Initial survey of the impact of Tropical Cyclone Larry on reefs and islands in the Central Great Barrier Reef

Australian Government

Great Barrier Reef Marine Park Authority

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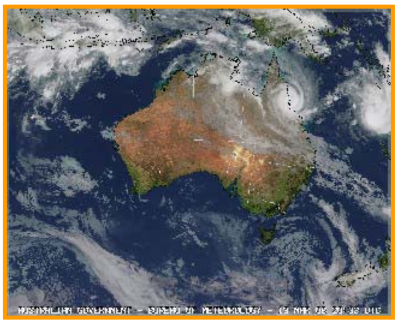

Image courtesy of the Bureau of Meteorology

Summary

Tropical Cyclone Larry (TC Larry) crossed the Queensland coast on 20 March 2006, close to the town of Innisfail. TC Larry was a severe Category 5 cyclone and generated a 50km wide band of 'very destructive' winds between Cairns and Tully. To the north 'destructive' winds were experienced in a band between Cairns and Cape Tribulation. To the south 'destructive' winds were experienced between Tully and the Hinchinbrook/Cardwell region. To assess the impact of TC Larry, the Research and Monitoring Coordination Unit inspected eight reefs between Townsville and Cairns (between 17º and 19º South). This included surveying six reefs primarily for Cyclone impacts, and an additional two reefs as part of the on-going Coral Bleaching Response Programme. These reefs lie perpendicular to TC Larry's track and represent exposure to a variety of wind strengths.

Reefs were surveyed using the 'manta tow' method, and where time and conditions permitted, detailed assessments were conducted by snorkel or SCUBA. While all six 'target' reefs were surveyed for cyclone damage, poor weather conditions prevented assessment of all parts of each reef.

The most common signs of impact included damage to the underlying reef structure, broken and dislodged corals and movement of coral rubble and debris. The majority of the reefs surveyed had experienced previous damage through crown-of-thorns starfish outbreaks. Consequently, coral cover was at low levels before TC Larry affected these reefs and most of the observed impact was damage to the reef structure rather than damage to living corals.

Of the living coral present, coral breakage was most commonly seen on branching and table *Acropora* corals. Coral breakage ranged between 5% and 30% of the corals present, with most reefs showing breakage in approximately 20% of the corals present. Dislodged corals were mainly tabulate *Acropora* and *Porites* bommies. More sheltered back-reef habitats also exhibited coral damage as they had a higher proportion of fragile corals such as branching or tabulate *Acropora* species.

The extent and type of impact varied with proximity to the path of the cyclone. The most heavily damaged reefs were Feather Reef, Ellison Reef and Taylor Reef. These reefs are situated between Tully and Innisfail where the most destructive winds occurred. Reefs further to the north and south were less affected. Hedley Reef appeared to be the least affected of the mid-shelf reefs.

Normanby Island reef (part of the Frankland Islands group) was the only inshore reef surveyed and thus comparisons with other inshore reefs in the region are not possible.

Anecdotal information from tourism operators involved in the "Eye on the Reef" Programme indicated that reefs offshore from Cairns have suffered only minor damage.

Overall, the impacts observed are consistent with those resulting from previous cyclone events. In the absence of further pressures or perturbations, the affected reefs should fully recover. Future surveys of these reefs by the Australian Institute of

Marine Science Long-term Monitoring Programme will enable their recovery to be assessed

A rapid assessment of island flora and fauna was also undertaken at Russell Island (south of Cairns and part of the Frankland Islands group). Damage to vegetation and beaches varied in different parts of the island. The north-western beach of Russell Island suffered the greatest erosion while large amounts of coral rubble and debris were deposited on the western beach. Vegetation damage varied depending on the trees present and their location on the island. Most trees suffered some damage such as broken branches and stripped leaves, but most of the vegetation remained intact. However, vegetation on the northern and north-western aspects suffered severe damage with trees broken and completely stripped of all foliage. Camping infrastructure on the islands was damaged although three Marine Parks mooring buoys were still present.

Observations of damage to island vegetation among the Frankland Island group were also recorded while sailing past Round Island, Mabel Island, Normanby Island and Little Fitzroy Island. The most extreme vegetation damage was again located on the northern and north-western aspects of these islands.

Introduction

The reefs of the Great Barrier Reef are very dynamic ecosystems. Coral reefs are periodically affected by major disturbances such as cyclones or outbreaks of crown-of-thorns starfish. The intense winds generated in a cyclone can create massive waves that break upon coral reefs. These waves, and the debris carried by them, can completely remove all the standing corals and break up the physical structure that forms the reef platform.

The impact of cyclones on coral reefs is often 'patchy' (Puotinen et al. 1997). In the southern hemisphere, wind and wave fields are stronger on the southern side of the cyclone's path and may result in greater damage on reefs situated to the south of a cyclone's track compared to reefs located to the north. Similarly, some reefs may be sheltered from cyclone-generated waves by other reefs closer to the cyclone's track. Damage may also vary across a single reef with the more sheltered 'lee' side of a reef receiving less wave energy than the more exposed reef front.

The amount of damage caused may also vary according to the characteristics of the reef community including:

- the strength of the coral attachment to the substrate;
- the nature of the substrate (loose rubble vs consolidated limestone);
- the amount and type of coral present (fragile branching or plate corals vs large 'boulder' corals); and
- the size of the corals present (medium sized corals are more easily dislodged by waves (Puotinen et al, 1997).

Recovery from cyclone events

In the absence of further disturbances or impacts, coral reefs usually recover in subsequent years. In 1986 Cyclone Manu crossed the coast near Cooktown and generated winds of up to 100km/h. The cyclone reduced live coral cover by 25% on fringing coral reefs at Cape Tribulation. While recovery was hindered by a coral bleaching event in 1987, reef recovery was rapid. Subsequent surveys showed that recovery was well underway and driven by fast growing *Acropora* 'staghorn' and 'table' corals that had survived these events (Chin & Ayling, 2000). However, the rate of recovery is thought to depend on a number of factors including:

- the amount of damage caused;
- the amount and type of coral remaining (fast growing species hasten recovery);
- additional factors such as subsequent storms, coral bleaching, crown-of-thorns starfish outbreaks and water quality; and
- the variety of topography whereby refuge from cyclone damage is offered by overhangs, ridges and outcrops, thus enabling the surviving corals to quickly re-establish the coral community.

More information on the variation of cyclones and coral reefs is contained at Appendix 1.

Tropical Cyclone Larry

Tropical Cyclone Larry (TC Larry) formed in the Coral Sea on March 18 and travelled west until it crossed the Queensland coast near Innisfail on the morning of 20 March 2006 (See Fig. 1). TC Larry was a relatively small cyclone, but was very intense with estimated wind gusts of up to 240/290 km/h and sustained winds of up to 170/215 km/h (Bureau of Meteorology, 2006). Townships under the northern and southern 'eyewall' (Babinda and Silkwood) received most damage.

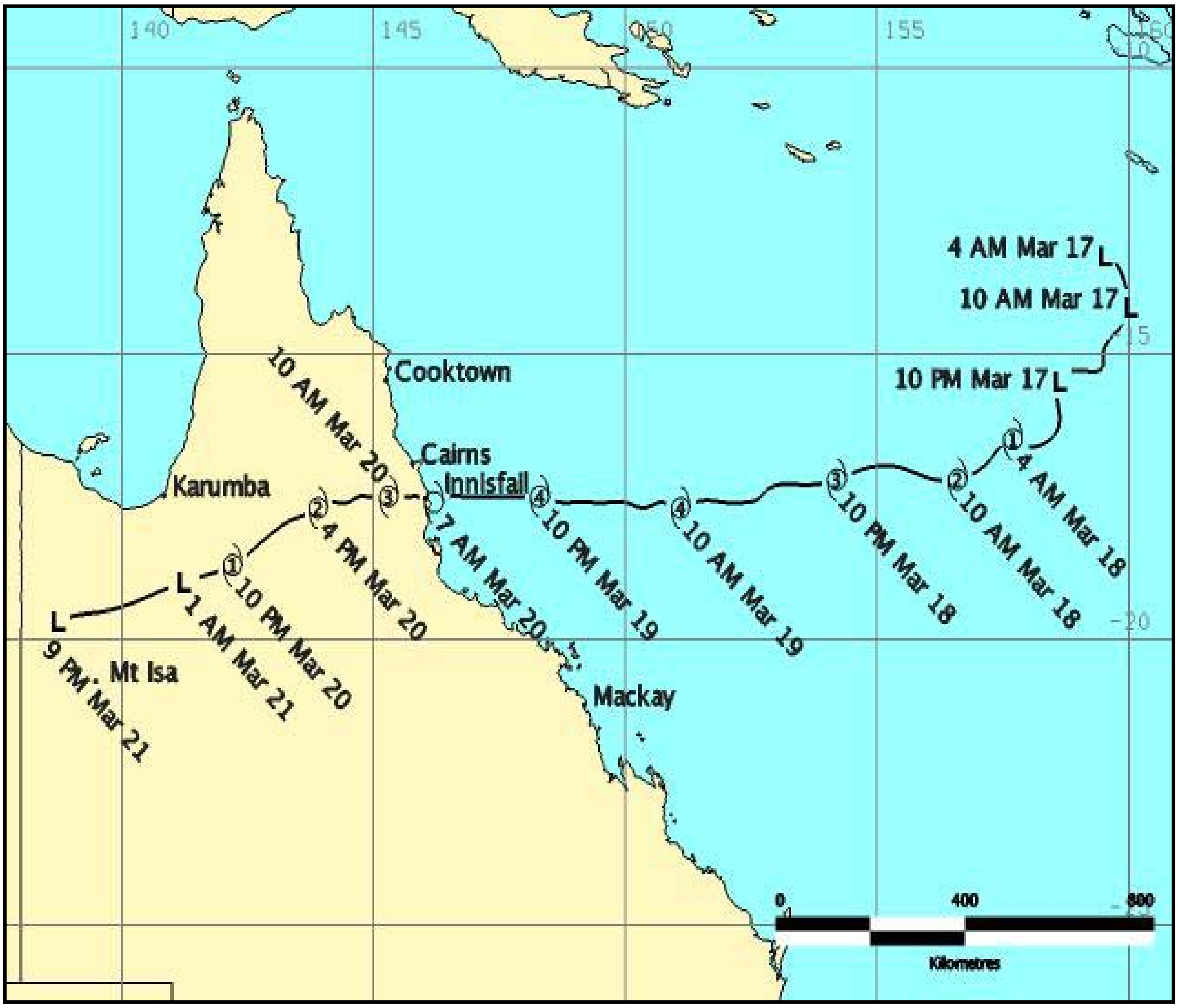

Fig 1. Track of Tropical Cyclone Larry. Image courtesy of the Bureau of Meteorology

TC Larry generated very destructive winds over approximately 5% of the area of the Great Barrier Reef Marine Park in a band between Cairns and Tully. This area covers a number of inshore fringing coral reefs, mid-shelf and outer reefs and several island groups (see Fig. 2).

Survey sites and methodology:

A team from the Great Barrier Reef Marine Park Authority was undertaking a reef-wide coral bleaching survey when TC Larry formed. The survey team was already positioned to conduct coral bleaching surveys on reefs between Townsville and Cairns and was able to travel to reefs affected by TC Larry to conduct impact assessments. The survey trip was conducted from 23-27 March 2006, meaning that the team arrived at the first site only three days after the cyclone had passed through the region.

The survey design was based on previous surveys of cyclone impacts undertaken by the Australian Institute of Marine Science (AIMS). Five mid-shelf reefs at varying distances to TC Larry's track were surveyed to provide information on how damage varied with distance to the 'eye' of the cyclone (see Fig.2). An inshore reef (Normanby Island) was also assessed to identify cyclone effects on inshore reef communities.

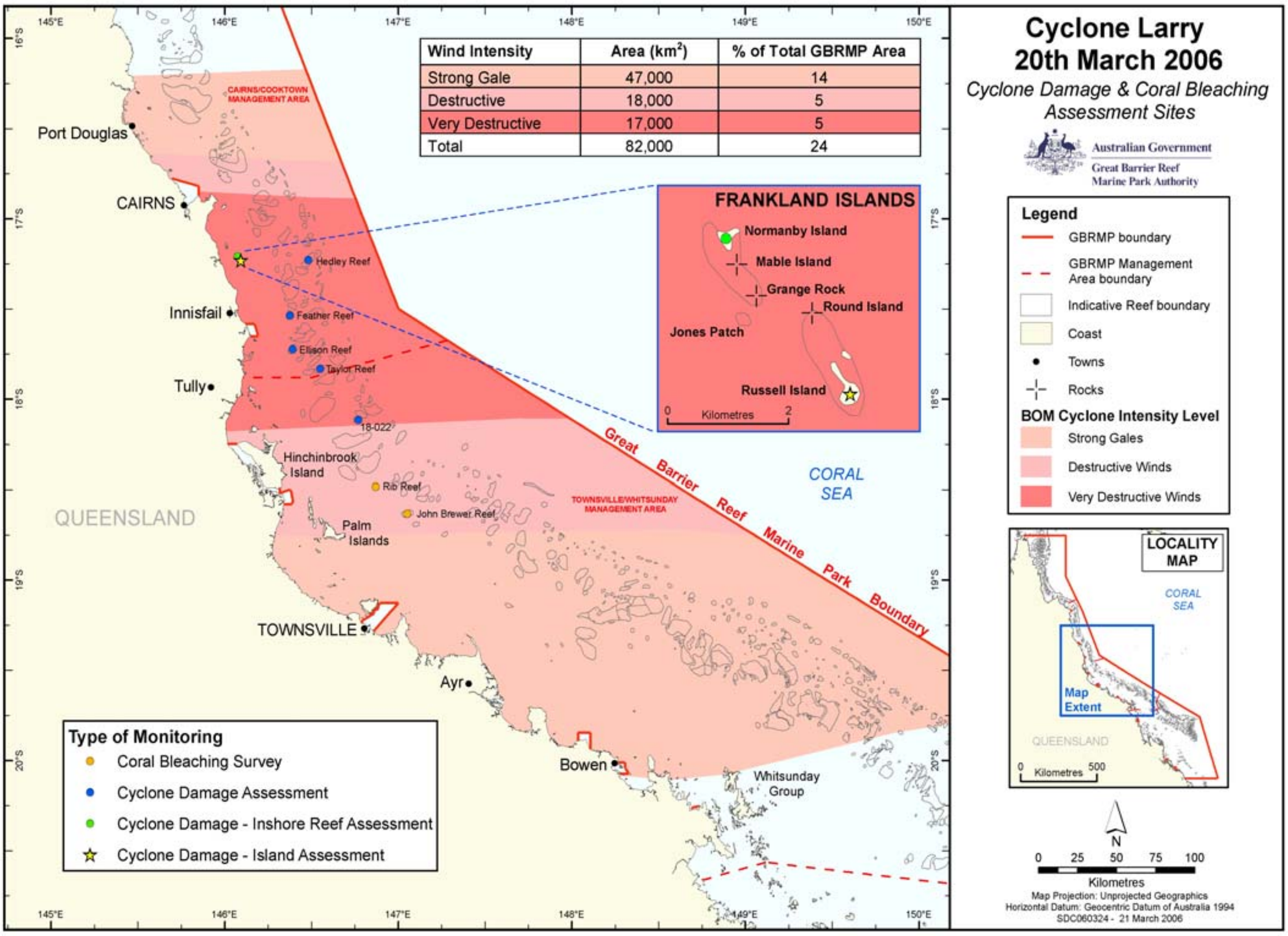

Fig 2. Wind intensity bands generated by TC Larry and cyclone assessment survey sites

Where possible, assessments were conducted at reef sites that are regularly monitored by other programmes such as the AIMS Long-term Monitoring Programme. This provided a baseline against which to assess the actual impact of the cyclone. Selecting these sites also allows the collection of information about reef recovery when these reefs are next surveyed.

At each reef, observers first described the reef community and then assessed damage according to categories established by previous surveys of cyclone impacts. The assessment methods included manta tow, snorkel assessments and detailed assessments on SCUBA.

- **Manta tow surveys** involve a snorkeller being towed behind a boat at a slow speed (2 knots) along the reef edge. This technique allows coverage over large areas of reef. However this technique does not allow the collection of more detailed information or video records. Manta tows allowed assessment of the different reef 'zones'. The more exposed reef zones are the NE flank and reef front, while more sheltered zones include the NW flank, SW flank and the 'back reef'. At each zone, six manta tows of two minutes each were planned. However, poor weather conditions meant that at some reefs, more exposed zones could not be assessed for safety reasons. Over the five-day trip approximately 10km of reef was surveyed by manta tow.
- **Snorkel surveys** were conducted to collect more detailed information at specific sites. Snorkelling surveys covered a small amount of reef with some detail and observers took notes and photographs of key features. Snorkelling was restricted to shallower sites and more sheltered locations.
- Surveys were conducted at several sites by divers using **SCUBA** equipment. SCUBA surveys allow the collection of detailed observations at a variety of depths, and the collection of photographs and video records. SCUBA surveys were intensive but confined to a limited area.

The surveys undertaken at each reef are detailed in Table 1.

Indicators

The following indicators were recorded at each site:

Describing the reef community:

- Percentage live coral cover: the amount of the substrate covered by live hard corals.
- Percentage soft coral cover: the amount of the substrate covered by soft corals.
- Percentage macroalgae cover: the amount of the substrate covered in macroalgae.

Describing cyclone damage

- Coral breakage: the proportion of live corals present that were broken.
- Soft corals torn: the proportion of soft corals present that were torn.
- Scarring: the proportion of live hard coral showing scarring from debris.
- Matrix exfoliation: the amount of substrate showing signs of 'matrix exfoliation' – where the surface of the reef structure, or 'reef matrix', was peeled off revealing the underlying layers.
- Corals dislodged: the amount of substrate covered in dislodged corals such as broken tabulate *Acropora* corals or coral boulders such as *Porites* bommies.
- Slab slip: the amount of substrate where slabs of coral matrix had fallen away down the reef slope.

- Sediment transport: the amount of substrate covered in transported sediment or debris such as sand and coral rubble, including ‘gutters’ filled with coral rubble.
- Matrix excavation: the amount of substrate where the reef matrix had been gouged out and the underlying material removed.

Table 1: Survey effort at each reef site (numbers in parentheses denote the number of 2 minute manta tows conducted).

Date	Reef	Flank	Method	Comments
23/03/06	John Brewer Reef	NE flank	SCUBA	Dive conducted at AIMS LTMP site
	Rib Reef	NE flank	SCUBA	Dive conducted at AIMS LTMP site
24/03/06	18-022	NE Flank (X 4)	Manta tow	Testing the manta tow method. Survey terminated due to rough conditions.
24/03/06	Taylor Reef	NE front (X3) NE flank (X 4) NW flank (X 1)	Manta tow Manta tow Manta tow	Surveys terminated due to rough conditions. NW flank was sheltered back reef.
25/03/06		Back reef behind intertidal cay	Snorkel	Rapid snorkel assessment near intertidal cay.
25/03/06	Ellison Reef	SE flank (X 6) Reef front (X 6) NE flank (X 6)	Manta tow Manta tow Manta tow	Rough conditions with low visibility.
25/03/06	Feather Reef	SE Flank (X 6) NE flank (X 6) NW flank (X 1)	Manta tow Manta tow Manta tow	Size of the reef meant that the SE and NE surveys also covered parts of the Reef front. Rough conditions.
		NW flank (back)	Snorkel	Rapid snorkel assessment in sheltered back reef
		NE flank	SCUBA	Dive conducted at AIMS LTMP site
26/03/06	Hedley Reef	S (back reef) (X6) NW flank (X6) NE flank (X3)	Manta tow Manta tow Manta tow	NE flank survey cut short due to logistical difficulties
		NE flank	SCUBA	Dive conducted at AIMS LTMP site
		NW flank (back)	Snorkel	Rapid snorkel assessment in sheltered back reef
27/03/06	Normanby Reef	NE	SCUBA	Dive conducted at AIMS inshore monitoring site

Island assessments:
Several island groups and sand cays were exposed to very destructive winds. Where possible, the survey team assessed the effects of the cyclone on flora and fauna of these islands as described in Table 2.

Table 2: Island surveys for cyclone damage and survey activity undertaken

Island	Survey activities
Taylor Cay (25/3/06)	A bird count was conducted from a Zodiac passing near an un-vegetated inter-tidal cay to the southwest of Taylor Reef. The count was conducted on an ebbing tide.
Russell Island (27/03/06)	Survey team walked the island perimeter and noted damage to vegetation, camping infrastructure, Marine Parks mooring buoys, erosion and deposition on beaches and debris. Bird count conducted.
Round Rock (27/03/06)	Sailed to the east of Round Rock en route to Cairns. Damage to vegetation on the southern, western and northern aspects noted.
Mabel Island (27/03/06)	Sailed to the west of Mabel Island en route to Cairns. Damage to vegetation on the southern, eastern and northern aspects noted.
Normanby Island (27/03/06)	Sailed to the east of Normanby Island en route to Cairns. Damage to vegetation on the southern, eastern and northern aspects noted.
Fitzroy Island (27/03/06)	Sailed to the west of Fitzroy Island en route to Cairns. Damage to vegetation on the southern, western and northern aspects noted.

Survey results

John Brewer Reef and Rib Reef
Surveys by AIMS in April 2005 found that both John Brewer Reef and Rib Reef had low coral cover and were recovering from crown-of-thorns starfish outbreaks in 2003.

The current surveys were conducted at the NE flanks of John Brewer Reef and Rib Reef to assess coral bleaching using video transects. The video transects will be analysed at a later date. In the interim, a rapid assessment was also undertaken that revealed that both reefs had very little (<10%) live hard coral cover. Both reefs exhibited some signs of cyclone damage with some broken corals and patches of exfoliated matrix.

Example of coral breakage. Branching and plate *Acropora* corals are more easily damaged that boulder shaped *Porites* corals.

Reef 18-022
Reef 18-022 appeared to have had low coral cover before TC Larry affected it. Remaining live coral cover was estimated at 20%, soft coral cover 20%. The surface layer of the reef matrix had been exfoliated or peeled back in some places revealing the normally hidden underlying layers.

The main damage indicators observed at the NE flank were dislodged boulder corals, matrix exfoliation and the deposition of coral rubble. Approximately 25% of the hard corals present were damaged where coral branches had been broken or sheared off.

Reef 18-022 damage summary (numbers in parentheses indicate the number of manta-tows conducted)

Reef zone	Coral breakage	Corals dislodged	Scarring	Soft coral torn	Matrix exfoliated	Slab slip	Sediment transport	Matrix excavation
NE flank (4)	25%	30%	20%	15%	20%	5%	30%	10%

Taylor Reef
Surveys by AIMS in December 2005 found that coral cover was low. Taylor Reef has had a history of outbreaks of crown-of-thorns starfish.

Taylor Reef is located to the south of TC Larry's track and is monitored by AIMS. Both hard and soft coral cover was low (<10%). Impacts were highest on the NE flank and NE front where most of the wave energy would have been expended. These sites had up to 50% of exfoliated matrix. There was also damage to soft corals. Damage extended to a depth of 7m with debris from the upper crest rolling down the reef slope.

Matrix excavation at Taylor Reef. Note the distinctive yellow colouration that identified this as new material. The yellow colouration was caused by colonising diatoms that will rapidly be replaced by turfing algae.

The more sheltered NW edge appeared relatively undamaged with the reef structure appearing to be mostly intact aside from a few patches of exfoliated matrix and some broken corals.

Taylor Reef damage summary (numbers in parentheses indicate the number of manta-tows conducted)

Reef zone	Coral breakage	Corals dislodged	Scarring	Soft coral torn	Matrix exfoliated	Slab slip	Sediment transport	Matrix excavation
NE Front (3)	10%	5%	10%	10%	50%	10%	20%	10%
NE flank (4)	5%	10%	0%	10%	50%	0%	10%	10%
NW flank (1)	10%	5%	5%	5%	15%	5%	10%	0%

A snorkel assessment was also conducted in the sheltered back reef of Taylor Reef at a site north of Taylor Cay. The substrate was mainly sand and hard substrate with patches of coral. Overall hard coral cover was <5%, soft coral cover was 10-15% and macroalgae cover <5%. At least 50% of the branching and table corals were damaged to some extent, with branches broken and sheared off. About 10-15% of soft corals were torn. There was some matrix excavation with blocks of the coral matrix up to 1m in size excavated and left exposed. There were a few ‘gutters’ or ‘bowling alleys’ evident in the coral patches. Corals growing on the sides of these gutters had been damaged by debris which was often deposited in a fan shaped wedge at the end of the gutter.

Most of the coral rubble, debris and toppled corals found at Taylor reef were long dead suggesting that this reef did not have much live coral cover before being affected by the cyclone.

A damaged branching *Acropora* coral in the sheltered back reef of Taylor Reef. This was most likely damaged by debris washed off the more exposed reef front.

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Matrix exfoliation (left). The top layer has been peeled away revealing the substrate underneath. Note the characteristic yellow colouration.

Ellison Reef
Surveys by AIMS in December 2005 found that coral cover was moderate to low.

Ellison Reef is located to the south of TC Larry’s track. This reef had slightly more hard coral cover than Taylor Reef, with up to 15% coral cover in the SE flank but only about 10% hard coral cover on the NE and NW flanks. Soft coral cover was 10%. Many of the remaining branching corals were broken, particularly in the SE flank. There was a significant level of exfoliated reef matrix and coral rubble in gutters. There was a debris field on the lower slope extending along the reef front. Much of this debris was from freshly broken coral (not yet covered by surface algae). The same level of damage was observed for the NE sector, although there was an increase in exfoliated matrix. The more sheltered NW showed lower levels of damage compared to the seaward side. However, the NW back-reef area showed that destructive forces had extended to the more fragile coral community. Damage here was ‘patchy’ with some areas showing extensive coral breakage, torn soft corals and sponges, toppled corals, and rubble deposition. It is possible that cyclone-generated waves had swept over the front reef and swept debris (like shrapnel) across the back-reef area. Surprisingly, on the boundary with the NW reef slope, live corals appeared untouched with standing fragile table corals surrounded by loose rubble.

Ellison Reef damage summary (numbers in parentheses indicate the number of manta-tows conducted)

Reef zone	Coral breakage	Corals dislodged	Scarring	Soft coral torn	Matrix exfoliated	Slab slip	Sediment transport	Matrix excavation
SE flank (6)	30%	10%	10%	<5%	35%	5%	20%	10%
NE flank (6)	15%	10%	10%	<5%	50%	10%	30%	10%
NW flank (6)	10% (80% in patches)	20%	10%	<5% (60% in patches)	10%	<5%	20% (70% in patches)	20%

Feather Reef
Surveys by AIMS in December 2005 found that coral cover was moderate to low. Feather Reef is recovering from a crown-of-thorns starfish outbreak in 2001.


The reef slope on the NE flank and front reef was quite steep and live coral cover was low.

Feather Reef lies directly to the east of Innisfail and TC Larry passed directly over this reef. Both the SE and NE flank sites had low coral cover with ~10% hard coral cover and between 10-20% soft coral cover. Matrix exfoliation was significant. There was significant rubble deposition in the gutters and a broad debris field were observed. The reef slope became steeper in the middle section of reef (between the SE and NE flanks) and much larger patches of reef surface were missing (matrix exfoliation). The NE flank had lots of broken branching corals but damage was patchy. At least a third of the encrusting soft corals were torn or shredded at this site.


There were several rubble filled ‘gutter’s or ‘bowling alleys’ that were filled with rubble. Corals growing on the edges of these gutters showed signs of damage including broken branches or scarring from debris (evident here as patches of white).

A SCUBA survey was conducted at the NE site. The site was a steep reef slope with many small coral colonies intact, but surrounded by fresh rubble spilling out from gutters. A portion of the reef edge had collapsed onto the slope and there were several broken branching corals. However, many live corals remained and it seems that there were sheltered patches where live corals were protected; eg: behind outcrops, on solid surfaces, in crevices.

Feather Reef damage summary (numbers in parentheses indicate the number of manta-tows conducted)

Reef zone	Coral breakage	Corals dislodged	Scarring	Soft coral torn	Matrix exfoliated	Slab slip	Sediment transport	Matrix excavation
SE flank (6)	20%	5%	0%	10%	40%	0%	30%	<5%
NE flank (6)	<5% (50% in patches)	0 % (10% in patches)	0%	30%	40%	0%	20%	<5%

Time also permitted a short snorkel survey of the back reef habitat behind the NW flank. The water was shallow (2-4m depth). The majority (50%) of the substrate was comprised of sand and hard substrate covered in turfing algae and crustose coralline algae. Deposited sand and recently exposed rubble comprised 10-20% of the substrate. Live coral cover was less than 5% and concentrated in patches, soft coral cover was <5% and macroalgae cover was <1%. Some corals were broken and the matrix was exposed in patches. Some overturned, long-dead tabulate *Acropora* colonies were observed.

The NW back reef was sparsely populated by corals. Some matrix exfoliation, coral breakages and dislodgement was observed such as this overturned *Acropora* table coral.

Hedley Reef

Surveys by AIMS in November 2005 found that coral cover was moderate to low.

Hedley Reef is located to the north of Cyclone Larry's path. The current survey revealed that the SW back-reef has a moderate gradient to depth, with modest live hard coral cover (15%) and soft coral cover (15%). Up to 20% of the corals present exhibited signs of breakage. The northern most tows at this site revealed an increasing amount of exfoliated substrate. The gutters on the back-reef were filled with newly exposed debris. The middle of the back reef showed signs of deposition with lots of *Porites* colonies, larger than bowling balls that had been dislodged and deposited in the back-reef. This debris damaged hard corals and scarred encrusting corals. These 'bowling balls' were finally deposited in gutters and on the sand flat. Surprisingly, many tabulate corals remained untouched by the passage of this debris. The back-reef manta-tow continued with observations of

Gutters in the back-reef were filled with coral rubble. However the more exposed front reef did not appear to have as much damage with less rubble, matrix exfoliation, coral breakage or dislodgement.

rubble-filled gutters and exfoliation of surface substrate. Clearly the cyclone was able to significantly influence the more fragile back-reef community despite its more sheltered position.

The NE edge of Hedley reef had the highest amount of live coral cover of all reefs surveyed. Coral cover was much higher here (35% live hard coral cover; 40% soft coral cover), with a large diversity of corals including large-sized table corals. Both hard and soft corals experienced minor damage. The steep-sloped edge gave way to a spur and groove system around the NE corner and closer to the reef front. There appeared to be little damage to the coral community with only a few tabulates turned over and some broken branching corals. On the sand base at 8m there were stands of branching corals, all intact, and a strong contrast to the back-reef.

The NE flank of Hedley Reef had the highest coral cover of all the reefs surveyed. This site did not experience significant impacts compared to other sites and reefs.

Hedley Reef damage summary (numbers in parentheses indicate the number of manta-tows conducted)

Reef zone	Coral breakage	Corals dislodged	Scarring	Soft coral torn	Matrix exfoliated	Slab slip	Sediment transport	Matrix excavation
SW back reef (6)	20%	30%	10%	10%	30%	0%	20%	20%
NE flank (9)	10%	5%	0%	0%	0%	0%	5%	0%

A SCUBA survey was conducted at the NE flank that is also monitored by AIMS. At small spatial scales, impacts became more apparent with few overturned tabulate *Acropora* corals and shredded soft coral. However, the overall impression was of a healthy, functioning, reef community that did not suffer major damage from the cyclone.

Snorkel at Hedley Reef Northwest flank – back reef

A snorkel assessment was conducted on sheltered coral patch reefs behind the NW flank. The reef consisted of patches of reef amongst sand. Live hard coral cover and soft coral cover were both 10%, but there was a high proportion of the substrate

At Hedley Reef, cyclone impacts were minor at even shallow and exposed sites. The prevalence of crustose coralline algae may have helped to consolidate the reef matrix, enabling it to better withstand cyclone waves.

covered with crustose coralline algae (30-40%) and algae turfs 20-30%. Macroalgae cover was less than 5%. Some excavated rubble gutters were observed and matrix exfoliation was estimated at 20% cover. Nevertheless, there was not much rubble present and the substrate appeared to be consolidated by crustose coralline algae. Minor damage was observed to soft and hard corals, but there did not appear to have been many of the more fragile branching or table corals at this site.

Frankland Islands – Normanby Reef

Surveys by AIMS in February 2005 found moderate levels of coral cover at this site.

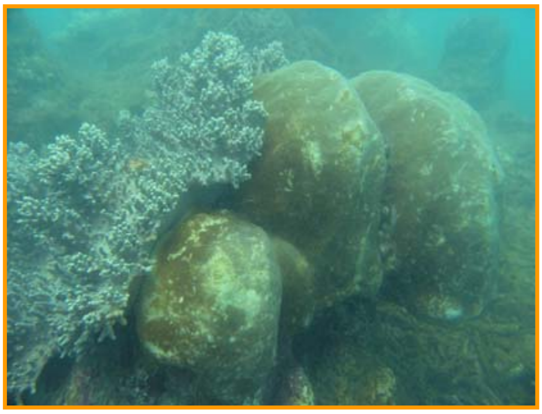
The conditions and visibility meant that it was not possible to survey this site using the manta-tow method. Consequently, a survey was conducted on SCUBA at a site on the NE side of Normanby Island. This site is also monitored by the AIMS.

Visibility was low with a significant amount of suspended sediment. Consequently it was not possible to estimate coral cover. The live corals that were found were widely dispersed and clumped in patches amid an expansive rubble field. This rubble field pre-dated the cyclone and most likely originated from other disturbance events including coral bleaching in1998 and crown-of-thorns starfish (AIMS 2006; Chin & Ayling 2000).

The survey revealed widespread coral breakage and matrix exfoliation with many *Acropora* table corals overturned or broken across the tips. There were many recently broken coral fragments dispersed throughout the rubble field indicating significant coral breakage from the cyclone. Many soft corals were torn and small Porites boulders (<1m across) had been dislodged. Damage may have been exacerbated by the relatively shallow water as this site.

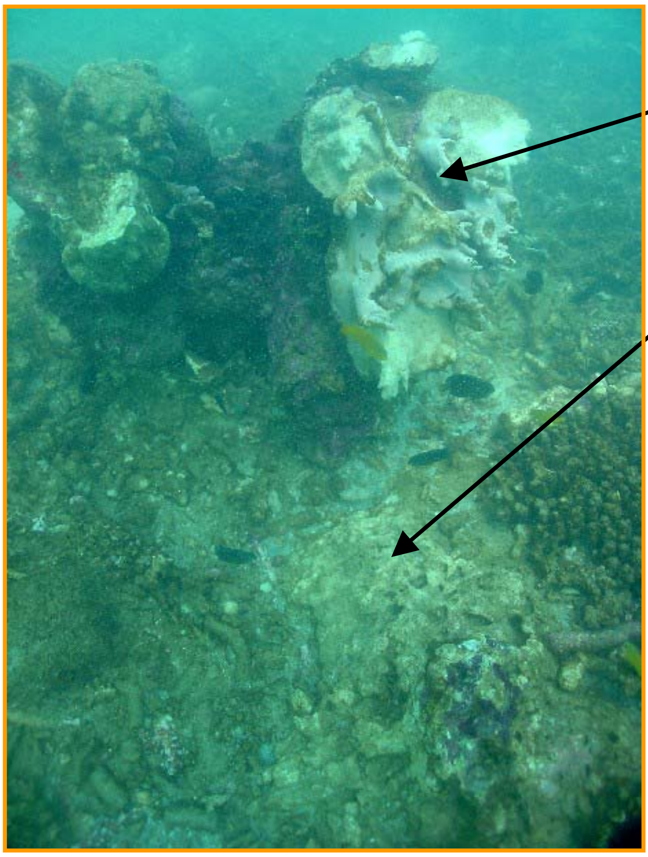
Live corals were found in patches amid an extensive rubble field. The rubble was mainly comprised of older material, but significant amounts of new coral fragments and debris (white) were present.

The coral patches included large *Porites* bommies and *Acropora* plate corals. Cyclone related damage was evident on many of these corals with a large number exhibiting broken tips and edges.



Some of the *Porites* boulder corals showed abrasions and scars that were probably caused by re-suspended debris during the cyclone's passage.

Normanby Reef continued:



Many of the soft coral clumps were damaged and torn.

Patches of matrix exfoliation were observed where the surface layers of the reef were peeled off.

The cyclone broke off the tips of many large tabulate corals (above). New fragments of branching coral were scattered across the rubble field (below).

Rapid assessment of cyclone damage to islands

Taylor Cay

While conducting a snorkel survey in the sheltered back reef, the number and species of birds present on an inter-tidal sand cay were counted. The survey was conducted on the morning of March 25th, on an ebb tide approximately 2 hours after the peak of high tide. An estimated 200 birds were present including 3 brown boobies, approximately 30 common and white-capped noddies, and between 150 and 170 other tern species. The birds were actively feeding.

Seabirds were roosting on Taylor Cay approximately two hours after the turn of the tide .The survey was conducted five days after the cyclone had passed through this region.

Russell Island

While the vessel was anchored in the Frankland Island Group, there was an opportunity to visit Russell Island to assess the impact of the cyclone on the island's flora and fauna. A shore party landed on the northern beach at the campsite managed by the Queensland Environmental Protection Agency (EPA) and walked around the island in an anti-clockwise direction. The shore party noted damage to the different vegetation zones, signs of erosion and deposition of beach material, conducted a bird count, took photographs and made video records.

The Russell Island campsite was littered with broken branches and some fallen trees. However the camping infrastructure appeared to be intact.

Northern side

The impact on beaches at Russell Island varied with some beaches appearing to be untouched while others showed extensive erosion or deposition. The north-facing beach closest to the EPA campsite was heavily eroded with sand washed away past the high tide mark, exposing the roots of trees. The beach at the single campsite to the west of the main camping area had been heavily eroded and one of the campsite benches had been washed onto the beach.

The main campsite was largely intact and the infrastructure (tables, benches, posts and signage) appeared to be unharmed. However, there were broken branches and several fallen trees in the camping area. The walking track leading from the campsite was impassable due to fallen debris. Most of the casuarinas on this side of the island were still standing but many had broken branches. In contrast the beach almond trees behind the fringing zone of casuarinas appeared to have been more heavily damaged, with more fallen trees, larger broken branches and the emergent tops of these trees were stripped of their leaves.


Examples of beach erosion on the north-facing beach (above). Sand had been removed from beyond the high tide mark, exposing tree roots and in some cases causing trees to fall over and washing away a bench from the beach-front campsite. The bush almond trees towards the interior appeared to be more heavily damaged (below centre and below right) than the casuarinas.



Western side

The northwest and west-facing beach appeared to be a deposition zone. Large amounts of coral rubble had been excavated from the surrounding shallows and dumped high on the beach. There was also floating debris present in the surf zone. The casuarina fringe on this side appeared to be more intact than the northern beach and there were fewer broken branches and fallen trees. The vegetation behind the casuarina fringe was also mostly intact except for distinct patches where larger trees (casuarinas and bush almond) had fallen over. The southern end of this beach appeared to have been a deposition zone for large trees and other floating debris that had accumulated here.

Rubble piled up on the NW side of the island.

At the southern end of the island the western beach joined the east-facing beach to form a narrow sand spit. This spit joined the 'main' island to a vegetated rocky islet to the south.

Southern islet

The southern islet was comprised of two rocky hills that were not accessible. A navigation light was situated on the eastern hill and appeared to be functioning normally. Impacts to vegetation on the north-eastern, northern and north-western aspects of the islet were noted. The vegetation on these aspects was severely damaged with all foliage stripped off, branches broken and trees snapped. The damage was most severe on the northern and north-western aspects of the islet where vegetation had been reduced to bare trunks and branches.

Floating debris accumulated at the southern end of the west-facing beach.

The vegetation on the NW and northern aspects of the rocky islet south of Russell Island were most affected with trees 2-3 meters above sea level stripped of all foliage.

Island fauna

The shore party noted the presence of several small skinks and observed a 3m long reticulated python in a pile of wooden debris on the sand spit. It is unknown whether this was an existing resident or a new arrival washed onto the island via floating debris from the mainland.

A bird count was conducted on the sand spit joining the main island to a rocky islet to the east. Approximately 110 lesser-crested terns were observed roosting on the spit and actively feeding on baitfish.

Round Island, Mabel Island, Normanby Island and Fitzroy Island
While sailing to Cairns, the survey team used binoculars to note vegetation damage on other islands in the Frankland Island group (Round Island, Mabel Island and Normanby Island), and on Fitzroy Island (south of Cairns). All the islands exhibited a similar pattern of vegetation impact, with vegetation mostly intact except for the northern and north-western aspects of each island where trees were stripped of their foliage and only bare trunks remained.

Other information

Information about the impacts of TC Larry at other reefs was also received from tourism industry staff involved in the Eye on the Reef Programme, a joint initiative between the GBRMPA, the CRC Reef and the Great Barrier Reef Tourism Industry. Industry staff reported that damage was minor at Michaelmas Reef and Moore Reef with only minor breakage of fragile branching and table corals observed.

Discussion and conclusions

Of the reefs surveyed, Feather Reef, Ellison Reef and Taylor Reef were the reefs most affected by TC Larry. However, the extent and type of impact caused by this cyclone was extremely variable. Damage observed included some breakage, tearing and dislodgement of corals and damage to the reef structure through matrix exfoliation or excavation. Most of the dislodged corals and coral rubble appeared to be material that had died prior to the cyclone. Pre-cyclone surveys by AIMS showed that most of these reefs had low coral cover due to factors such as crown-of-thorns starfish outbreaks. Consequently, there were relatively few live hard corals present when the cyclone passed and the most significant signs of damage were exfoliation and excavation of the reef structure. The cyclone did damage between 10% and 30% of the remaining corals but these were mainly more fragile branching and table *Acropora* corals. These corals are relatively fast growing corals and are likely to recover in the next 1-3 years.

The cyclone may have completely removed small coral colonies that had recruited to these sites since previous disturbance events such as crown-of-thorns starfish outbreaks between 2000 and 2003. Consequently, recovery from these previous events (eg: outbreaks of crown-of-thorns starfish between 2000-2003) could be delayed. Alternatively, the removal of long standing dead coral and loose coral rubble may have created new areas of stable substrate for colonisation. Additionally, a few of the scattered fragments of coral may be able to establish themselves and grow into new corals. The overall effects of TC Larry on recovery from previous disturbances will only become evident with subsequent monitoring.

Of the reefs surveyed, Ellison Reef and Feather Reef were closest to TC Larry and are two of the three most affected reefs. Interestingly, both Taylor Reef and Hedley Reef are located a similar distance from TC Larry's track but Hedley Reef had relatively minor damage. It is possible that Hedley Reef was provided some protection by the RAAF shoals to the east whereas the reef complex surrounding Taylor Reef did not afford the same level of protection. Another potential factor is that being located to the south of TC Larry, Taylor Reef may have been exposed to stronger winds and waves characteristic of the southern side of cyclones in the southern hemisphere.

The more exposed and fragile parts of the reef exhibited the most extensive damage. The NE flanks, reef fronts and SE flanks were the most affected however it should be noted that poor weather conditions often made it impossible to survey the most exposed sections. The cyclone still affected more sheltered back-reef sites with signs of debris deposition, matrix exfoliation, coral breakage and dislodgement of corals. Impacts in 'sheltered' back reef environments may have been exacerbated by the abundance of more fragile coral growth forms in these areas, and the deposition of debris and dislodged corals. Cyclone Larry's crossing also coincided with neap-low tides that may have increased the effects of cyclone waves in these back reef environments. Damage was also very patchy on some sites where small sections of the reef had up to 80% coral breakage.

Overall, the impacts observed are consistent with those resulting from previous cyclone events. In the absence of further pressures or perturbations, these reefs could be expected to make a full recovery. Further surveys of these reefs by the AIMS Long-term Monitoring Programme will enable their recovery to be assessed.

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Appendix 1: Variation on coral reefs

An extract from the State of the Great Barrier Reef *On-line*
http://www.gbrmpa.gov.au/corp_site/info_services/publications/sotr/index.html

Variation on coral reefs

Variation across space
Although some systematic cross-shelf and north-south trends can be found among the reefs of the Great Barrier Reef, a great deal of natural variation can exist among these reefs. It is not unusual for coral cover to vary greatly between two reefs that are relatively close to each other, as events such as storms or crown-of-thorns starfish outbreaks may devastate one reef while leaving a nearby reef relatively untouched. Furthermore, widely differing levels of coral cover and species assemblages (or community composition) are normally encountered at different depths, or on different sides of a reef.

Storm waves have significant effects on coral cover and composition. A cyclone can reduce coral cover to zero or leave only the most robust corals standing

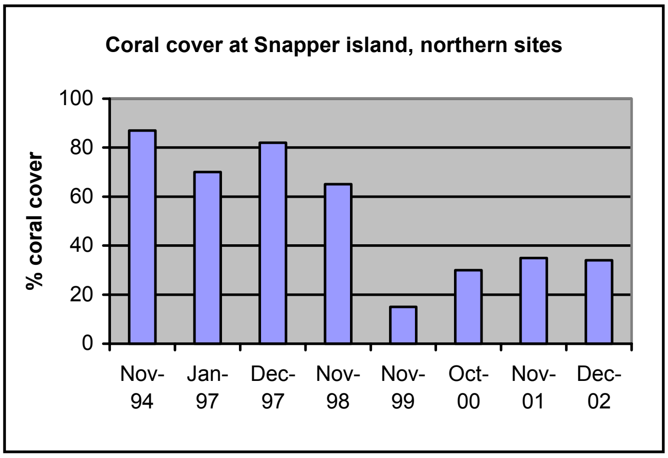
Variation over time
Coral cover and community composition can vary greatly over time. During the summer, warmer water temperatures prompt the rapid growth of macroalgae on many inshore reefs, altering the reef's appearance and community composition. However, during the cooler winter months much of this marcoalgae dies and corals become dominant once more. Variability over time is further increased by disturbance events such as crown-of-thorns starfish outbreaks and cyclones. These events can reduce coral cover to zero but subsequent recovery and regrowth should return coral cover to pre-disturbance levels. As such, a 'normal' reef could exist in any of the following states:

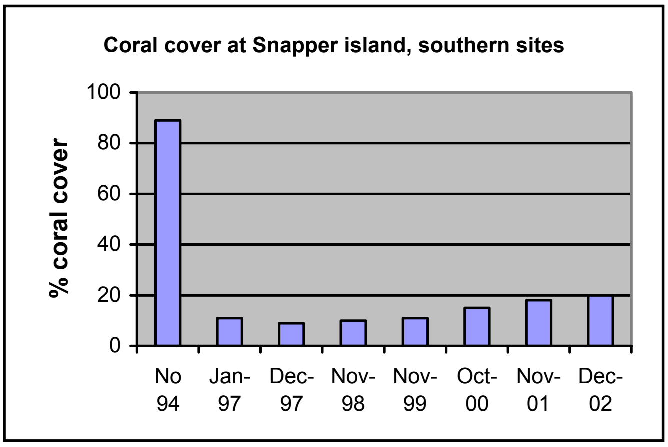
- low level of coral cover and reduced diversity (eg: reef severely damaged by a recent cyclone with more fragile species being disproportionately affected);
- intermediate levels of coral cover and fluctuating community composition (eg: reef recovering from the cyclone, some species recovering, pulse of new recruitment and growth to colonise empty space, coral cover gradually increasing and bare substrate being colonised by new corals);
- high levels of coral cover (eg: the reef exists in a relatively stable state or state of gradual change with mildly fluctuating coral cover and community composition).

The transition between these states may be as rapid as one or two years and any of these three states could be considered "normal" for a healthy reef. As such, the Great Barrier Reef has been described as a "patchwork mosaic" of reef communities at various stages of growth or recovery at any one time.

A number of studies have demonstrated the level of variability and extent of reef community mosaics. In one 30-year study on Heron Island in the southern Great Barrier Reef, coral cover was found to vary between 0 and 80 percent depending on the site. In another study, annual surveys of inshore reefs demonstrated large fluctuations in coral cover and community composition from year to year in response to cyclones, freshwater flood events and coral bleaching (see below). Furthermore, the extent of these impacts and recovery rate depended on the community composition present before and after the impact, and environmental conditions.

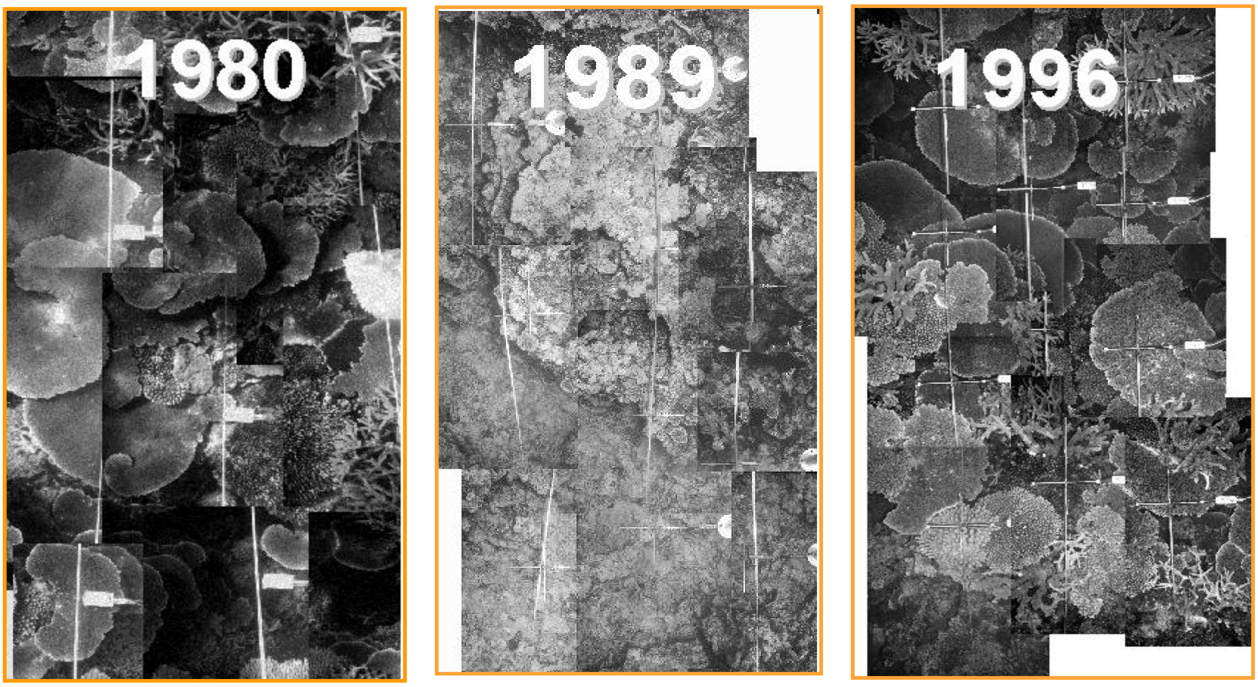
A comparison of coral cover at two locations at Snapper Island demonstrates the variability of coral reefs. In March 1996, the Daintree region received heavy rainfall resulting in major freshwater runoff. Flood plumes inundated Snapper Island and coral cover on the south facing sites was reduced from 90 percent to just ten percent with most of the surviving colonies being resistant *Porites* corals. Meanwhile, the northern facing sites (only 3 kilometres away from the southern sites) were only slightly affected, as they were protected from the flood plume. However, coral cover was dramatically reduced at these northern sites later by the 1998 reef wide bleaching event, and cyclone Rona in 1999. In contrast, the southern sites, while still having low coral cover, did not suffer such dramatic reductions as the remaining *Porities* corals are very robust and weathered the impacts of both the bleaching event and the cyclone. New growth of fast growing Acroporid corals is now occurring at the southern Snapper Island sites which should result in a rapid increase in coral cover - unless the reef is affected by some other disturbance event.





The variability of coral reefs is vividly demonstrated in another long-term study by AIMS scientists who regularly photograph patches of coral reef. In the example shown below, a patch of reef at Rib Reef in the Central section of the GBRMP had very high coral cover and diversity in 1980. However, an outbreak of crown-of-thorns starfish in 1985 and damage caused by Cyclone Aivu in 1989 reduced coral cover to almost nothing. However, over the next seven years, coral cover rapidly increased and by 1996 had reached pre-disturbance levels.

Photographs courtesy of Dr. Terry Done, Australian Institute of Marine Science



A different type of long-term study has involved the analysis of coral density bands, which provide estimates of growth similar to that obtained from tree rings. This study has shown that a full analysis of the last 231 years indicates a series of repeated declines and recoveries of similar or even greater magnitude.

Another method of investigating possible cases of reef degradation over long periods is through the comparison of historical photographs of the reef with contemporary scenes from the same location. A comprehensive survey of historical photographs dating back to 1893, undertaken by the Great Barrier Reef Marine Park Authority (GBRMPA), has indicated that out of 14 reefs investigated:

- six showed no obvious changes;
- four showed decreases in hard coral cover; and
- four showed decreases in coral cover only in certain areas.

The Great Barrier Reef is a "patchwork mosaic" of different reef communities, all at different states of growth, decline or recovery