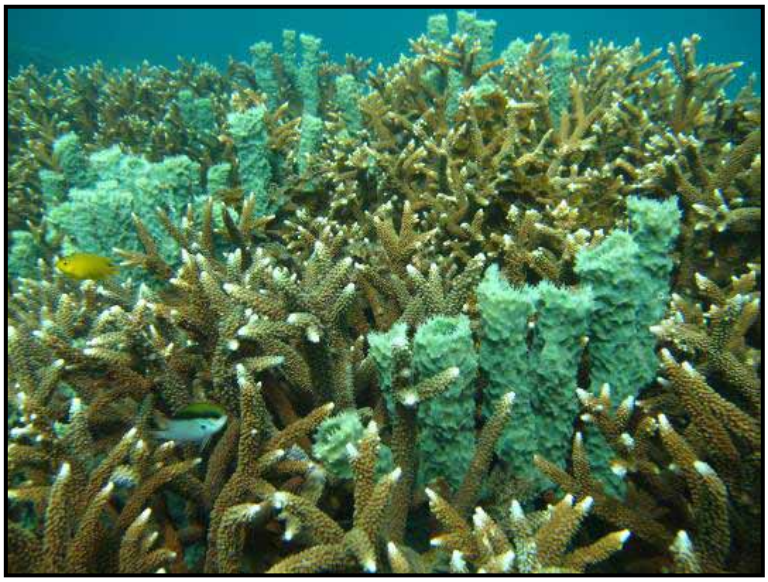
Big Peninsula Upper Slope



Big Peninsula Lower Slope

Location 15 – Half-Tide Rocks (23-822)

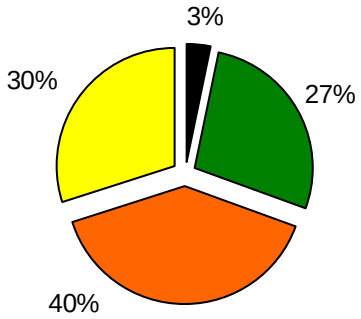
Habitat:



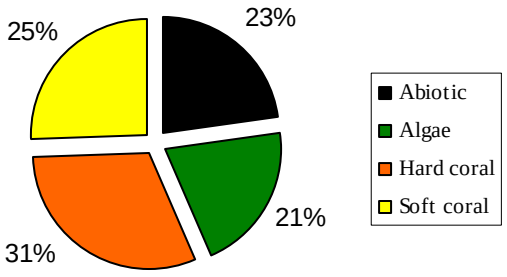
Half Tide Rocks is made up of rocky outcrops and boulders and a shallow gradient down the reef slope to a sand and silt base at 5 meters. The upper reef slope is dominated by hard corals (50%) made up primarily by branching Acropora colonies (85%). Soft corals were also abundant (30% of the benthos) and included *Sarcophyton*, *Sinularia* and *Xenia* sp. On both the upper and lower reef slope there are tabulate *Acropora* colonies with a mixed size-class distribution (0.4 to 2 meters in diameter). On the lower reef slope the benthos is divided evenly amongs hard corals, soft corals, algae, and sand/rubble (~25% each).

Impacts, current condition and summary:

On both the upper and lower reef slope 5 to 10% of the substrate is made up of dead standing tabulate *Acropora* colonies covered in filamentous turf algae. This coral mortality is likely due to the bleaching event in early 2006 or a heavy rainfall event that coincided with an extreme low tide in mid-November 2006. At adjacent sites, as much as 60% of the hard corals bleached during 2006. It is likely that the same percentage of corals were impacted by bleaching at Reef 23032, which indicates that a large portion of what was categorized as algae during these surveys is a result of the colonisation of corals dead due to bleaching. Ecologically, this site is significant due to the high hard and soft coral cover there. Importantly, the site is vulnerable to future bleaching events due to there being mono-specific stands of highly-susceptible *Acropora* corals on both the upper and lower reef slopes.



Half-Tide Rocks Upper Slope



Half-Tide RocksLower Slope

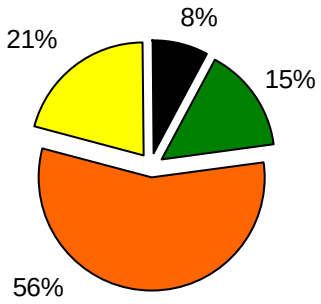
Location 16 – Outer Rock

Habitat:

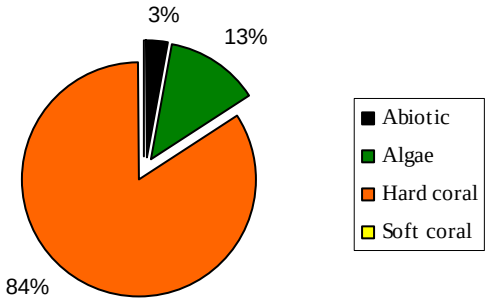
The surveyed site at Outer Rock is on the sheltered north-western side and has a broad slope with a moderate depth gradient. The upper and lower reef slopes are dominated by branching and tabulate forms of *Acropora* (55 and 85% of the benthos respectively). The southern tip of the ledge is more exposed and coral cover is low there (<20%) though soft corals and turf algae are both common. There are a few scattered *Porites* bommies. During the 2007 surveys, few fish were seen though reef-associated fishes like damsels and wrasses were seen on the upper reef slope.

Impacts, current condition and summary:

At the time of the surveys the coral community was in good condition. There was no evidence of bleaching-induced mortality and very little algae though some very minor anchor or storm damage was observed on the upper reef slope. This site was not surveyed during or after the 2006 bleaching event. However, if the coral communities at Outer Rock were affected almost all of the corals survived the bleaching event. Ecologically, this site is important because of the high coral cover on both the upper and lower reef slopes. This site is, however, vulnerable to future bleaching events due to there being mono-specific stands of highly-susceptible *Acropora* corals in the shallows.



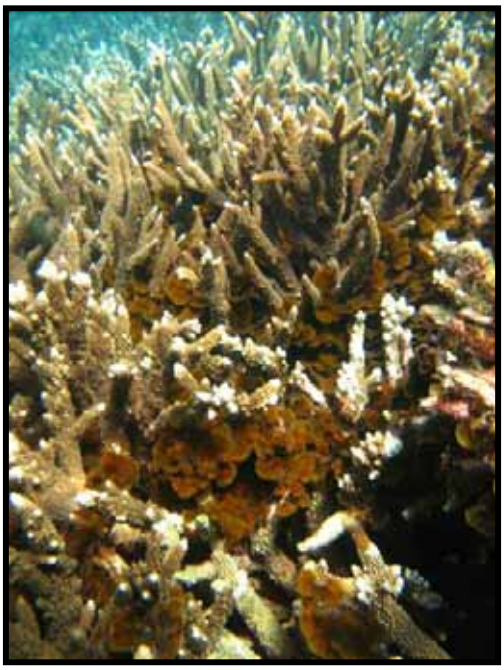
Outer Rock Upper Slope



Outer Rock Lower Slope

Location 17 – Halfway Island

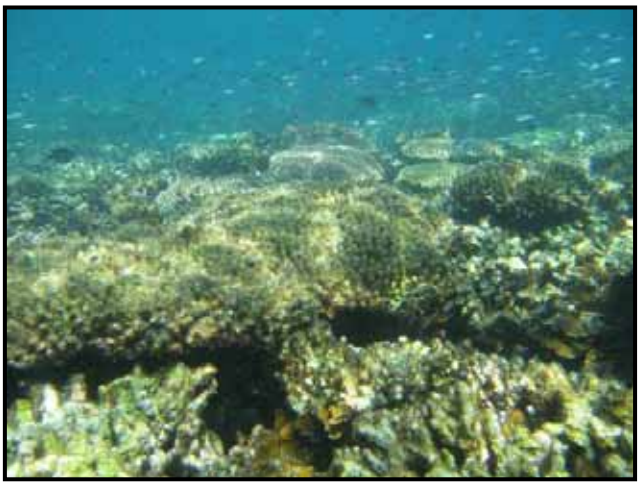
Habitat:

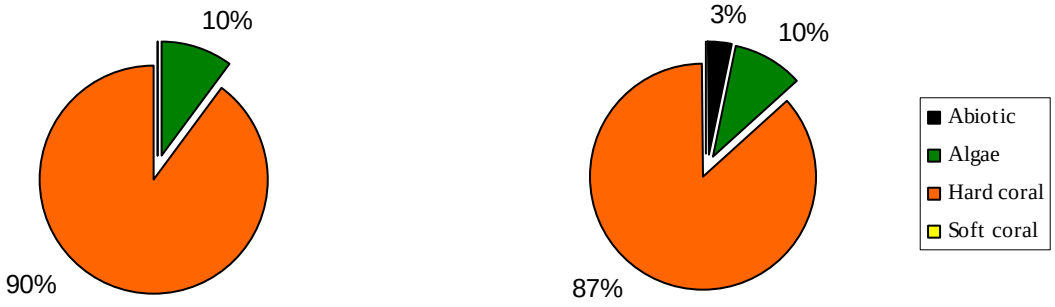


The survey site, on the western side of the island has a broad expanse of reef habitat and a slight depth gradient that transitions to a sand base at 6 meters. Both the upper and lower reef slopes are dominated by branching and tabulate *Acropora* colonies (70 and 90% of the benthos respectively). The macroalgae *Lobophora* grows between almost all of the branches of the *Acropora* colonies. Five large *Porites* bommies were found on the western edge of the reef slope though nowhere else. On the lower reef slope tabulate *Acropora* and soft corals are more common than on the upper slope.

Impacts, current condition and summary:

During the bleaching surveys of 2006, 60% of the hard corals at Halfway Island were affected by bleaching, and a great majority of those were completely bleached. At the time of the 2007 surveys between 5 and 10% of the benthos on the upper and lower reef slope was made up by dead standing branching and tabulate *Acropora* colonies, indicating that a great majority of the corals that bleached in 2006 survived. Coral cover at the site remains extremely high (~90%) though coral cover at this site would most certainly have been close to 100% prior to the 2006 bleaching event. In the extreme shallows (0.5 meters) many of the tabulate, digitate, and branching *Acropora* colonies were dead at the time of the 2007 surveys and covered only by thin turf algaes. This suggests that these corals died when heavy rainfall coincided with an extreme low tide in mid-November 2006. Ecologically, this site is significant due to the high hard coral cover on both the upper and lower reef slopes. This site is vulnerable to bleaching events in the future due to there being mono-specific stands of highly-susceptible *Acropora* corals in the shallows.





Halfway Island Upper Slope

Halfway Island Lower Slope

Location 18 – Humpy Island

Habitat:

The reef at Humpy Island extends from the northeast to the southwest of the western side of the island. Two sites were surveyed; Site A on the northeast side of the reef and Site B, along the western reef slope, opposite the campground. At both sites a broad reef slope extends along a shallow depth gradient to a sand base at 7 meters. Physically they are similar though the benthic communities differ dramatically between the sites.

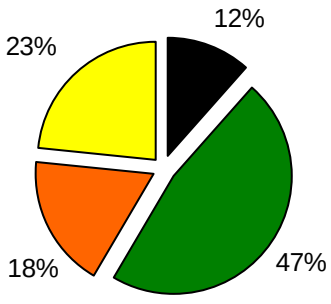
Site A: The upper reef slope at Site A has a low coral cover (20%) made up of tabulate and branching *Acropora* colonies.
Coral cover on the lower reef slope, however, is high (80%) and, like the upper slope, is made up of tabulate and branching *Acropora* colonies.

Site B: The upper and lower reef slopes at Site B are dominated by the macroalgae *Lobophora* (70 and 60% of the benthos respectively). The hard coral communities are, as at Site A, dominated by tabulate and branching *Acropora*.

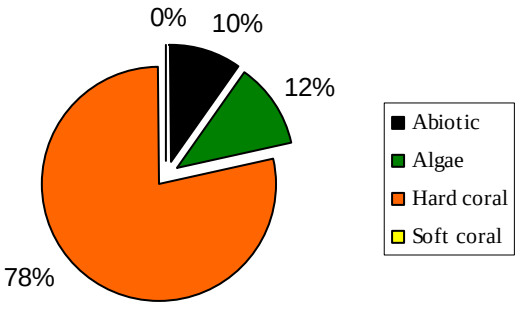
At both sites small fish like damsels were common among the branches of *Acropora* colonies. Rabbitfish, fusiliers, and gobies were also seen during the surveys though not in great abundance.

Impacts, current condition and summary:

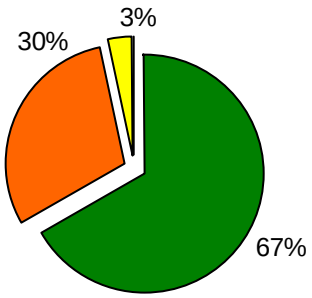
At Site A dead standing branching *Acropora* colonies covered with filamentous turf algae made up 10% of the benthos. This mortality is likely due to the 2006 bleaching event. This site was not surveyed during or after the 2006 bleaching event. However, at adjacent sites, as much as 60% of the hard corals bleached during 2006. It is likely that a similar percentage of corals were impacted by bleaching at Humpy Island, indicating that a great portion of what was categorized as algae during the 2007 surveys is attributable to algae rapidly colonising corals that died during the bleaching event. There were no impacts from anchoring observed during the 2007 surveys. Ecologically, this location is important because of the high hard coral cover on the lower slope. As a result though, the location is vulnerable to future bleaching events since there are mono-specific stands of highly susceptible *Acropora* corals on the upper and lower reef slopes.



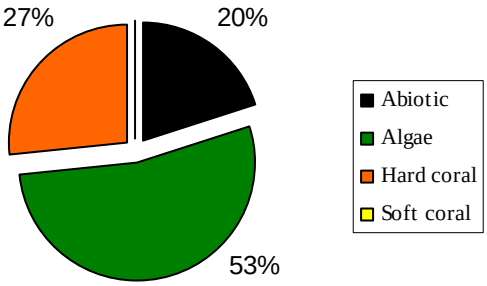
Humpy Island Site A Upper Slope



Humpy Island Site A Lower Slope



Humpy Island Site B Upper Slope



Humpy Island Site B Lower Slope

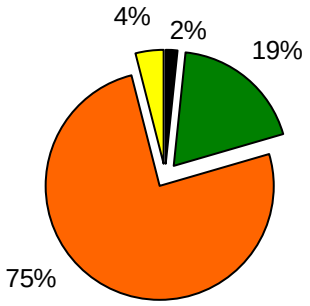
Location 19 – Miall Island

Habitat:

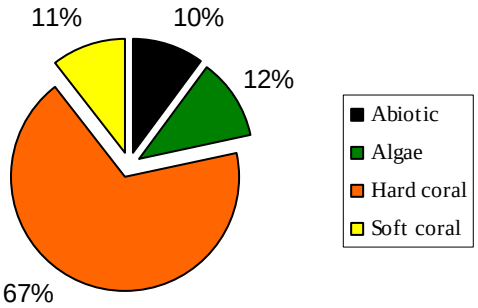
The fringing reef of Miall Island forms along the north and north-eastern slopes and drops quickly from the shallows to 3 meters at which point a reef slope with a shallow depth gradient extends to a sand base at 8 meters. Coral cover exceeds 80% all along the reef slope. The hard coral community on both the upper and lower reef slopes is dominated by branching and tabulate *Acropora* with a well-mixed size class distribution (0.2 to over 2 meters in diameter). Hard coral diversity is highest on the upper reef slopes and encrusting Faviids and *Montipora* sp. are common. Soft corals are patchily distributed along the reef slope, make up 10-20% of the benthos, and are almost entirely made up of *Sinularia* and *Klyxum* species. Wave energy is highest on the eastern slopes and coral cover there is slightly reduced.

Impacts, current condition and summary:

During the bleaching surveys in 2006, 40% of the coral colonies were impacted by bleaching and many colonies were completely bleached. During the 2007 surveys all of the coral communities were in good condition indicating that many corals at this location survived the bleaching event and returned to a healthy condition. Coral cover at Miall Island was higher prior to the 2006 bleaching event by 10 to 15% indicating that a portion of what was classified during these surveys as algae and abiotic is a direct result of corals dying during the bleaching event in 2006. There was some evidence of anchor damage characterized by small pockets of rubble among the stands of branching *Acropora.* During the 2007 surveys there were also a few sightings of coral disease as well as a patchy distribution of the corallivorous gastropod *Drupella*. In the extreme shallows (<0.20 meters) almost all of the corals making up a narrow fringe of reef are dead. It is most likely that this is the result of a heavy rainfall event coinciding with an extreme low tide in mid-November 2006. Ecologically, this location is significant due to the high hard coral cover on both the upper and lower reef slope. Importantly, this location is vulnerable to future bleaching events since the reef is dominated by mono-specific stands of highly-susceptible *Acropora* corals.



Miall Island Upper Slope



Miall Island Lower Slope

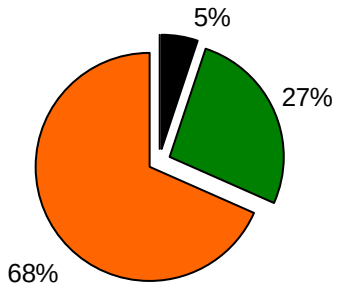
Location 20 – Middle Island - Observatory

Habitat:

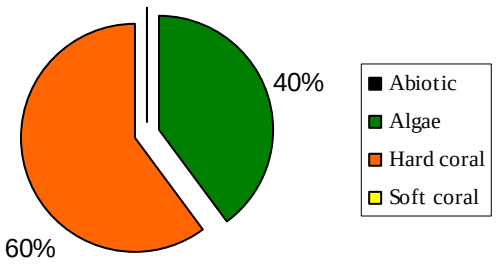
The Observatory is located in the middle of a fringing reef that rapidly changes in depth from 0.5 to 5 meters where there is a sandy base. The coral community is entirely made up of a broad expanse of branching *Acropora* sp. with the macroalgae *Lobophora* common among the base of the branches. Fish are in great abundance and include large trout, sweetlips, snapper, emperor, and parrotfish.

Impacts, current condition and summary:

During the bleaching surveys in 2006, 60-70% of the corals were impacted by bleaching and 30-40% of these were completely bleached. At the time of the 2007 surveys 30% of the benthos was made up of large patches of dead standing *Acropora* colonies covered by filamentous algae, suggesting that many of the colonies that completely bleached in 2006 did not survive. In the extreme shallows (0.2 meters) there is a high level of mortality (>75%) of all corals most likely due to a heavy rainfall event coinciding with an extreme low tide in mid-November 2006. Instances of disease and *Drupella* damage were also observed during the 2007 surveys. Ecologically, this location is significant due to the high levels of hard coral cover and the abundance, diversity, and size of the fish communities that reside there. Though coral cover is still high, cover would have been much higher prior to the 2006 bleaching event and this location is still highly vulnerable to bleaching impacts in the future since there are stands of mono-specific highly-susceptible *Acropora* colonies.



Observatory Site A



Observatory Site B

Discussion

The Keppel Islands are an ecologically and socially important region due to the great variety of habitats, the unusually high coral cover and fish diversity, the variety of active stakeholders and user groups, and the cultural value to its traditional owners. The reef communities of the Keppel Islands are exposed to a range of environmental pressures. In the last decade alone, reefs have been affected by flood plumes from the Fitzroy River (Van Woesik 1991), thermal bleaching events in 2002 and early 2006, and a shallow-water mortality event when a heavy rainfall event coincided with an extreme low tide in late 2006 (Berkelmans and Oliver 1999, Berkelmans et al. 2004).

This assessment has found that the coral communities at almost all of the 20 locations surveyed are dominated by fast growing branching *Acropora* species. Fast-growing *Acropora* species are the most susceptible types of corals to thermal stress (Marshall and Baird 2002), meaning that most of the reefs within the Keppel Islands are highly vulnerable to elevated sea temperatures in the future. In the past, the fringing reefs of the Keppel Islands have demonstrated a capacity for resilience, with remarkable tolerance of the 1998 and 2002 bleaching events and strong recovery from historic flood events. The long-term outlook, however, is for an increase in the frequency of warm temperature anomalies, and the region is therefore likely to suffer from future bleaching.

The loss of almost 40% of corals during the 2006 bleaching event highlights the potential for future degradation of reef quality in Keppel Bay. In the context of climate change, it will be particularly important to restore and maintain the resilience of the reefs in this region. Stress to reefs from degraded water quality, anchor damage, overfishing or other pressures can significantly undermine their natural resilience to large-scale disturbances such as elevated sea temperatures. Building resilience by reducing other sources of stress will give reefs in the Keppel Islands the best chance of coping with climate change. While further degradation is unlikely to be avoided, the extent of damage over coming decades is likely to be influenced by the effectiveness of local management. The strong linkages between people of the Keppel region and the surrounding marine environment suggest that there is much at stake, but also great potential for strong local support for initiatives that aim to build the resilience of reefs in the area.

This initial assessment of the condition of habitats in the Keppel area provides a snapshot of the impacts of recent coral bleaching events and other environmental disturbances. It also identifies sites that are exposed to localised stressors (such as anchoring or fishing) that could affect the resilience of reef communities - there were signs of avoidable damage (such as anchoring impacts) at sites that were otherwise in very good condition.

Further ecological surveys would substantially improve our ability to determine trends in habitat condition. They would also enable a more detailed understanding of the resilience of reef habitats in the area, and the factors that might build or erode their resilience. This knowledge would provide a solid basis for implementing a management response aimed at maximising the resilience of the region to climate change. More detailed studies of patterns of use, local values and resource dependency would also help future planning and response efforts in the region. The enthusiastic participation of local community members in the surveys included in this report indicates the potential for strong community engagement and support for initiatives aimed at conservation and sustainable use. In total, the Keppel Islands offers a valuable and worthy opportunity for developing and implementing management responses that both support the natural resilience of the marine environment and work to support and maintain the cultural values that make the region so unique.

Acknowledgements

We would like to thank QPWS Roslyn Bay for logistical support for this survey; the use of the vessel *Woppaburra* and the enthusiastic assistance from QPWS field staff – John Messersmith, John Olds, Chris Maples, David Marshall and Rod Mackenzie. In addition, we would like to thank the LMAC representatives for their assistance with field work – Brian Hose, Mark Jeffries, Shane Westerly and Alison Jones. Organisation and administration of this study was made possible by QPWS – David Orgill and GBRMPA. Southern Regional Office – Dave Lowe and Kalair Conaghan.

References

Berkelmans R and Oliver J (1999) Large-scale bleaching of corals on the Great Barrier Reef. Coral Reefs Vol 18, 1, 55-60

Berkelmans R, De'ath G, Kininmonth S and Skirving WJ (2004) A comparison of the 1998 and 2002 coral bleaching events on the Great Barrier Reef: spatial correlation, patterns, and predictions. Coral Reefs Vol 23, 1, 74-83

Great Barrier Reef Coral Bleaching Response Plan 2006-2007 http://www.Great Barrier Reefmpa.gov.au/__data/assets/pdf_file/0020/13169/Coral_Bleaching_Response_Plan_2006-07_Final.pdf

Intergovernmental Panel on Climate Change Fourth Assessment Report Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability. Summary for Polocy Makers 23pp http://www.ipcc.ch/SPM13apr07.pdf

Johnson JE and Marshall PA (2007) Climate change and the Great Barrier Reef. GBRMPA

Marshall PA and Baird AH (2000) Bleaching of corals on the Great Barrier Reef: differential susceptibilities among taxa. Coral Reefs 19: 155-163

Van Woesik R (1991) Immediate impact of the January 1991 floods on the coral assemblages of the Keppel Islands, Great Barrier Reef Marine Park Authority Research Publication No23, Townsville

Van Woesik R, DeVantier L and Glazebrook J (1995) Effects of cyclone 'Joy' on nearshore coral communities of the Great Barrier Reef. Mar Ecol Prog Ser Vol. 128: 261-270

Wilson SK, Graham NAJ and Polunin NVC (2007) Appraisal of visual assessments of habitat complexity and benthic composition on coral reefs. Mar Biol 151: 1069-1076

Appendix A. Coordinates of sites surveyed

Location	Site	Latitude	Longitude
40 Acres	A	23 9.029	150 53.379
40 Acres	B	23 8.992	150 53.353
Square Rocks	A	23 5.96	150 53.2
Square Rocks	B	23 5.982	150 53.085
Square Rocks	C	23 6.042	150 53.15
Sloping Island	A	23 5.844	150 53.988
Sloping Island	B	23 5.856	150 53.899
Sloping Island	C	23 3.136	150 53.198
Corroboree Island	A	23 3.109	150 53.331
Corroboree Island	B	23 3.213	150 53.463
Corroboree Island	C	23 3.134	150 53.198
Conical Rocks	-	23 2.797	150 52.618
Pelican Island	A	23 14.5016	150 52.7452
Pelican Island	B	23 14.32	150 52.52
Pelican Island	C	23 14.24	150 52.23
Man & Wife Rocks	-	23 6.947	150 59.4964
Barren Island	-	23 9.447	151 4.21
Bald Rock	-	23 10.1943	150 59.5735
23-032	A	23 10.57	150 59.538
23-032	B	23 10.6948	150 59.679
Middle Is - Olive Point	A	23 9.72	150 55.05
Middle Is - Olive Point	B	23 9.67	150 54.87
Middle Is - Olive Point	C	23 9.72	150 55.19
Middle Is - Olive Point	D	23 9.72	150 55.19
Big Peninsula	A	23 8.95	150 58.23
Big Peninsula	B	23 8.86	150 58.29
Big Peninsula	C	23 8.92	150 58.5
Big Peninsula	D	23 9.09	150 58.51
HalfTide Rocks	A	23 9.27	150 56.32
HalfTide Rocks	B	23 9.238	150 56.316
HalfTide Rocks	C	23 9.164	150 56.31
Outer Rock	-	23 3.864	150 57.031
Halfway Island	A	23 12.025	150 57.99
	B	23 12.436	150 58.336
	C	23 12.57	150 57.96
Miall Is	A	23 9	150 54.114
	B	23 9.186	150 54.477
	C	23 9.29	150 54.439
Observatory	A	23 10.2	150 50.25
	B	23 10.2	150 50.25