RESEARCH PUBLICATION No.23

Immediate Impact of the January 1991 Floods on the Coral Assemblages of the Keppel Islands

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Great Barrier Reef Marine Park Authority

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A REPORT TO THE GREAT BARRIER REEF MARINE PARK AUTHORITY

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Bibliography.
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1. Corals - Queensland - Keppel Islands - Effect of water level on. I. Great Barrier Reef Marine Park Authority (Australia). II. Title. (Series: Research publication (Great Barrier Reef Marine Park Authority (Australia)) ; no. 23).

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EXECUTIVE SUMMARY

Flood waters from the Fitzroy River inundated the Keppel Islands in January 1991 resulting in considerable decreases in salinity, for a period of 19 days, at the surface (8 to 10 ppt) and at shallow depths (15 to 28 ppt at 3 m). Data from coral surveys undertaken in 1989 were used to assess the degree of damage. The shallow coral reefs on the leeward edge of the islands were substantially damaged by the flood waters. Approximately 85% of the coral was dead and overgrown by turf algae. Absolute mortality continued to -1.3 m Low Water Datum (LWD), below this demarcation a narrow band of bleached coral was evident (expelled zooxanthellae). Beyond this distinct band, corals remained alive - although the reef only extended a further 1.0 to 1.5 m onto sand. The exposed slopes of Great Keppel Island, Bald Rock and Barron Island were only marginally affected. In contrast to the leeward side, these reefs have only narrow reef flats. Approximately 5% of the established colonies appeared recently dead and overgrown with turf algae, approximately 10% of the corals were bleached.

Mortality was most extensive for acroporids and pocilloporids. Survival in shallow habitats was apparent for faviids (*Leptastrea, Cyphastrea, Goniastrea, Favites, and Favia species) Turbinaria spp., Porites spp., Psammocora sp. and Coscinaraea sp.* Ironically, the species most vulnerable to low salinities (*Acropora* species) dominate the reef assemblages - a consequence of regional circumstance.

INTRODUCTION

Extensive rainfall in the Rockhampton region, in late December 1990 and early January 1991, led to considerable flooding of the Fitzroy River catchment (Figure 1). This area is about 14 million hectares making it the second largest catchment in Queensland. Typical flood discharges are 10,000 m^3s^{-1}, although in 1918 it discharged 24,000 m^3s^{-1} and in 1954 15,500 m^3s^{-1}. During these periods the river rose some 8m which was maintained for 26 days in 1918 and 13 days in 1954 (Figure 2).

Discharge from the Fitzroy is directed into Keppel Bay (Figure 3). The depth of the bay does not exceed 20 metres. Although the Fitzroy River discharges to the south, exposure of its plume to the predominant south east winds and currents (Beach Protection Authority 1979), once out of the protection of Curtis Island, causes a residual movement of discharge to the north via long-shore drift. Within the region spring tides fluctuate to 5.1m inducing strong semi-diurnal tidal currents. Some tidal deflection occurs around the mouth of the Fitzroy River and around the islands, although tides generally flood to the north and ebb to the south.

The 1991 floods initiated an integrated research project by the Queensland National Parks and Wildlife Services (QNPWS) and the Great Barrier Reef Marine Park Authority (GBRMPA) in order to assess regional and temporal variation in salinity and nutrient conditions and assess the immediate impact on coral assemblages fringing the continental islands within Keppel Bay. The present study was undertaken in February 1991. This period coincided with a brief (four day) flood, three weeks after the main event.

A preliminary SCUBA survey was conducted in 1989 to examine the coral assemblages within Keppel Bay (Van Woesik 1989). Fish assemblages were surveyed simultaneously (Steven 1989). Benthic communities appeared as distinct ecological entities when compared with other fringing reefs in the Northumberland, Cumberland and Whitsunday Islands. They supported mainly fast growing arborescent *Acropora* (staghorn) species. The reefs were primarily dominated by *A. formosa, A. microphthalma and A. millepora.* Leeward reefs were shallow, supporting high coral cover on well defined reef flats, crests and steep, although shallow, reef slopes. Windward reefs extended deeper, they did not however support any reef flats although coral diversity was higher in these locations.

This report describes the effects of the flood waters on the coral assemblages on seven islands in Keppel Bay using a previously collected dataset as a reference.

METHODS

Field surveys were conducted using SCUBA from the 11th to the 15th of February, 1991. The original intention of the field study was to re-survey the eight permanent sites established in 1989 (Van Woesik 1989), and assess changes to the benthic constituents. However, a different and more appropriate experimental design was adopted due to, firstly, the poor visibility (1-1.5m), and secondly, as the majority of previous sites,

FIGURE 1. Fitzroy River catchment area. (From BPA report 1979).

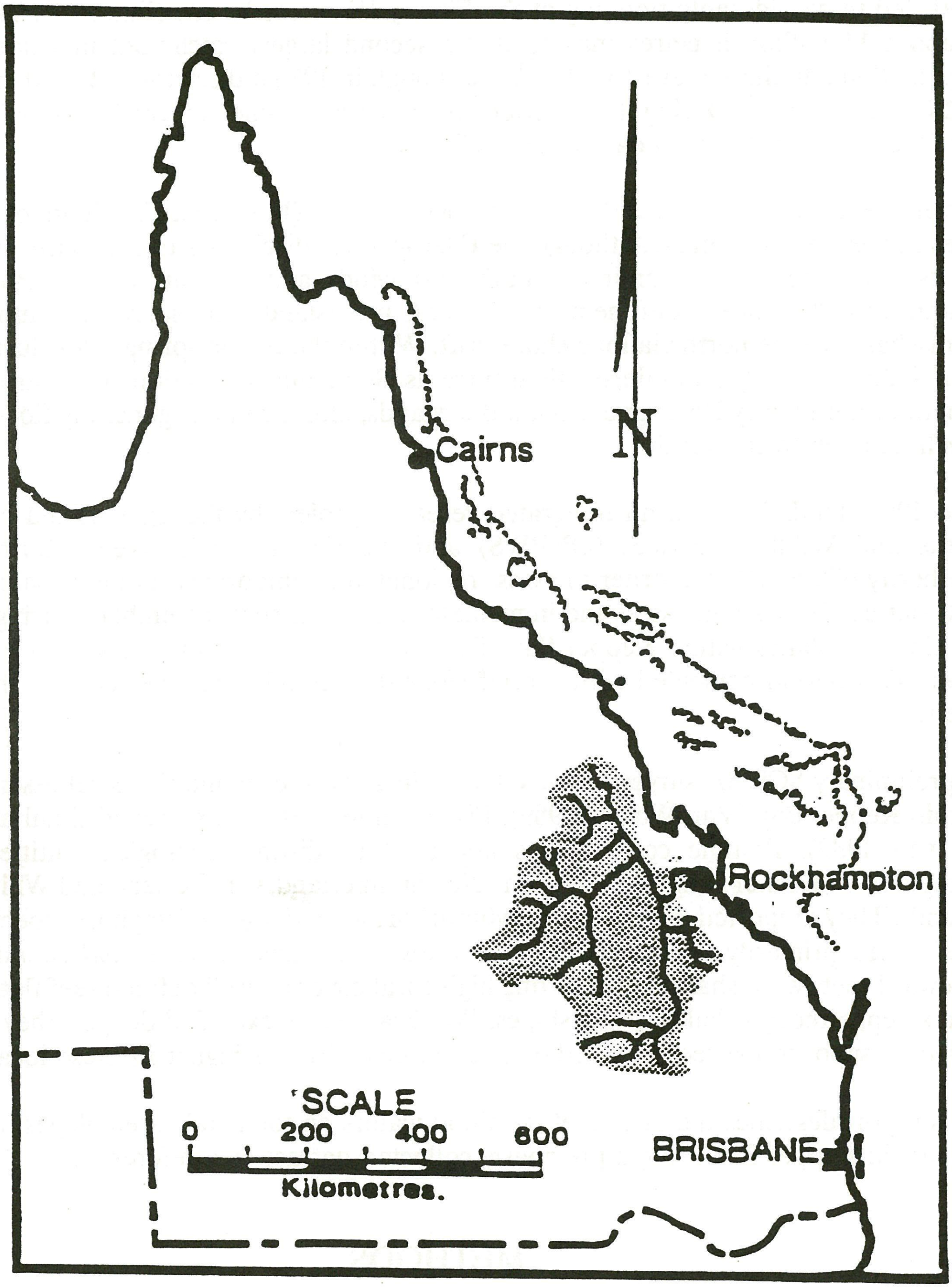
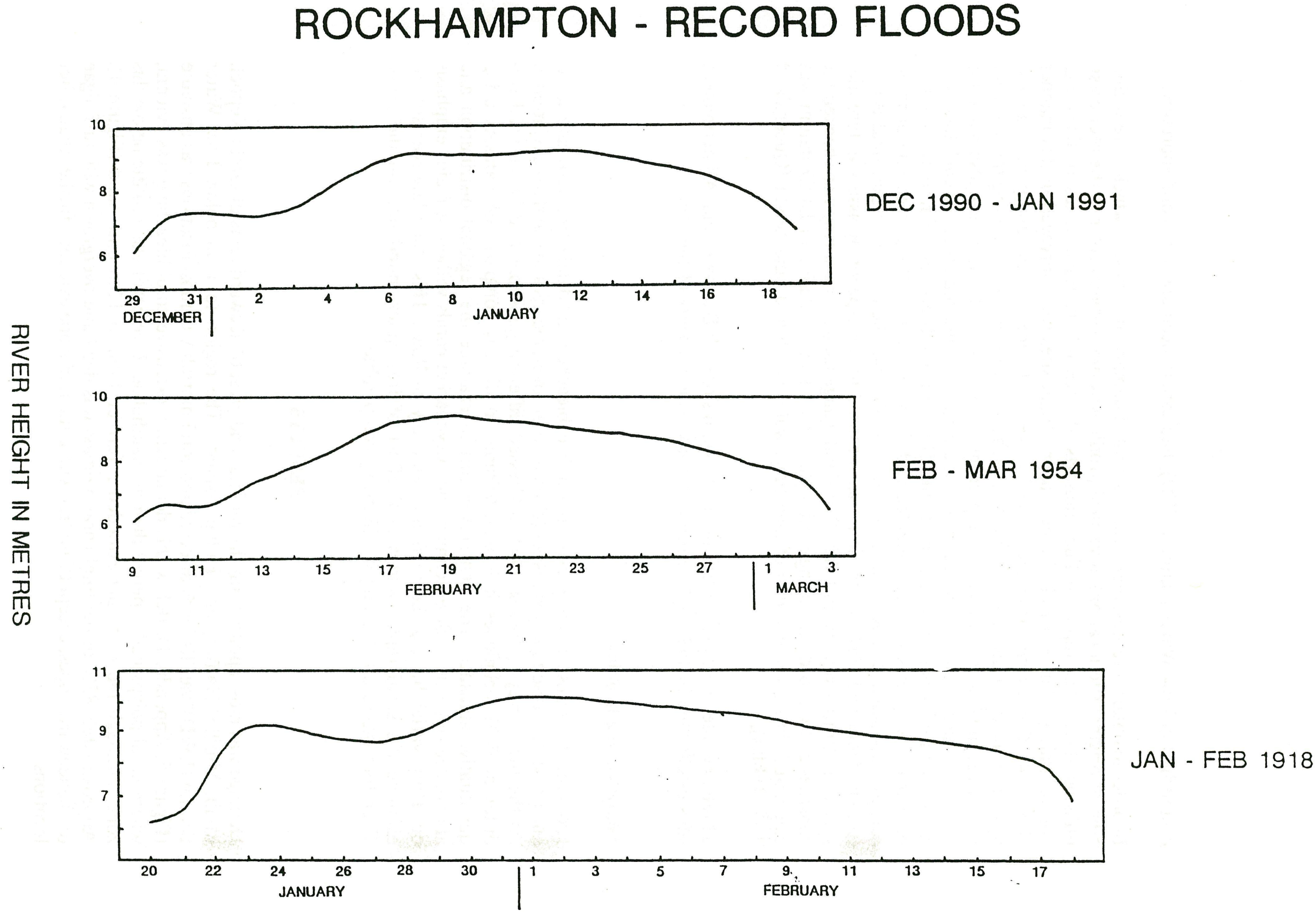


FIGURE 2. Data derived from Bureau of Meteorology report 1991.



established at Low Water Datum (LWD), had experienced absolute coral mortality.

In order to obtain a representative assessment of damage at each site (which were within 50m of original site location), a vertical profile was run perpendicular to the reef crest, utilising three 15m replicate line transects at each depth. Each series of lines was approximately 1.0m (vertical distance) apart. Eight sites were surveyed in this manner (Figure 4). Cover estimates were made for live coral, recently dead and bleached coral by measuring the transitional intercept at each biotic category and summing the intercept lengths. Estimates were expressed in percent cover. Cover estimates were also made for soft coral, macroalgae, turf algae, sand/rubble, sponges and zoanthids. At each location, random searches were undertaken within a $50m^2$ area to observe any differential survival of species. A species list was compiled and each colony was allocated to one of three categories - dead, damaged (bleached or partially bleached) or alive and unaffected. Colony depth and observation time was recorded to retrospectively assess differential species responses relative to LWD. The depth gauge used in the survey was checked for consistency by two divers using a fibreglass tape. Depth relative to LWD datum was calculated through integration of dive time, water depth and tidal height (Queensland Tide Tables).

Three new sites were established on the leeward slopes of Barron Island. All permanent sites established in 1989 will be useful for assessing recovery of the reef.

Analytical methodology

From the line transects, cover estimates of live, bleached and dead coral were calculated and presented as summary statistics (percent total cover, means and standard deviations). As the two surveys (1990 & 1991) addressed different questions and hence used two different field techniques it is unacceptable to directly compare the datasets using quantitative statistics. The first survey sort to examine the regional distribution and abundance patterns of Scleractinian and Alcyonarian corals without a major emphasis on depth variability (as the reefs are relatively shallow). This study however sort to examine the stratigraphic and spatial effect of freshwater inundation on the reefs. Therefore the results are only qualitatively comparable.

RESULTS

Damage was most apparent on the reef flat and crest on leeward reefs of Great Keppel, Miall, Middle, Halfway and Humpy Islands. The region to 1.3m below Low Water Datum (LWD) was distinctly affected and coral mortality at most locations was absolute (Figure 5, Appendix 1). Below this demarcation extensive coral bleaching was evident, where coral polyps had expelled their zooxanthellae. Live coral was prolific below this zone, although the reef only extended a further 1.0m to 1.5m onto sand (Figure 4). Approximately 85% of the total coral biomass was dead and overgrown with turf algae on the leeward slopes, except Clam Bay where the reef slope extended further than other locations.

FIGURE 3. Keppel Bay.

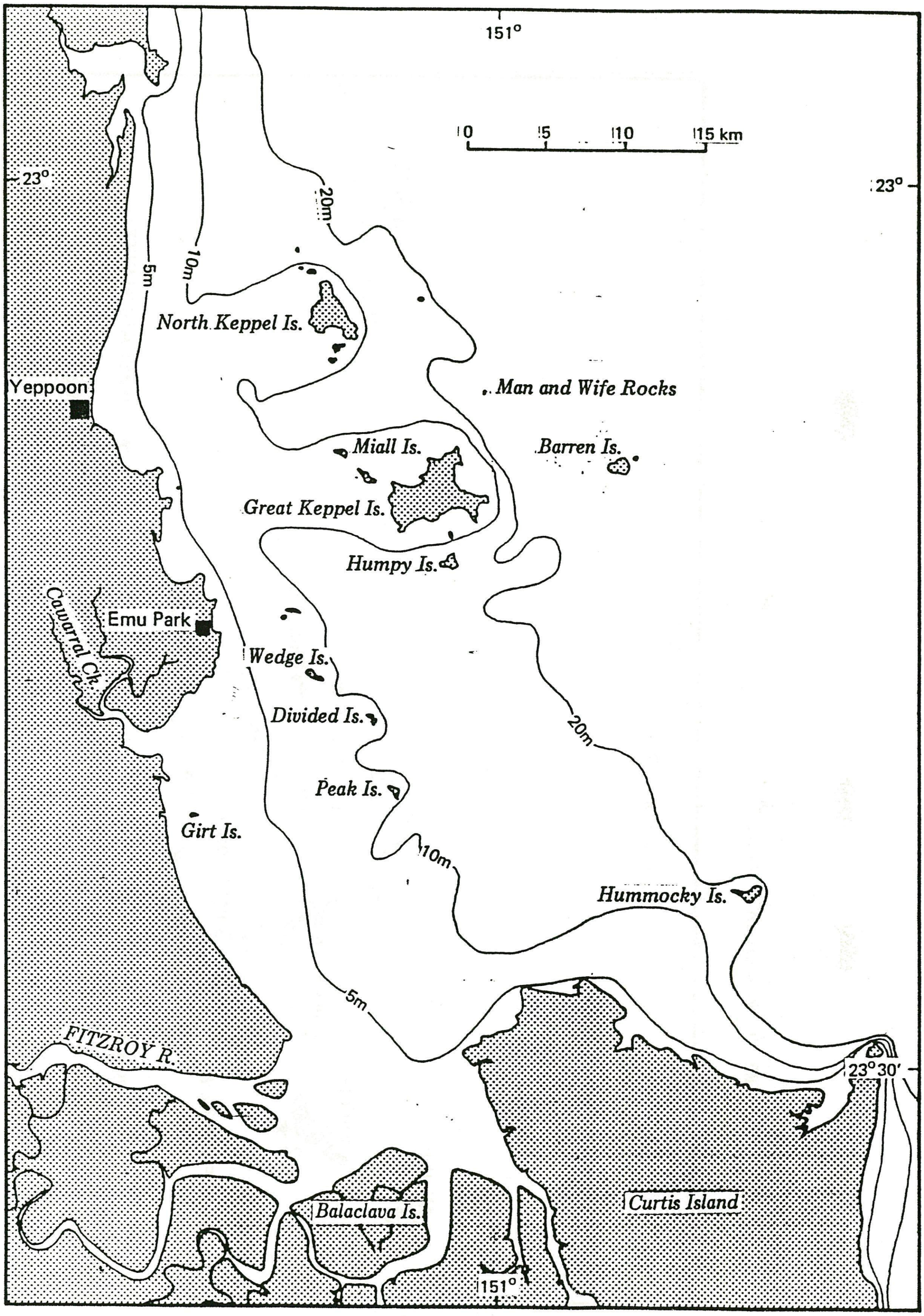
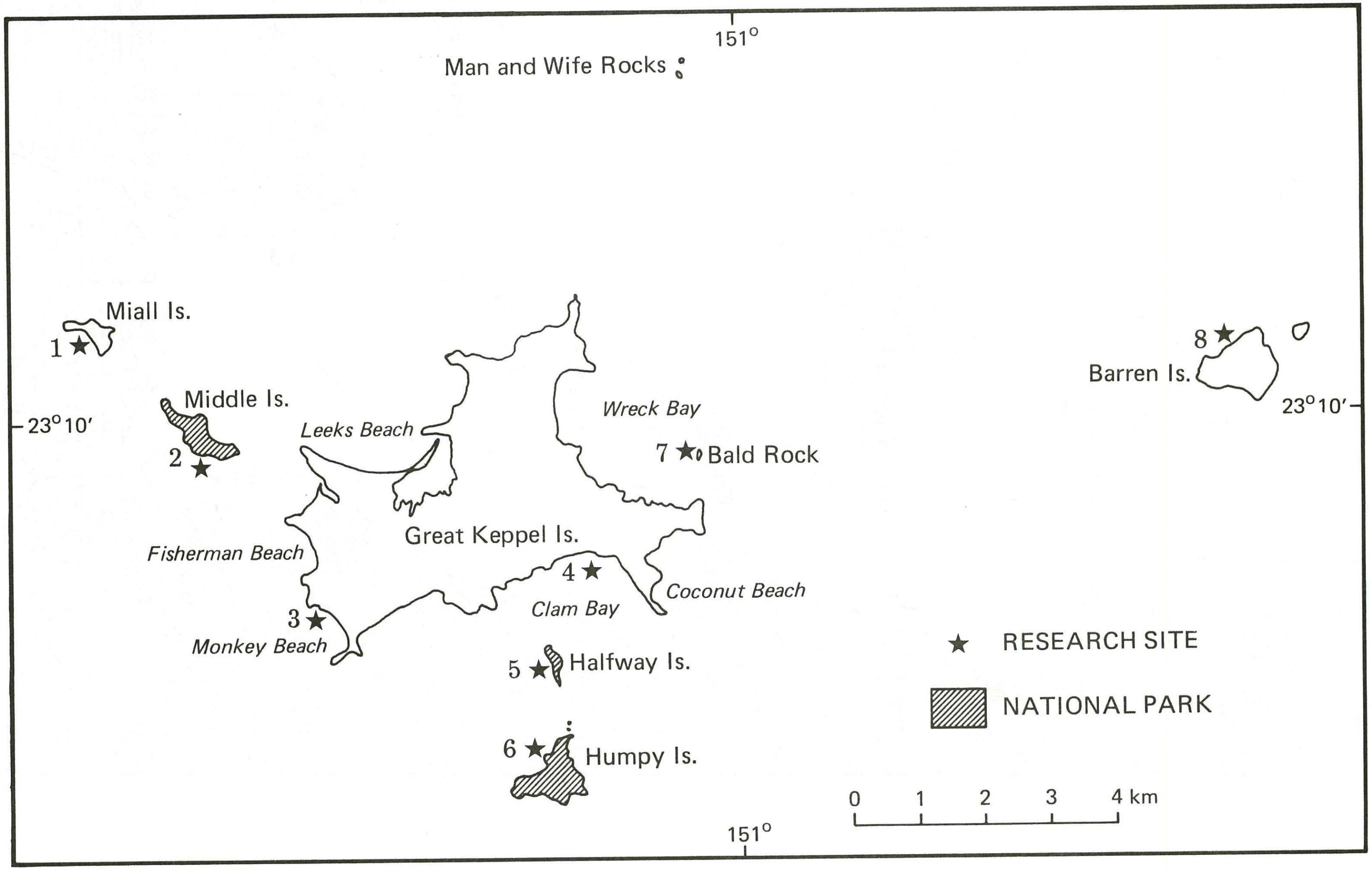


FIGURE 4. Research sites.



The exposed slopes of Great Keppel Island, Bald Rock and Barron Island were not extensively affected. Approximately 5% of the established colonies appeared recently dead and had been overgrown with turf algae, 10% remained bleached.

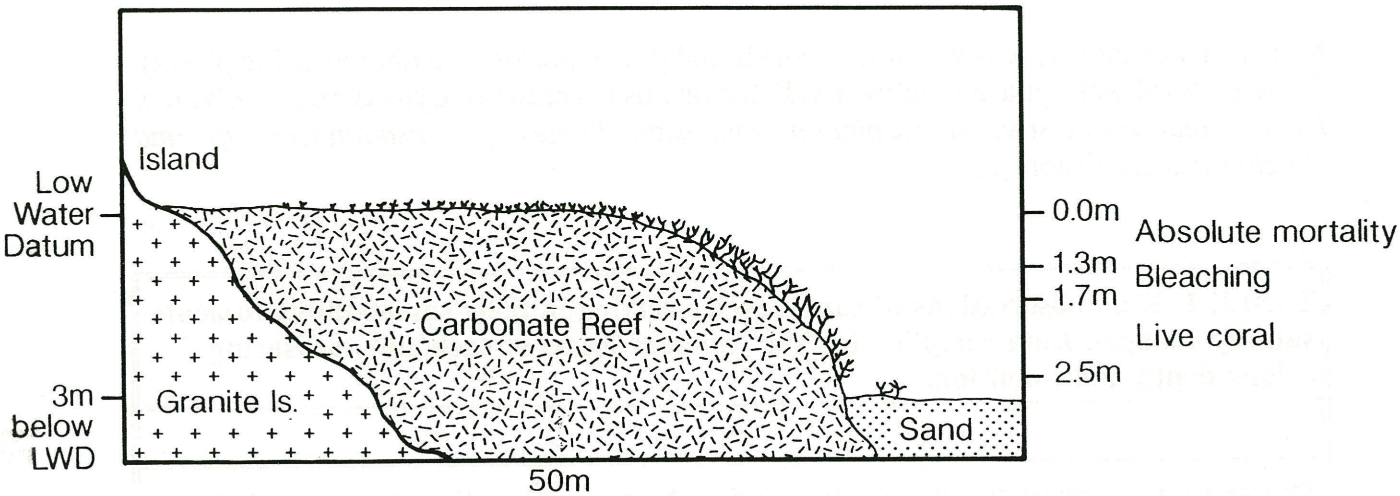
Mortality was most extensive for acroporids and pocilloporids (see photographic plates). Some survival was apparent below LWD for faviids (*Leptastrea, Cyphastrea, Goniastrea, Favites, and Favia species) Turbinaria spp.*, some *Porites spp., Psammocora sp. and Coscinaraea sp.* (Table 1).

TABLE 1. Field observations of coral species varying in their susceptibility to acute salinity changes. Data compiled by 50m^2 random swims at each site, measuring colony depth and condition.
Corals that appeared to consistently survive the hyposaline disturbance in shallow waters (1.0m below LWD).
Scleractinia: *Goniastrea favulus, Goniastrea retiformis, Goniastrea australiensis, Platygyra sinensis, Cyphastrea chalcidicum, Cyphastrea serailia, Leptastrea purpurea, Leptastrea inequalis, Favites russelli, Favites complanata, Favites pentagona, Favites flexuosa, Favites halicora, Favia pallida, Coscinaraea columna, Turbinaria mesenterina, Turbinaria bifrons, Turbinaria peltata, Turbinaria stellulata, Psammocora contigua.* Alcyonaria: *Capnella sp.*
Coral that were partially bleached and appeared to have recovery potential (1.0m below LWD).
Scleractinia: *Favia favus, Porites australiensis, Porites lutea/lobata, Goniopora spp., Montipora spp., Galaxea fasicularis, Hydnophora pilosa, Favia rotumana.* Alcyonaria: *Sarcophyton sp., Efflatournaria sp., Xenia sp., Alcyonium sp.*
Corals most susceptible to mortality (at 1.0m below LWD).
All *Acropora* species, all Pocilloporids.
Alcyonaria: *Dendronephthyea sp. Nephthea sp.*

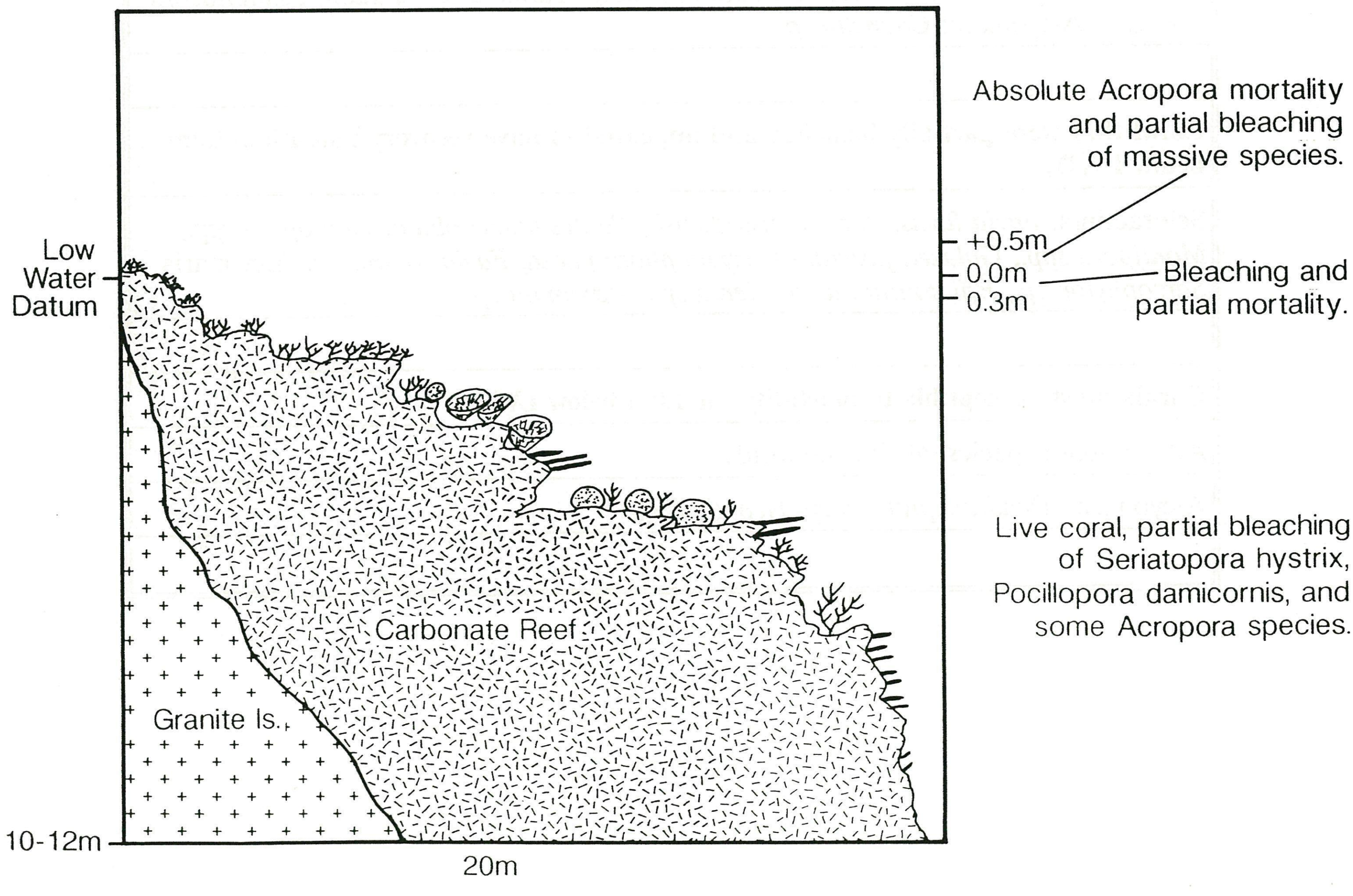
FIGURE 5.

THE KEPPEL ISLANDS

LEEWARD REEF´s (Vertical exaggeration)



WINDWARD REEF´s



Effects at individual islands

Miall Island (site 1)

Before the flood events hard coral cover was 36% at -0.5m LWD and sand and rubble covered 59% of the substrate. After the floods, cover was reduced to 8% at -1.5m LWD (Appendix 1). All *Acropora* species (*A. millepora, A. loripes, A. tenuis, A. cytherea, A. aspera, A. formosa, A. microphthalma* and *A. clathrata*) and *Pocillopora damicornis* colonies were totally dead and covered in turf algae. Living corals were primarily *Cyphastrea chalcidicum, Goniastrea retiformis, Goniastrea palauensis, Platygyra sinensis, Porites australiensis* (partially bleached), *Turbinaria bifrons* and the soft coral *Capnella sp.*

From -1.3 to -1.6m (LWD), a similar suite of species appeared to have survived the low salinities (Table 1) including *Psammocora contigua, Cyphastrea serailia, Leptastrea inequalis, Leptastrea purpurea, Favia favus* and the soft coral *Alcyonium sp*. Below 2.0m LWD, there was considerable bleaching of acroporids and pocilloporids however most colonies were alive *(A. cytherea, A. clathrata, A. sarmentosa, A. millepora, A. nasuta, A. microphthalma, A. formosa, A. secale, A. nobilis, A. valida, A. cerealis* and *A. aspera).*

Middle Island (site 2)

Before the floods the reef flats were partially lithified and covered in turf algae - a consequence of semi-diurnal emersion processes. Thick, mono-specific stands of *Acropora formosa* occupied most of the reef flat and 83% of the slope. *Lobophora variegata* the fine, fan-shaped macroalgae was common among the *Acropora* beds. Its abundance did not appear to be affected by the low salinities. After the floods mortality was absolute to 1.3m below LWD. Below this depth a narrow band of bleached coral (46%) extended to live *A. formosa* covering upto 78% of the benthos. The shallow reef slope continued to 2.5m below LWD (Figure 5; photographic plates).

Great Keppel Island, Monkey Point (site 3)

Before the floods this site supported 64% coral cover and 29% brown macroalgae. *Acropora formosa, A. nobilis* and *A. microphthalma* were most common. *Montipora tuberculosa, A. nasuta, A. tenuis, A. latistella, A. millepora* and *A. sarmentosa,* some fungiid species and *Pocillopora damicornis* were also present down the reef slope. Coral cover was reduced to 10% at -1.5m LWD, above this depth there was virtually 100% mortality.

Great Keppel Island, Clam Bay (site 4)

Before the floods hard coral cover was 93% (1.0m below LWD), composed of large mono-specific acroporid stands mainly *A. formosa* and *A. microphthalma, A. millepora, A. nasuta, A. tenuis, A. sarmentosa, A. latistella* and *A. clathrata*. Faviids were common, constituting mainly *Favites spp., Leptastrea spp., Cyphastrea chalcidicum, Leptoria phrygia* and *Platygyra sinensis.*

The shallow slopes were reduced to remnant *Acropora* beds covered in turf algae. Live coral was first evident at 1.3m below LWD and at 2.0m covered 9% of the substrate (Appendix 1). Cover increased progressively down the slope from 33% at 2.5m to 79% at 7.0m below LWD. These deep slopes were completely unaffected in the short term and still supported large mono-specific stands of *A. formosa, A. microphthalma* and *A. nobilis*.

Halfway Island (site 5)

Before the flood *Acropora formosa, A. microphthalma* and *Pocillopora damicornis* quantitatively dominated this site. Caespitose acroporids were also prolific; *A. millepora, A. sarmentosa, A. nasuta, A. secale, A. valida, A. cerealis, A. humilis, A. cytherea, A. clathrata, and A. latistella*. Massive faviid corals were abundant and diverse; *Cyphastrea chalcidicum, Cyphastrea microphthalma, Leptastrea spp., Montastrea curta, Oulophyllia crispa, Goniastrea australiensis, Favites russelli, Goniastrea favulus, Leptoria phrygia, Favia favus* and *Acanthastrea echinata*.

Mortality was evident for all *Acropora* species even at 2.0m below LWD, which was lower than at other locations. The only surviving colonies were the faviids *Cyphastrea, Leptastrea* and *Goniastrea* species and occassional *Turbinaria peltata*. Hard coral cover was reduced from 66% to 0% live coral at -0.3m LWD, 10% bleached coral at -0.8m LWD and 1% live coral at -1.5m LWD (Appendix 1).

Humpy Island (site 6)

Although this reef is not extensive, small coral aggregations were present at the northern end of the island. The slope supported relatively diverse massive colonies; *Cyphastrea microphthalma, Cyphastrea chalcidicum, Leptastrea inequalis, Leptastrea transversa, Goniastrea australiensis, Platygyra sinensis, Leptoria phrygia, Favia speciosa, Porites spp*. These colonies appeared to survive relatively well. In fact most colonies survived, although there was some bleaching of *Acropora, Pocillopora damicornis* and *Stylophora pistillata*.

Bald Rocks (site 7)

Acropora diversity was high and their size increased considerably with depth. All corals were alive below -0.3m LWD. Bleaching was evident above this depth for acroporids, *Favites flexuosa, G. retiformis* (partial), *G. favulus* (partial), *Galaxea fascicularis* and *Favites halicora.* The amount of bleaching varied from 16% on the shallow slopes (0.5m

LWD) to 10% at LWD leading to 7% at 0.2m below LWD (Appendix 1). Below this depth minimal bleaching was evident - only Pocilloporids. The soft coral *Capnella sp.* appeared to survive the disturbance event at all depths.

Lower down the slope, coral communities were unaffected at the time of the survey. Acroporids were diverse and covered upto 70% of the substratum. Soft coral diversity was high when compared with other regions surveyed (*Efflatournaria sp. Alcyonium sp.*, *Xenia sp.* and *Sarcophyton sp.*)

Barron Island (site 8)

The reef topography was similar to Bald Rock where the coral assemblages grew slightly above LWD (0.2m) on the granite boulders. Percent estimates of live and dead coral cover were analogous on the shallow slope - 34% and 36%, respectively (Appendix 1). Large *Acropora* colonies were damaged (*A. hyacinthus, A. millepora, A. latistella, A. valida*). Substantial damage was evident to 0.3m below LWD (48% dead coral). Below this depth live coral cover increased to 58% at 2.5m below LWD to 69% at 3.0m. Most noteable was the extensive effect on the Pocilloporids - *Seriatopora hystrix* and *Pocillopora damicornis* - at depths beyond 2.0m. These colonies appeared bleached with substantial tissue necrosis. These species were only relatively common. Communities were dominated by large colonies of diverse acroporids which covered over 60% of the slope to well beyond 20m.

Fish assemblages

Large vagile fishes moved from the shallow leeward reef area during the course of the floods (*pers. comm.* E. Ruyss, Middle Island observatory operator), however most territorial fishes (approximately 30 species) remained in their habitat and were subsequently washed ashore on the 20th of January. The only remaining territorial fish observed were the damselfish, *Chromis nitida*, still present in similar abundances as before the flood event. Large vagile fishes were first seen on the reef habitat on the 23rd of January.

DISCUSSION

The first freshwater plume spread over the reefs of Great Keppel Island on the 2nd of January, 1991. Salinities were low for 19 days. During the height of the flood salinities were in the order of 7 to 10 ppt at the surface, 15 to 28 ppt at 3m, 31 to 34 ppt at 6m and 33 to 34 ppt at 12m (Data supplied by QNPWS, Rockhampton). Tidal fluctuations were in excess of 4m during the peak flood period allowing semi-diurnal dilution (of hyposaline waters) on the high tides.

Consistent survival of most faviid species in shallow waters on inner islands contrasted with bleached pocilloporids on deep slopes on islands some distance offshore. Slight variations (centimetres) in depth appeared to substantially affect species specific bleaching events. This indicates that fine stress thresholds are apparent. A similar phenomenon was reported by Goreau (1964) who described mass expulsion of zooxanthellae due to flooding of coastal regions (Jamaica) following Hurricane Flora in 1963. Goreau convincingly argues that low salinity were the prime cause of bleaching. Differences in susceptibility (to bleaching) were consistently noted in different species. The bleached zone extended to -3m. Bleaching does not however indicate coral death, as corals can persist quite readily without zooxanthellae for several months (Goreau 1964; Hayes and Bush 1990).

Substantial research has focused on when and why bleaching occurs (Coral Reefs Vol. 8, pp 155-232), it appears associated with coral stress and simply stated it is the expulsion of zooxanthellae. However, the thresholds and mechanisms involved with expulsion are unclear and somewhat species specific. Some authors have described bleaching as a response associated with the release of excess mucus (excreted from the corals gastrovascular cavity disrupting the gastrodermis where the zooxanthellae are contained) (Hayes and Bush 1990). *In vitro* experiments indicate that zooxanthellae become motile (forming zoospores) when food reserves are depleted (Freudenthal 1962), this has interesting connotations within a symbiotic relationship specially when we consider that some zooxanthellae are classified in the (order Peridinieae) family Blastodiniaceae which is a parasitic family (Freudenthal 1962). Zoospores may re-enter the gastroderm (Goreau 1964), however Hayes and Bush (1990) indicated that reinvading zooxanthellae were different and vacuolated, which Freudenthal described as a vegetative phase in the process of actively reproducing.

The flood events of 1991 are not unique to the Keppel Island region as inundation by freshwater, in the wake of the Fitzroy plume, occurs regularly (Figure 6). Events of similar magnitude were evident in the years 1954 and 1918. A visual manifestation of the coral communities surrounding the Keppel Islands may at first appear to be caused by natural selection at the extreme of a communities adaptability to tolerate intermittent freshwater run-off events. That is, hypothetically speaking, intermittent disturbance events (frequent flooding) may allow the least susceptible species to dominate - *superior reliquiae diluvies* - such as *Porites* and faviids. However the colonies which survived the flood event in the short-term are not dominant within the region. Ironically, one of the most susceptible species to low salinities - *Acropora* - dominates the reefs. Although periodic disturbances affect the shallow communities these phenomena do not structure the assemblages and dominance of *Acropora* appears to be a consequence of geographic circumstance - which was further investigated.

In order to compare the benthic assemblages of the Keppel Islands with those on fringing reefs further north, thirty-nine 20m by 10m sites (at similar depths) where utilised in a comparative analysis. A Hybrid Multi-Dimensional Scaling (HMDS) analysis (Kruskal and Wish 1978) was undertaken on the data. This technique utilised the Bray-Curtis dissimilarity coefficient (Bray and Curtis 1957) using both hard and soft coral abundances and size structure data (1989). The results indicate that reefs were substantially different in the Keppel region (Figure 7), due to their low diversity and dominance of *Acropora* colonies and minimal support of large and abundant faviid and *Porites* colonies. Except for some anomalies *Acropora* dominant assemblages were generally only found on fringing reefs (in the southern marine park) some considerable distance from the mainland (Cockermouth and Scawfell Island are 40 and 45 km offshore).

In 1985 personnel from the Australian Institute of Marine Science (AIMS) collected quantitative data on 31 reefs in the Capricorn, Swain, Pompey and Whitsunday complex of reefs (Figure 8) (The Crown-of-thorns study 1985, volumes 1-13). Data on reefs unaffected by Crown-of-thorns starfish were compiled into summary form in order to assess the variance between Acropora and non-Acropora dominance. Total percent cover was summed for each site and converted to ratios (Table 2). It appears that the Capricorn region has a distinct dominance of *Acropora* corals, specially at shallow depths. Notably *Acropora* becomes relatively less dominant as we move further north (Pompey and Whitsunday complex).

It is postulated that rapid recovery of the reefs within Keppel Bay will be apparent within a period of 7 to 9 years. It is also highly probable that the reef will once again be dominated by *Acropora* species, a direct consequence of the highly fecund species from not only a local source (remnant survivors on the lower slopes) but also from a regional source. These postulations are based on a study conducted by Lovell (1989) who worked in Moreton Bay before and after the 1974 flood event. He also recorded differential survival of some species and vulnerability of others.

A final point that warrants mention is the question concerning fate of the river discharge. Low salinities were recorded 40km offshore throughout the floods however detailed recordings of its northern extent were not made. Inorganic and organic nutrient levels were high during the event and extensive planktonic blooms were recorded in the form of high chlorophyll counts (Brodie, *pers.comm*). Although the extent of their persistence is unknown sedimentation records allow us to infer some general conclusions about the fate of fine sediments and their associates.

Mud-facies (very fine grain deposits) are virtually nonexistent (1%) from south of the Keppel Islands to Repulse Bay (the southern Whitsunday Islands) (Maxwell 1967). Within the Whitsunday complex, fine muds are prominent in leeward embayments (40-60%). Residual movement of fine sediment north via long-shore drift is evident, however shallow inshore shelfs prevents fine sediment from settling (outlined by Maa 1986). In the vicinity of the Whitsunday Islands the inner shelf is protected by the mid and outer reefs and the islands become large enough to act as barriers. Wave activity and long-shore drift decline and the migration of southern mud ceases. Any residual drift north is minimal beyond the Whitsunday Islands (Maxwell 1967).

This information has important cònnotations regarding the binding and flocculating properties of sediments and the dynamics of associated particulate and dissolved nutrients. Understanding their systematics (availability) and their inter-relatedness with biological assimilation addresses the question of ecosystem connectivity between these two apparently large spatial distances. These types of studies need considerable work.

TABLE 2. Spatial variance of Acropora dominance between four regions using data from appendix in volumes 10, 11, 12 and 13 Crown-of-thorns study, AIMS (1985).

REGION (n = reefs surveyed)	Acropora	non-Acropora
Capricorn-Bunker (4) 3 metres	1:	0.31
6 metres	1:	0.55
12 metres	1:	1.17
Swain Complex (n = 10) 3 metres	1:	0.76
6 metres	1:	1.02
12 metres	1:	1.87
Pompey Complex (n=9) 3 metres	1:	0.83
6 metres	1:	0.86
12 metres	1:	2.25
Whitsunday complex (n= 9) 3 metres	1:	1.11
6 metres	1	1.33
12 metres	1	1.96

References

Beach Protection Authority report (1979). Capricorn Coast Beaches. A detailed study of coastline behaviour along the Capricorn Coast of Queensland, Australia. pp 238

Bray JR and Curtis T (1957) An ordination of upland forest communities. Ecol Mono 27: 325-349

Bureau of Meteorology Report (1991). Floods associated with severe tropical cyclone Joy, December 1990-January 1991. 11pp

Freudenthal HD (1962) *Symbiodinium* gen. nov. and *Symbiodinium microadriaticum* sp. nov., a Zooxanthellae: Taxonomy, Life Cycle, and Morphology. J Protozool 9(1):45-52.

Goreau TF (1964) Mass expulsion of zooxanthellae from Jamaican Reef Communities after Hurricane Flora. Science 145: 383-386.

Hayes RL and Bush PG (1990) Microscopic observation of recovery in the reef-building scleractinian coral, *Montastrea annularis*, after bleaching on a Cayman reef. Coral Reefs 8:203-209.

Kruskal JB and Wish M (1978) Multidimensional Scaling. Sage publications, Beverely Hills, California. pp 93.

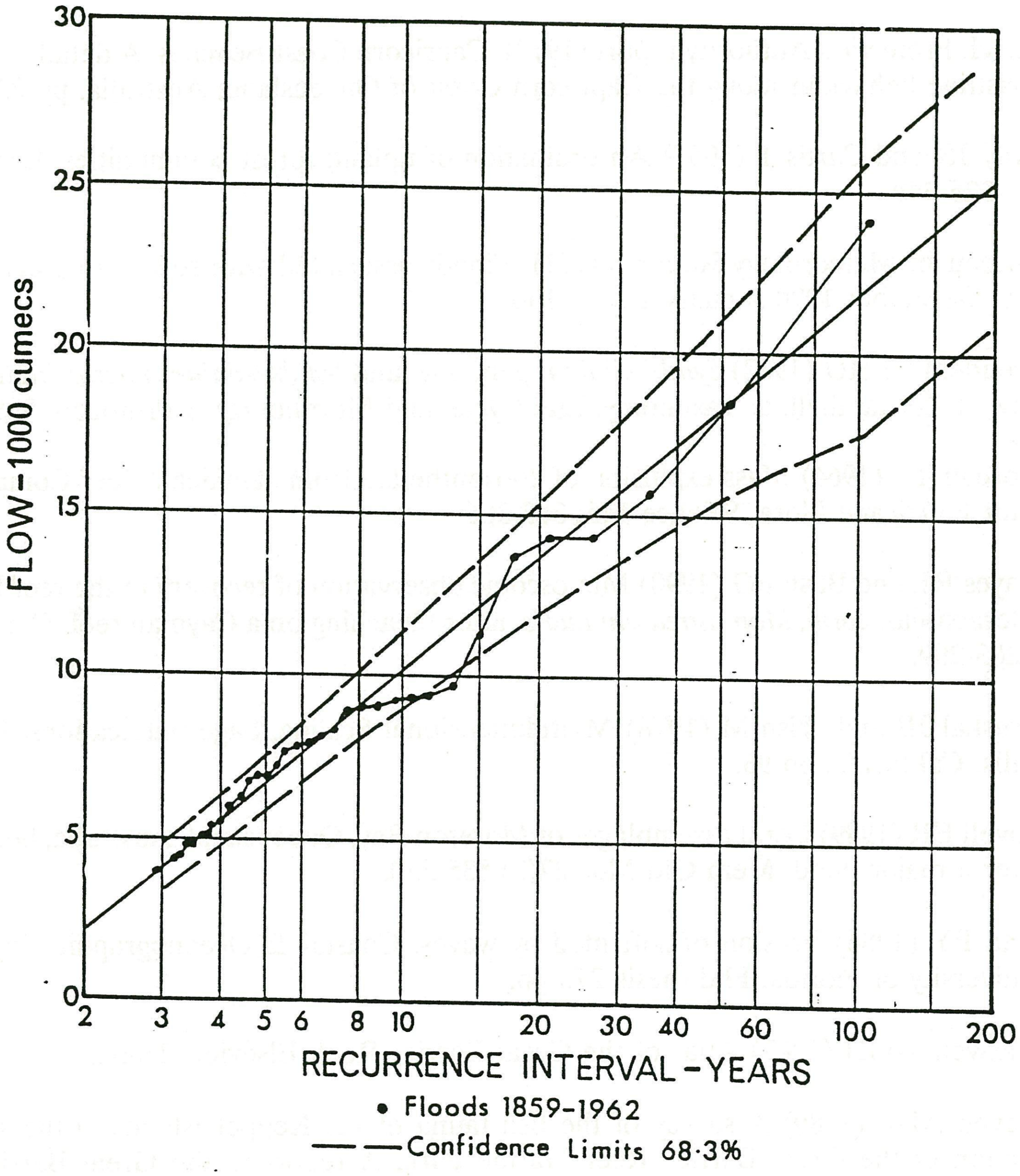
Lovell ER (1989) Coral assemblages of Moreton Bay, Queensland, Australia, before and after a major flood. Mem Qld Mus 27(2):535-550.

Maa PY (1986) Erosion of soft mud by waves. Coastal & Oceanographic Eng. Dept, University of Florida. Phd thesis 276 pp.

Maxwell WGH (1967) Atlas of the Great Barrier Reef. Elsevier, 258pp.

Steven ADL (1989) A survey of the fish fauna of the Keppel Islands in the southern section of the Great Barrier Reef Marine Park. A report to the Great Barrier Reef Marine Park Authority. 16 pp.

Van Woesik (1989) An assessment of the coral reef communities on the Keppel Isles. A report to the Great Barrier Reef Marine Park Authority. 23 pp.



Fitzroy River Flood Statistics

FIGURE 6. (From BPA report 1979)

Figure 7. A two-dimensional representation of a multi-dimensional scaling analysis undertaken to examine the similarity of benthic communities on the Keppel Islands compared with those in the Whitsunday, Northumberland and Cumberland Islands.

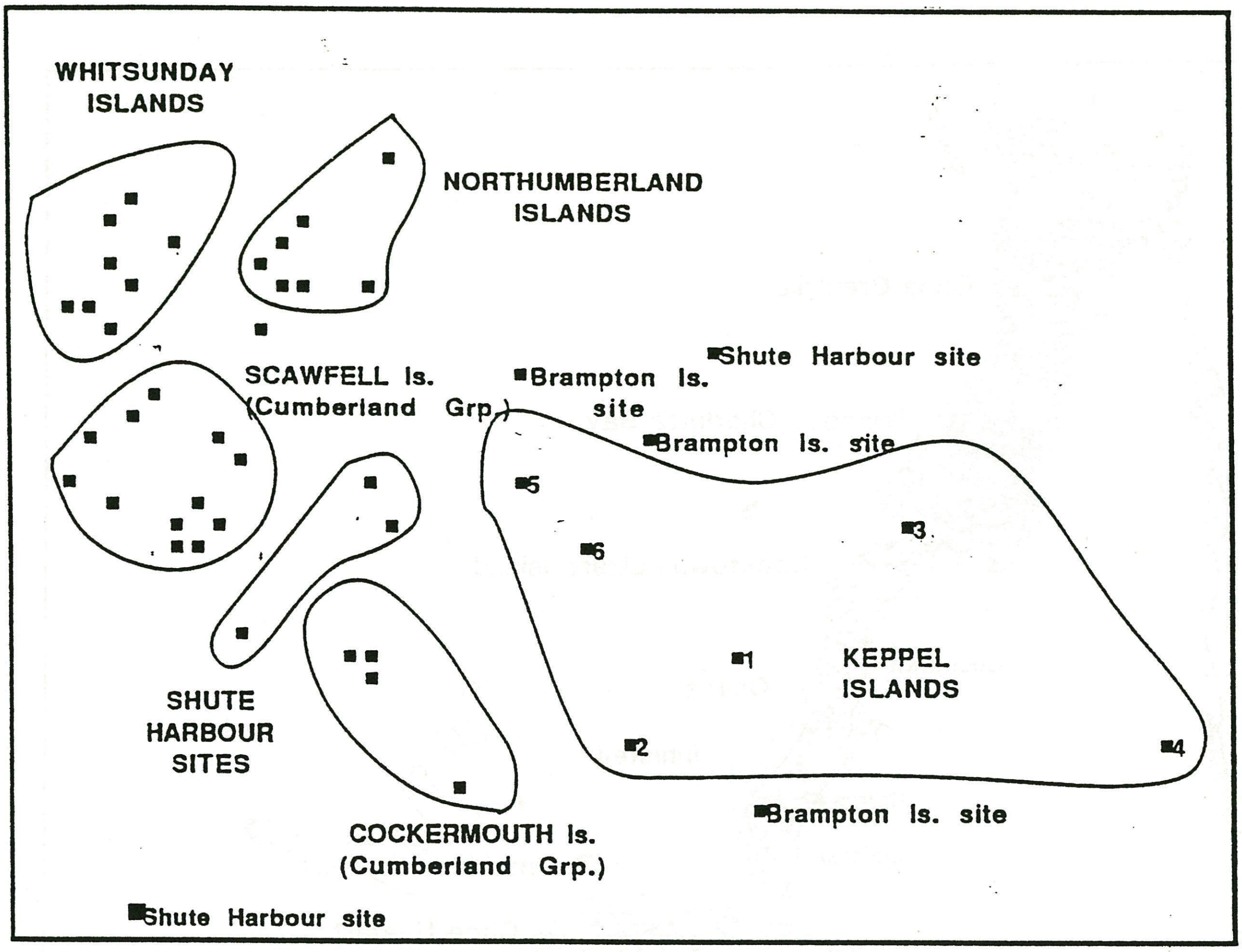
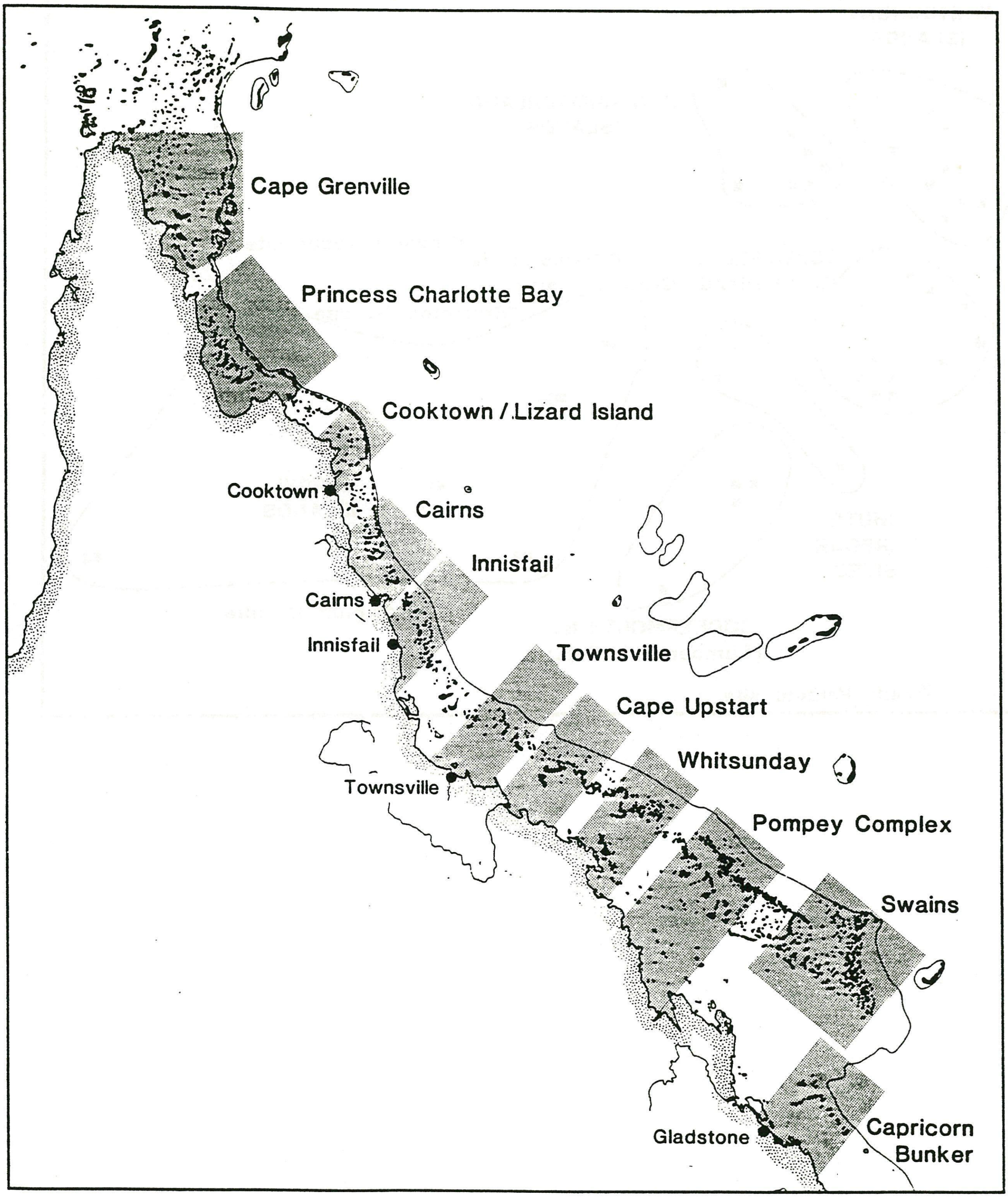


FIGURE 8.



Cape Grenville
Princess Charlotte Bay
Cooktown / Lizard Island
Cooktown
Cairns
Innisfail
Cairns
Innisfail
Townsville
Cape Upstart
Townsville
Whitsunday
Pompey Complex
Swains
Gladstone
Capricorn
Bunker

APPENDIX 1. Summary statistics of line transect data (nb. The before flood data was based on two 20m line transects [40m], the after flood data, due to poor visibility was based on the average of three 15m transects [45m]). Where E is the total cover, and n, SD and mean are the number of recordings, standard deviation and mean of each particular category.

SITE 1 (Miall Island) before the flood at 0.5m below LWD

	n	E	SD	mean	%
Hard coral	41	1451	36.6	35.4	36.5%
Sand/rubble	27	2362	101.1	87.5	59%
Turf algae	2	85	10.6	42.5	2%
Dead coral	4	59	6.9	14.8	1.5%
Soft coral	2	43	3.5	21.5	1%

AFTER THE FLOOD at -1.5m.

	n	E	SD	mean	%
Hard coral	3	112	32.8	37.4	8%
Sand/rubble	5	455	78.9	91	30%
Turf algae	4	144	15.2	36.0	10%
Dead coral	13	472	13.5	36.3	31%
Bleached coral	8	317	34.4	39.5	21%

SITE 2 (Middle Island) before the flood at 1.0m below LWD

	n	E	SD	mean	%
Hard coral	35	3311	85.1	94.6	83%
Macroalgae	18	293	12.7	16.3	7%
Dead coral	2	16	2.8	8.0	1%
Sand/rubble	5	257	12.6	51.4	6%
Turf algae	4	123	21.2	31.0	3%

AFTER THE FLOODS
At 1.5m below LWD.

	n	E	SD	mean	%
Live hard coral	5	327	84.8	65.4	22%
Bleached coral	20	699	65.1	34.9	46%
Dead coral	3	324	281.9	108	22%
Sand/rubble	4	150	14.2	37.5	10%

At 2.0m below LWD

	n	E	SD	mean	%
Live hard coral	22	1170	60.1	53.2	78
Bleached coral	2	52	8.6	26.0	4%
Dead coral	3	45	7.9	15.0	3%
Sand/rubble	5	233	13.2	46.6	15%

SITE 3 (Monkey Bay) before the floods at 1.0m below LWD

	n	E	SD	mean	%
Hard coral	80	2574	62.4	32.1	64%
Macroalgae	61	1164	16.6	19.1	29%
Turf algae/rubble	16	246	23.7	15.4	6%
Coralline algae	3	16	7.2	5.3	1%

AFTER THE FLOOD

	n	E	SD	mean	%
Hard coral	5	152	28.8	30.4	10
Bleached coral	1	8	0	8	1
Dead coral	14	1182	108.9	84.4	78
Turf algae	6	148	11.8	24.7	10
Coralline algae	2	10	1.4	5.0	1

SITE 4 (Clam Bay) before the floods at 1.0m below LWD

	n	E	SD	mean	%
Hard coral	12	3740	347.6	311.6	93.5%
Rubble	3	260	116.8	86.6	6.5%

At 8.5m below LWD

	n	E	SD	mean	%
Hard coral	15	2129	162.9	141.9	53%
Sand/rubble	12	1871	143.8	155.9	47%

AFTER THE FLOODS
At 1.0m below LWD

	n	E	Sd	mean	%
Live hard coral	0	0	0	0	0
Dead coral	1	1500	-	1500	100%

At 2.0m below LWD

	n	E	SD	mean	%
Live hard coral	5	134	22	26.8	9
Dead coral	9	1309	182.4	145.4	87
Bleached coral	3	57	18.5	19	4

At 2.5m below LWD

	n	E	SD	mean	%
Live hard coral	12	493	35.4	41.5	33
Dead coral	20	762	20.9	38.1	51
Bleached coral	10	245	14.9	24.3	16

At 4.0m below LWD

	n	E	SD	mean	%
Live hard coral	13	1190	112	91.5	79
Dead coral	4	153	14	38.3	10
Bleached coral	2	67	0.7	33.5	5
Rubble	1	90	0	90	6

At 6.0m below LWD

	n	E	SD	mean	%
Live hard coral	7	1328	192	189.7	89
Bleached coral	4	113	3.4	28.3	8
Sand/rubble	1	59	0	59	3

At 7.0m below LWD

	n	E	SD	mean	%
Live hard coral	10	1187	136	118.7	79
Bleached coral	1	7	0	7	1
Soft coral	2	43	0.7	21.5	3
Sand/rubble	3	263	78.2	87.7	17

SITE 5 (Halfway Island) at 0.5m above LWD

	n	E	SD	mean	%
Hard coral	48	2640	43.2	55.0	66%
Soft coral	2	35	3.5	17.5	1%
Turf algae	7	196	10.8	28.0	5%
Sand/rubble	23	1129	39.6	49.1	28%

AFTER THE FLOODS
At 0.3m below LWD

	n	E	Sd	mean	%
Dead coral	12	1037	81.1	86.4	69%
Sand/rubble	6	463	44.3	77.2	31%

At 0.8m below LWD

	n	E	SD	mean	%
Bleached coral	7	156	13.8	22.3	10%
Dead Coral	9	510	46.6	56.6	34%
Sand/rubble	10	834	64.3	83.4	56%

At 1.5m below LWD

	n	E	SD	mean	%
Live hard coral	1	9	0	9	1%
Bleached coral	2	53	7.8	26.5	3%
Dead coral	1	45	0	45	3%
Sand/rubble	12	1090	60.1	90.8	73%
Macroalgae	7	303	86.4	43.3	20%

SITE 6 (Humpy Island) at LWD.

Before the flood	n	E	SD	mean	%
Hard coral	26	752	25.1	28.9	19%
Macroalgae	13	186	5.3	14.3	5%
Soft coral	1	20	-	20	-
Sand/rubble	36	3042	77.8	84.5	76%

AFTER THE FLOOD
Problems obtaining line transect information on this dive.

SITE 7 (Bald Rock) after the flood 0.5m above LWD

	n	E	SD	mean	%
Live hard coral	11	218	10.4	19.7	14%
Bleached coral	10	232	14.5	23.2	16%
Dead coral	10	187	8.7	18.5	12%
Turf algae	19	860	24.0	45.2	57%
Soft coral	1	3	0	3	1%

At LWD

	n	E	SD	mean	%
Live hard coral	15	340	15.1	24.4	23%
Bleached coral	4	156	0	46.3	10%
Dead coral	10	370	18.5	40.6	25%
Turf algae	15	576	23.8	37.3	38%
Soft coral	2	58	2.8	29.0	4%

At 0.2m below LWD

	n	E	SD	mean	%
Live hard coral	15	427	18.2	28.5	28%
Bleached coral	3	102	17.6	34.0	7%
Dead coral	15	552	23.0	36.8	37%
Turf algae	9	321	11.5	35.6	21%
Soft coral	5	98	10.1	19.6	7%

SITE 8 (Barron Island) after the floods, new permanent sites.
At 0.2m above LWD

	n	E	SD	mean	%
Live hard coral	25	675	24.5	27.0	34%
Dead coral	14	724	52.9	51.8	36%
Turf algae	10	313	29.8	31.3	16%
Bleached coral	3	47	8.9	15.6	2%
Sand/rubble	4	241	40.5	60.3	12%

At LWD

	n	E	SD	mean	%
Live hard coral	24	683	28.8	28.5	34%
Dead coral	22	824	29.8	37.5	41%
Bleached coral	4	61	11.5	15.3	3%
Turf algae	8	358	38.2	44.8	18%
Sand/rubble	1	26	-	26	1%
Others	3	48	8.6	16	3%

At 0.3m below LWD

	n	E	SD	mean	%
Live hard coral	19	775	37.4	40.8	39%
Dead coral	21	964	35.9	45.9	48%
Bleached coral	2	88	41.0	44.0	5%
Turf algae	6	145	10.0	24.2	7%
Others	4	28	2.3	7	1%

At 2.5m below LWD

	n	E	SD	mean	%
Live hard coral	26	1157	40.6	44.5	58%
Dead coral	10	524	31.6	52.4	26%
Turf algae	6	92	11.6	15.3	5%
Soft coral	2	171	82.7	85.5	8%
Sand/rubble	2	56	8.5	28.0	3%

At 3.0m below LWD

	n	E	SD	mean	%
Live hard coral	36	1383	44.8	38.4	69%
Turf algae	11	251	18.0	22.8	13%

Soft coral	12	111	5.3	9.3	5%
Rubble	7	255	30.8	36.4	13%

Appendix 2. Species List (1989).

Pocilloporidae
Pocillopora damicornis
Stylophora pistillata
Seriatopora hystrix
Palauastrea ramosa

Acroporidae
A. tenuis
A. loripes
A. cytherea
A. glauca
A. hyacinthus
A. nasuta
A. nana
A. nobilis
A. sarmentosa
A. millepora
A. solitaryensis
A. pulchra
A. aspera
A. microphthalma
A. formosa
A. cerealis
A. dendrum
A. microclados
A. selago
A. aculeus
A. valida
A. clathrata
A. divaricata
A. subulata
A. latistella
A. humilis
A. secale
A. samoensis

Montipora aequituberculata
Montipora venosa
Montipora efflorescens
Montipora tuberculosa
Montipora crassituberculata
Montipora angulata
Montipora hispida

Poritidae
P. australiensis
P. lutea/lobata
Goniopora spp.
P. annae
P. densa

Faviidae
Favia rotumana
Favia lizardensis
Favia speciosa
Favites halicora
Favites flexuosa
Favites complanata
Goniastrea australiensis
Goniastrea favulus
Platygyra daedalea
Oulophyllia crispa
Cyphastrea chalcidicum
Cyphastrea serailia
Leptastrea transversa
Favia favus
Favia pallida
Favites russelli
Favites chinensis
Favites pentagona
Goniastrea palauensis
Goniastrea retiformis
Leptoria phrygia
Platygyra sinensis
Montastrea curta
Cyphastrea microphthalma
Leptastrea purpurea
Leptastrea inequalis

Dendrophylliidae
Turbinaria bifrons
Turbinaria stellulata
Turbinaria mesenterina
Turbinaria peltata
Turbinaria frondens
Turbinaria reniformis

Other families
Galaxea fascicularis
Hydnophora excesa
Coscinaraea columna
Pavona venosa
Hydnophora pilosa
Psammocora contigua
Acanthastrea echinata
Fungia spp.

PLATES

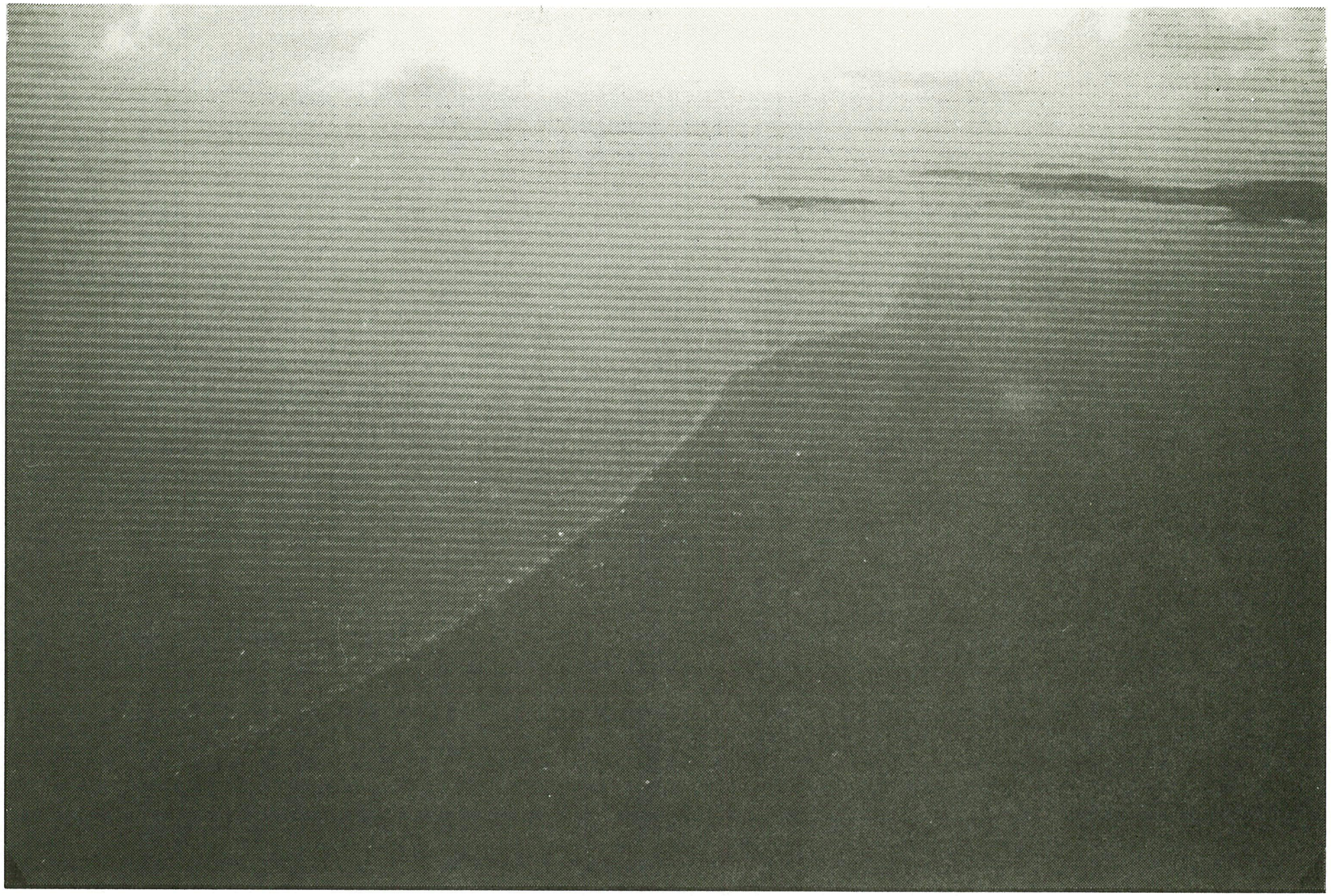


PLATE 1. Fresh water plume moving on the Keppel Islands (12/1/91). Photo QNPWS

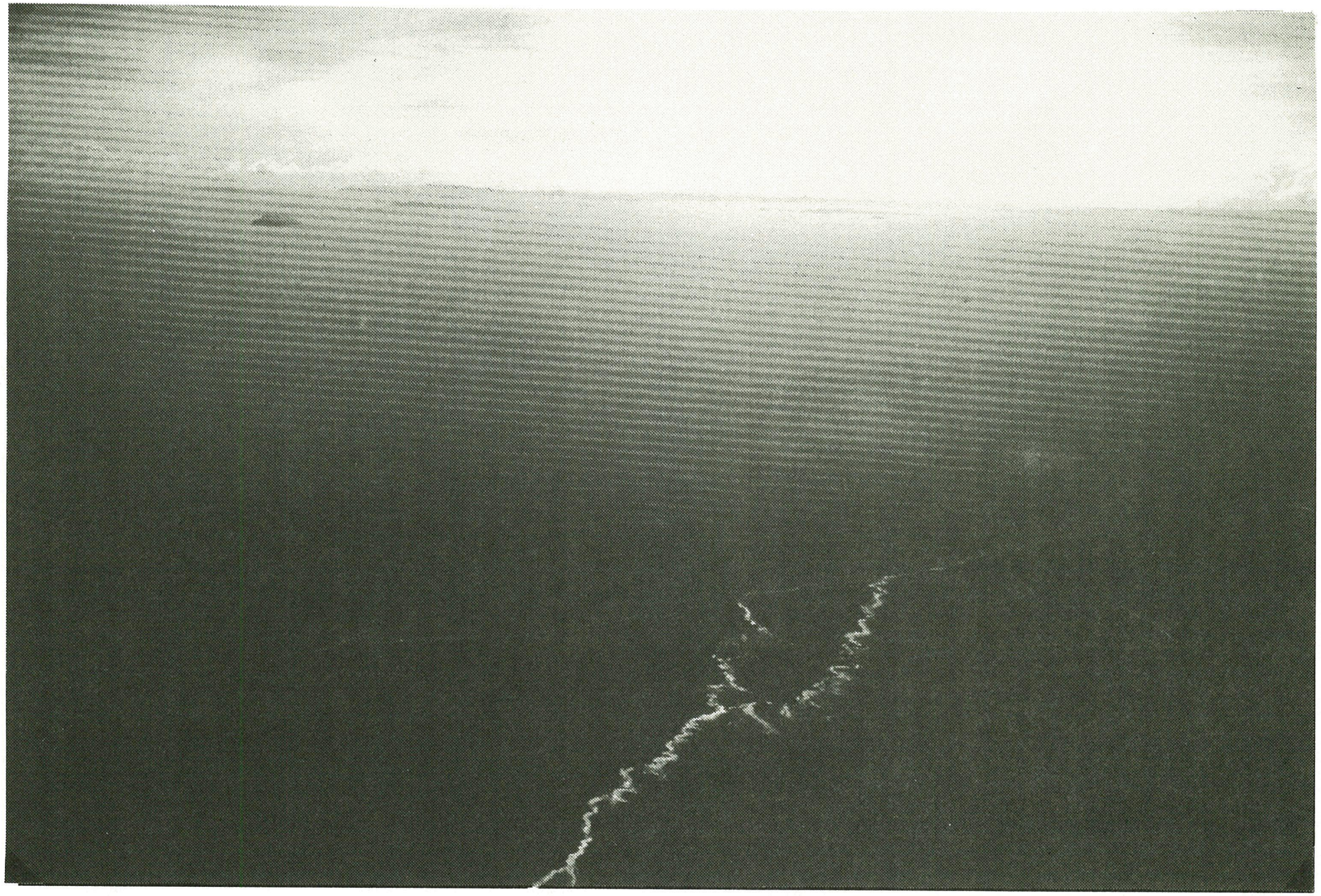


PLATE 2. Edge of Fitzroy River plume east of Keppel Islands (19/1/91). Photo QNPWS.

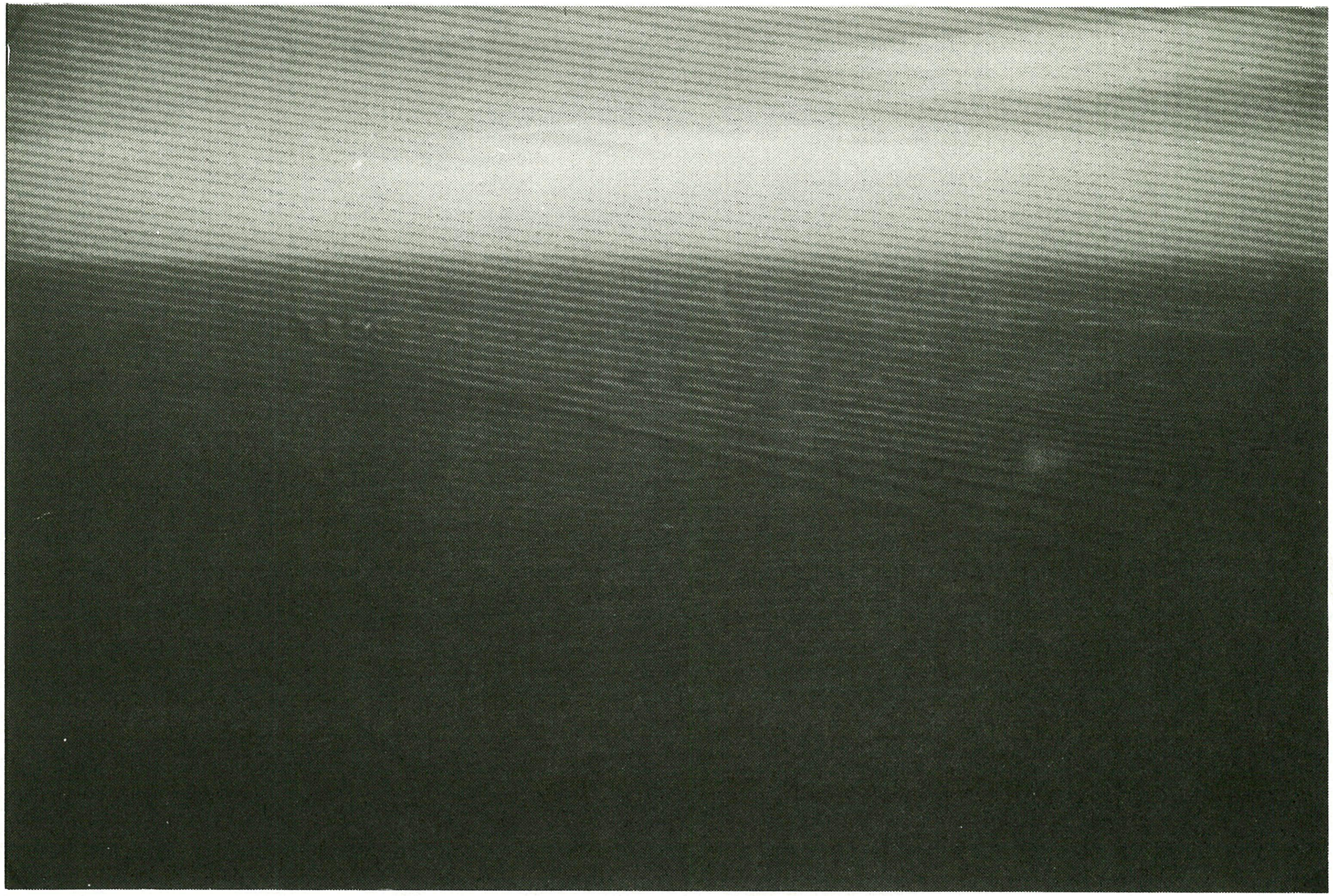


PLATE 3. Waves induced by freshwater plume moving over more dense saltwater, east of North Keppel Island. (19/1/91). Photo QNPWS.

PLATE 4. Acropora formosa beds before the floods, Clam Bay 1.0m and 4.0m below Low Water datum. (1989).

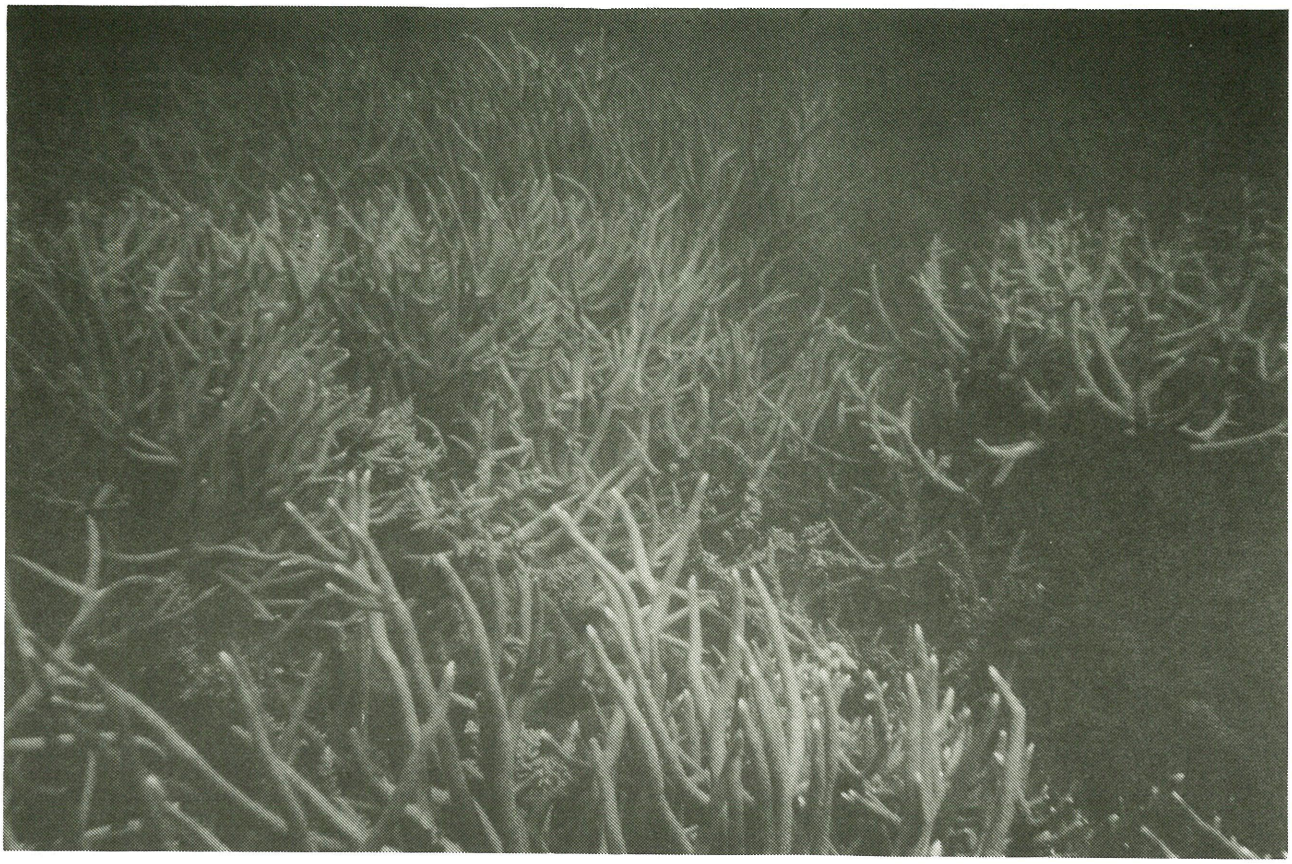


PLATE 5. Acropora formosa beds on the 14/2/91, Clam Bay at 2.5m below Low Water datum (LWD).