RESEARCH PUBLICATION No.24

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# Broadscale Survey of Impacts of Cyclone Ivor on Coral reefs

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A Report to the
Great Barrier Reef Marine Park Authority

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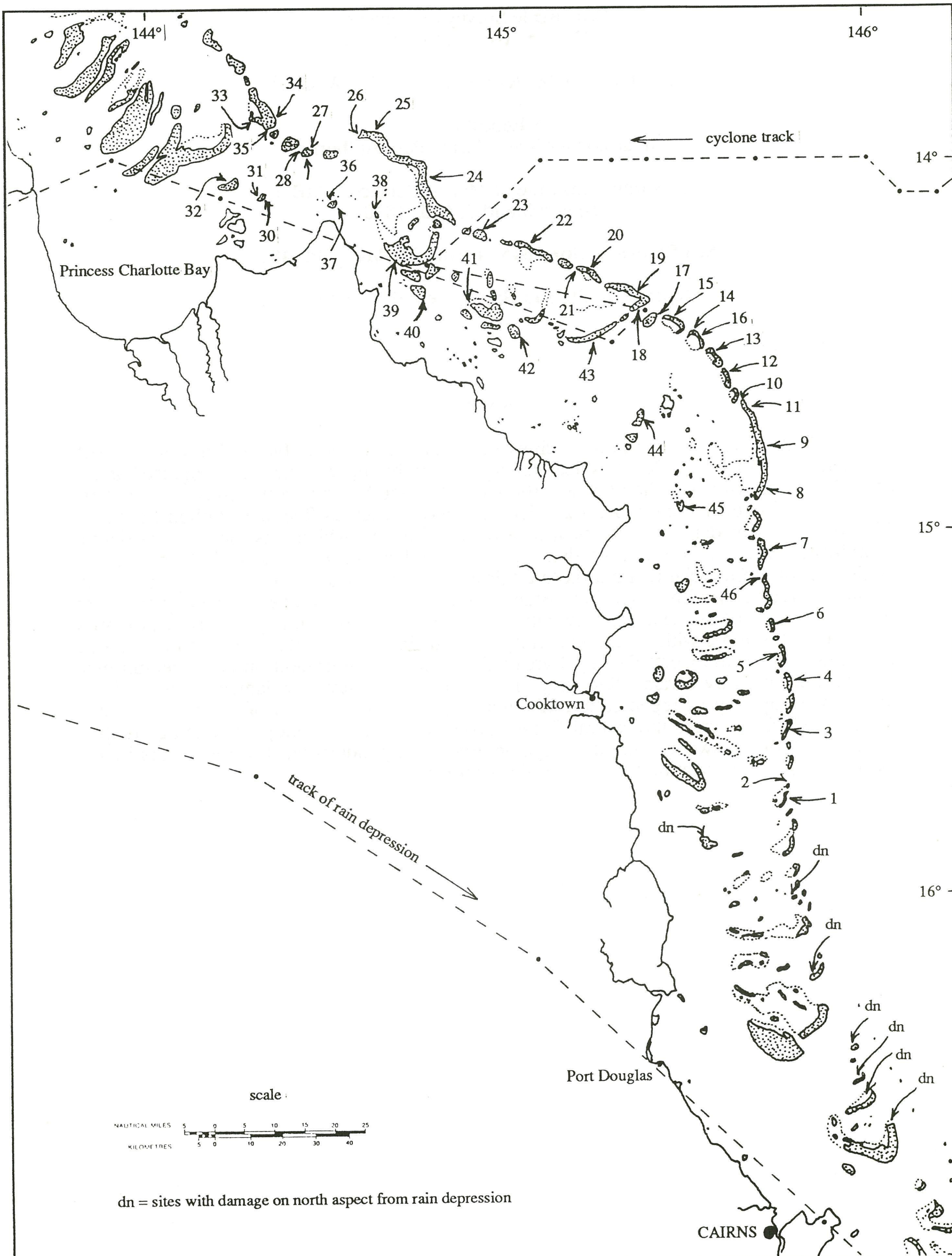
## Abstract

A survey of reefs in the vicinity of the path of Cyclone Ivor (19th March 1990) was conducted in July 1990. Physical damage caused by the cyclone was recognised as far as 40 km to the North of the path and 100 km to the South. Impact was most severe over a 50 km section of the outer Great Barrier Reef between Jewell Reef and Ribbon Reef No. 10. All forms of damage were seen to a depth of 20 m, which was the greatest depth examined. The major forms of damage were coral breakage, coral dislodgement, and peeling of the superficial reef matrix to a thickness of up to 1.5 m. The severity of impact declined irregularly with increasing distance from the path. Damage was patchy on scales of 100s -1000s $m^2$ associated partly with local shelter and topography, partly with matrix robustness, but more with coral community age and size structure than composition. Large denuded areas in the worst damaged area will be entirely dependent on larval recruitment for recolonisation by corals. Recovery of smaller and less severely damaged areas will in addition be by way of regeneration of remnant patches and growth of colonies on patch margins. Cyclones cross the central Great Barrier Reef at a frequency which suggests that, if the width of the swathe caused by Cyclone Ivor is any indication, few reefs would have escaped major modification by cyclones this century.

**FIGURE 1. MAP SHOWING CYCLONE IVOR TRACK AND STUDY SITES**



## INTRODUCTION

The historical influence of tropical revolving storms (hurricanes; cyclones; typhoons) on the structure and biological communities of coral reefs depends on the chronology of the storms, the nature of their impacts, the intensity and extent of impacts in relation to reef location and local shelter, and the rates of accretion and regeneration of reef building assemblages. Several studies have documented changes in reef morphology and coral populations (e.g. Woodley et al. 1981) and the behaviour of hurricane waves on reefs has been hindcast on the basis of meteorological records and oceanographic models (e.g. Kjerfve et al 1986). However previous studies have generally focused on localised areas, and the extent and ecological implications of damage in relation to revolving storms moving through tracts containing many reefs have not been investigated. The paths of all cyclone tracks in the Great Barrier Reef (GBR) since 1909 are documented (Lourensz 1981; and various authors in the Australian Meteorological Magazine, 1982-1989), and the present study attempts to establish the characteristics of physical damage to coral reefs associated with one such path.

Cyclone Ivor (central pressure 965-990) passed through the GBR region in March 1990 (Fig. 1). Two of us (A.M. Ayling and R. van Woesik) had recorded exceptionally high cover of hard and soft corals at Carter Reef within a few days prior to the cyclone, and major destruction at the same sites within days after. These are the prior community information referred to in Table 1.

An average of 13 cyclone per decade cross the 5° latitude/longitude square (approximately 290,000 km$^2$) including the study area (Lourensz 1981). Ivor was considerate only a moderate cyclone, never reaching the status of 'Severe Tropical Cyclone'. It was designated a Cyclone on 17th March while it was situated in the Coral Sea, and its path kept the eye in the vicinity of a 50 km section of the outer GBR for about 3 hours. The final approach was almost perpendicular to the section of the outer GBR bearing approximately 300° between Jewell Reef and Melville Passage. It passed over Waterwitch Passage on a SSW course at around 1800 hrs on 19th March, and then moved 50 km east over the next 2 hours, a course which took it back towards the outer reefs. It then retraced its path over the outer reefs, this time continuing over Cape Melville and crossing the west coast of Princess Charlotte Bay around midnight.

The cyclone lost intensity once it was over land, but nevertheless continued to generate rain and strong winds for several days. During this time, while classified as a rain depression (central pressure 999-1008 hPa), it reversed its course again, and travelled back out over the coast between Port Douglas and Cairns (Fig. 1).

## METHODS

Field work was conducted from the 12 m game boat 'Rodeway'. Surveys were conducted at 46 sites covering a 300 km section of the GBR (Fig. 1). All sites (around 3-

4,000 $m^2$) were located on the slopes of the indicated reefs and included normally exposed (front reef) and normally sheltered (back reef) aspects, specifically with a view to determining the effects of local shelter. We spaced sites evenly along the ribbon reefs (approximately 10-20 km intervals), and opportunistically on mid-shelf reefs. Once we were on stations we considered to represent positions of extreme exposure or extreme shelter, site selection was totally random. i.e. we leapt in with no prior knowledge of what we would see. The boat would approach to within a few meters of the designated study area. The three of us would enter the water and conduct a 15 - 20 minute reconnaissance of the area while the Rodeway hove-to at a safe distance. We would re-embark through the game door in Rodeway's transom and move to the next site. One to 3 sites were surveyed at each reef, (Fig. 1) and it usually took 30-45 minutes to travel the 10-20 km to the next reef, where the procedure was repeated.

The protocol for the reconnaissance was as follows. We agreed upon the following categories of damage (after Done et al. 1986): coral breakage; dislodged *Porites* heads (and occasionally other massive corals); scarring on standing corals caused by water-borne debris; evidence of soft corals having being ripped off; peeling and disintegration of framework; collapse of large (several m across) slabs of reef which remained largely intact after collapse; evidence of major deposition or removal of sand. Each of us assessed the extent of each of these categories on a 5 point scale; 1 = minor; 3 = moderate; 5 = severe. At the completion of the reconnaissance we would compare and agree upon gradings for the site. In addition, we had individual responsibilities; general site description, (TJD); record of predominant corals and zonation (RVW); video transects (AMA - in 34 of the 46 sites). All the data were subjective, and were arrived at by consensus after comparing notes.

Each video transect, which lasted 5 ($\pm$1) minutes, was conducted on a meandering swim (speed 0.5 $m.s^{-1}$) in the depth range of -2 to -12 m. The camera was pointed at about 45° below horizontal, and the distance from the bottom was kept at 1 - 1.5 m (Plate 14). No attempt was made to randomise the video transects. Rather, the path was chosen to ensure damaged and/or undamaged areas were filmed more or less in proportion to their perceived relative abundance.

Back in the laboratory, the video-tapes were analysed by an experienced reef researcher, Mr. Johnston Davidson, for an unbiased comparison with our visual estimates of bottom characteristics and damage. The tape was paused at approximately 50 random intervals, on each occasion a tally being kept of the major type of bottom cover (either damage category, hard coral, soft coral or substratum type) visible in the frame.

## RESULTS

The observations for all sites are presented in Tables 1 (visual estimates) and 2 (video estimates). The most commonly observed forms of damage were as follows: peeling of reef matrix (43.8% of the 64 sites - Plates 1-5); dislodged *Porites* (46.9% - Plates 6-10); coral breakage (39% - Plates 12-13). The remaining damage categories - soft coral stripping (Plate 11), and sediment transport (Plates 18-22) all occurred in 9 - 15% of the sites. At some sites we could see no evidence of cyclone damage (Plates 14-17).

There was systematic variability in the type and severity of damage in relation to reef position and aspect. The major trends are most easily seen by considering sites on the seaward slopes of the outer reefs separately from the remainder (viz. landward slopes of mid and outer reefs and seaward slopes of mid-shelf reefs).

### Seaward slopes of outer reefs.

**Reefs to the south of the path.** The greatest damage (Fig. 3) occurred in the 50 km section of reef to the south east of the cyclone path's most southerly position. The damage (Table 1) was mainly matrix peeling (many 3s and 4s - Fig. 2), coral breakage (2s and 3s) and *Porites* dislodgement (2s and 4s - Fig. 5). At its most severe (at Yonge, Carter and Jewell Reefs at depths between 2 and at least 20 m below the reef top), up to 1.5 m thickness of matrix had disintegrated, leaving exposed pitted and perforated limestone. Living coral was frequently completely absent over 100s to 1000s of square metres, and in the immediate vicinity, often had a cover of only 1-15%. Denuded areas will be highly dependent on larval recruitment for recolonisation by corals.

## TABLE 1. SITE DESCRIPTIONS AND ESTIMATES OF CYCLONE DAMAGE.

Several depth strata were categorised separately at some sites. Damage estimates were on a scale of 0-5, with 1 indicating low damage, 3 moderate damage and 5 severe damage. For more details of the damage categories refer text. s = south face, w = west face etc. * = based on prior community information.

| | | Site Description | | | | | | Cyclone Damage Categories (0-5) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site # | Reef | Latitude | Depth (m) | Slope | Hard coral (%) | Soft coral (%) | Dead coral (%) | Coral break. | *Porites* dislod. | Flying debris | Softs torn | Matrix peel. | Slab slip | Sed. trans. |
| OUTER BARRIER REEF FRONTS: | | | | | | | | | | | | | | |
| 34.1 | 13-125 | 13.90 | 2-5 | 15 | 50 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34.2 | 13-125 | 13.90 | 8-10 | 0 | 30 | 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | Scooterboot | 13.92 | 2-6 | 20 | 20 | 20 | 15 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 27.1 | Davie | 13.98 | 2-10 | 30 | 15 | 10 | 5 | 2 | 2 | 0 | 0 | 2 | 0 | 0 |
| 27.2 | Davie | 13.98 | 15-20 | 10 | 40 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | Scooterboot | 14.02 | 6-15 | 60 | 50 | 15 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23.1 | 14-047 | 14.20 | 3-5 | 5 | 15 | 15 | 10 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| 23.2 | 14-047 | 14.20 | 8-10 | 0 | 15 | 15 | 15 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| 22.1 | 14-074 | 14.23 | 3-6 | 20 | 10 | 10 | 10 | 0 | 2 | 0 | 0 | 2 | 0 | 0 |
| 22.2 | 14-074 | 14.23 | 18-20 | 0 | 20 | 20 | 10 | 0 | 2 | 0 | 0 | 1 | 0 | 0 |
| 20.1 | 14-077 | 14.30 | 2-4 | 10 | 40 | 10 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 20.2 | 14-077 | 14.30 | 4-8 | 15 | 30 | 30 | 5 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| 19 | Jewell | 14.35 | 3-12 | 30 | 5 | 5 | 20 | 4 | 4 | 3 | 0 | 4 | 3 | 4 |
| 15.1 | Hicks | 14.38 | 3-5 | 30 | 10 | 5 | 1 | 2 | 0 | 0 | *4 | 3 | 1 | 0 |
| 15.2 | Hicks | 14.38 | 8-10 | 0 | 1 | 1 | 10 | 0 | 1 | 2 | *4 | 3 | 1 | 0 |
| 17.1 | Hilder | 14.40 | 2-3 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17.2 | Hilder | 14.40 | 3-10 | 70 | 20 | 10 | 5 | 1 | 0 | 0 | 0 | 2 | 0 | 0 |
| 14 | Day | 14.47 | 3-5 | 10 | 5 | 5 | 1 | 1 | 2 | 0 | *4 | 2 | 0 | 0 |
| 16.1 | Day | 14.48 | 4-6 | 30 | 5 | 0 | 10 | 3 | 2 | 0 | *4 | 4 | 3 | 0 |
| 16.2 | Day | 14.48 | 6-10 | 15 | 5 | 1 | 10 | 3 | 2 | 0 | *4 | 4 | 3 | 0 |
| 13 | Carter | 14.52 | 2-5 | 30 | 20 | 0 | 5 | 2 | 2 | 2 | 0 | 3 | 2 | 0 |
| 12 | Yonge | 14.53 | 5-15 | 15 | 1 | 0 | 50 | 3 | 4 | 2 | 0 | 4 | 3 | 2 |
| 11.1 | Ribbon 10 | 14.68 | 3-5 | 10 | 40 | 0 | 1 | 2 | 0 | 0 | 0 | 2 | 0 | 0 |
| 11.2 | Ribbon 10 | 14.68 | 5-7 | 40 | 30 | 30 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 9 | Ribbon 10 | 14.78 | 8-10 | 10 | 10 | 1 | 0 | 3 | 0 | 0 | 0 | 3 | 0 | 0 |
| 8 | Ribbon 10 | 14.93 | 4-5 | 15 | 40 | 5 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| 7 | Ribbon 8 | 15.08 | 3-10 | 15 | 50 | 0 | 20 | 2 | 0 | 0 | 0 | 1 | 0 | 0 |
| 6 | Ribbon 6 | 15.28 | 3-4 | 15 | 40 | 0 | 10 | 1 | 0 | 0 | 0 | 2 | 0 | 0 |
| 4.1 | Ribbon 4 | 15.43 | 4-6 | 10 | 10 | 10 | 40 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.2 | Ribbon 4 | 15.43 | 15-17 | 0 | 10 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | Ribbon 2 | 15.53 | 3-5 | 45 | 20 | 20 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 1.1 | Ruby | 15.73 | 3-4 | 0 | 10 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.2 | Ruby | 15.73 | 4-5 | 5 | 10 | 10 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| OUTER BARRIER REEF BACKS: | | | | | | | | | | | | | | |
| 33.1 | 13-125 | 13.88 | 1-2 | 0 | 20 | 20 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33.2 | 13-125 | 13.88 | 4-5 | 0 | 20 | 20 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35.1 | 13-125 s | 13.90 | 1-2 | 0 | 5 | 0 | 15 | 0 | 3 | 0 | 0 | 2 | 0 | 0 |
| 35.2 | 13-125 s | 13.90 | 6-8 | 10 | 10 | 0 | 20 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 28.1 | Davie w | 13.97 | 1-2 | 0 | 50 | 15 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 28.2 | Davie w | 13.97 | 2-6 | 90 | 20 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 28.3 | Davie w | 13.97 | 6-8 | 0 | 10 | 0 | 40 | 0 | 2 | 1 | 0 | 0 | 0 | 0 |
| 29.1 | Davie | 13.98 | 2-5 | 10 | 1 | 0 | 5 | 0 | 4 | 0 | 0 | 4 | 0 | 4 |
| 26 | Scooterboot | 13.92 | 2-5 | - | 2 | 0 | 0 | 0 | 3 | 1 | 1 | 3 | 3 | 4 |
| 21 | 14-077 | 14.28 | 1-6 | 90 | 30 | 10 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18.1 | Jewell s | 14.40 | 2-3 | 0 | 30 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18.2 | Jewell s | 14.40 | 3-6 | 80 | 20 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | Cod Hole | 14.58 | 5-10 | 20 | 20 | 2 | 2 | 2 | 0 | 0 | 0 | 1 | 0 | 0 |
| 46 | Ribbon 7 | 15.15 | 1-6 | 90 | 15 | 5 | 20 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 5 | Ribbon 5 | 15.39 | 1-10 | 70 | 20 | 10 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | Pearl | 15.72 | 1-4 | 60 | 30 | 10 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 0 |

**TABLE 1. (Continued) SITE DESCRIPTIONS AND ESTIMATES OF CYCLONE DAMAGE.**

| Site # | Reef | Site Description | | | | | | Cyclone Damage Categories (0-5) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Latitude | Depth (m) | Slope | Hard coral (%) | Soft coral (%) | Dead coral (%) | Coral break. | *Porites* dislod. | Flying debris | Softs torn | Matrix peel. | Slab slip | Sed. trans. |
| MID-SHELF REEF BACKS: | | | | | | | | | | | | | | |
| 32 | Clack Is. | 14.06 | 2-5 | 0 | 40 | 0 | 10 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 31 | King Is. | 14.09 | 2-5 | 0 | 40 | 0 | 10 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 36 | Pipin Is. | 14.12 | 1-4 | 0 | 40 | 30 | 10 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 38 | N Warden | 14.20 | 1-4 | 5 | 30 | 30 | 30 | 0 | 3 | 0 | 0 | 0 | 0 | 1 |
| 39 | S Warden | 14.28 | 1-4 | 0 | 20 | 20 | 10 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41 | Combe | 14.38 | 2-4 | 0 | 30 | 20 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MID-SHELF REEF FRONTS: | | | | | | | | | | | | | | |
| 30 | King Is. | 14.10 | 2-5 | 10 | 40 | 5 | 5 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 37 | Pipin Is. | 14.13 | 3-4 | 5 | 20 | 15 | 10 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 40 | Switzer | 14.38 | 1-4 | 5 | 5 | 0 | 5 | 4 | 4 | 0 | 0 | 0 | 0 | 4 |
| 42 | Snake | 14.50 | 2-4 | 5 | 10 | 0 | 10 | 3 | 2 | 0 | 0 | 0 | 0 | 0 |
| 43 | Waining | 14.50 | 2-6 | 5 | 10 | 10 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 44.1 | Eyrie | 14.72 | 1-3 | 5 | 5 | 0 | 2 | 3 | 1 | 0 | 0 | 0 | 0 | 3 |
| 44.2 | Eyrie | 14.72 | 3-6 | 5 | 30 | 20 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45 | Heldson | 14.93 | 1-4 | 15 | 50 | 5 | 5 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |

## TABLE 2. SITE DESCRIPTION AND CYCLONE DAMAGE BASED ON VIDEO TRANSECTS

Damage measurements indicate the percentage of sample frames with the damage category represented.

| Site # | Reef | Position | Depth (m) | Hard coral (%) | Soft coral (%) | Dead coral (%) | Coral Breakage | *Porites* dislodged | Matrix peeling |
|---|---|---|---|---|---|---|---|---|---|
| OUTER BARRIER REEF FRONTS: | | | | | | | | | |
| 34 | 13-125 | front | 2-8 | 69.2 | 15.4 | 0 | 0 | 0 | 5.1 |
| 25 | Scooterboot | front | 4-8 | 3.7 | 3.7 | 0 | 0 | 0 | 30.4 |
| 27 | Davie | front | 4-10 | 21.3 | 1.6 | 0 | 0 | 0 | 29.5 |
| 24 | Scooterboot | front | 4-8 | 83.9 | 8.9 | 0 | 0 | 0 | 3.6 |
| 23 | 14-047 | front | 4-9 | 7.7 | 13.5 | 0 | 0 | 0 | 63.5 |
| 22 | 14-074 | front | 4-8 | 17.7 | 9.7 | 0 | 1.6 | 0 | 62.9 |
| 20 | 14-077 | front | 3-8 | 29.8 | 7.0 | 0 | 3.5 | 0 | 43.9 |
| 19 | Jewell | front | 4-10 | 3.5 | 0 | 0 | 0 | 0 | 89.7 |
| 15 | Hicks | front | 4-10 | 4.4 | 5.8 | 0 | 0 | 2.9 | 63.8 |
| 17 | Hilder | front | 4-8 | 48.5 | 5.9 | 0 | 0 | 0 | 30.9 |
| 14 | Day | front | 4-8 | 5.5 | 0 | 0 | 0 | 0 | 74.6 |
| 16 | Day | front | 4-12 | 5.3 | 5.3 | 0 | 0 | 0 | 35.1 |
| 13 | Carter | front | 4-10 | 16.0 | 0 | 0 | 0 | 0 | 66.0 |
| 12 | Yonge | front | 4-12 | 1.5 | 0 | 0 | 0 | 3.0 | 56.7 |
| 11 | Ribbon 10 | front | 4-10 | 40.6 | 1.5 | 0 | 0 | 0 | 53.6 |
| 8 | Ribbon 10 | front | 4-8 | 59.7 | 1.4 | 0 | 0 | 0 | 36.1 |
| 7 | Ribbon 8 | front | 5-8 | 40.0 | 0 | 0 | 12.3 | 0 | 13.9 |
| 6 | Ribbon 6 | front | 5-10 | 51.8 | 0 | 0 | 0 | 0 | 41.1 |
| 1 | Ruby | front | 5-8 | 18.0 | 4.0 | 0 | 2.0 | 0 | 0 |
| OUTER BARRIER REEF BACKS: | | | | | | | | | |
| 33 | 13-125 | back | 2-8 | 13.1 | 1.6 | 1.6 | 0 | 6.6 | 14.8 |
| 35 | 13-125 | south | 2-8 | 5.9 | 2.0 | 0 | 2.0 | 15.7 | 17.6 |
| 28 | Davie | west | 2-8 | 22.6 | 0 | 0 | 0 | 18.9 | 22.6 |
| 29 | Davie | south | 3-8 | 8.1 | 0 | 0 | 0 | 8.1 | 36.5 |
| 26 | Scooterboot | west | 3-10 | 1.8 | 3.6 | 0 | 0 | 8.9 | 70.4 |
| 18 | Jewell | south | 4-8 | 43.3 | 5.0 | 0 | 1.7 | 0 | 26.7 |
| 2 | Pearl | north | 3-6 | 47.1 | 41.2 | 5.9 | 0 | 0 | 0 |
| MID-SHELF REEF BACKS: | | | | | | | | | |
| 32 | Clack Is. | back | 2-5 | 50.0 | 0 | 5.0 | 0 | 18.3 | 0 |
| 38 | N Warden | back | 2-6 | 11.4 | 25 | 0 | 0 | 27.3 | 0 |
| MID-SHELF REEF FRONTS: | | | | | | | | | |
| 30 | King Is. | front | 3-5 | 39.1 | 0 | 2.2 | 19.5 | 2.2 | 0 |
| 37 | Pipin Is. | front | 3-6 | 38.6 | 4.5 | 0 | 2.3 | 2.3 | 0 |
| 40 | Switzer | front | 2-5 | 7.8 | 0 | 0 | 2.0 | 11.8 | 3.9 |
| 42 | Snake | front | 3-8 | 9.8 | 0 | 4.9 | 0 | 1.6 | 8.1 |
| 43 | Waining | front | 2-6 | 17.7 | 16.1 | 0 | 0 | 11.3 | 6.5 |
| 44 | Eyrie | front | 3-6 | 29.3 | 2.4 | 0 | 4.9 | 4.9 | 0 |

There were piles of fresh coarse rubble (dimension to several decameters) in flat areas and depressions at depths generally > 10 m, shallower slopes had been swept clean of loose sand and rubble. At the time of the survey (some 4 months after the cyclone), most of the exposed bedrock and fresh rubble was covered in sparse algal turfs. These areas gave the impression they were relatively heavily grazed but some peeled areas had denser turfs due to the presence of territorial damselfish (species not noted).

Over the next 50 - 80 km south along the ribbon reefs, matrix peeling and coral breakage remained the predominant forms of damage. Low severity scores (2s and 1s, and eventually 0s) became increasingly common with increasing latitude. Peeled patches were smaller (usually 10s of square meters), and more superficial (< 0.3 m thickness removed) than those closer to the cyclone path. Recolonisation of the smaller patches may in part be through growth of corals along the margins of patches.

**Reefs along the path.** There was remarkably little damage on the seaward slopes of the reefs to the north-west of Jewell Reef (Sites 18 and 19 - Fig. 1) where meteorological data indicate the cyclone dwelt for some 3 hours (around 1730 - 2030 hrs). On these slopes, which had the width of the reef between them and the nominal cyclone path (Fig. 1), the damage scores were up to only 1s and 2s for matrix peeling and for dislodgement of *Porites*, and 0s for the other categories. Subjectively, the minor damage here, almost on the path, appeared roughly equivalent to damage 50 - 80 km to the south, viz. small and more superficially peeled areas; little or no breakage.

### Back reef slopes of outer reefs

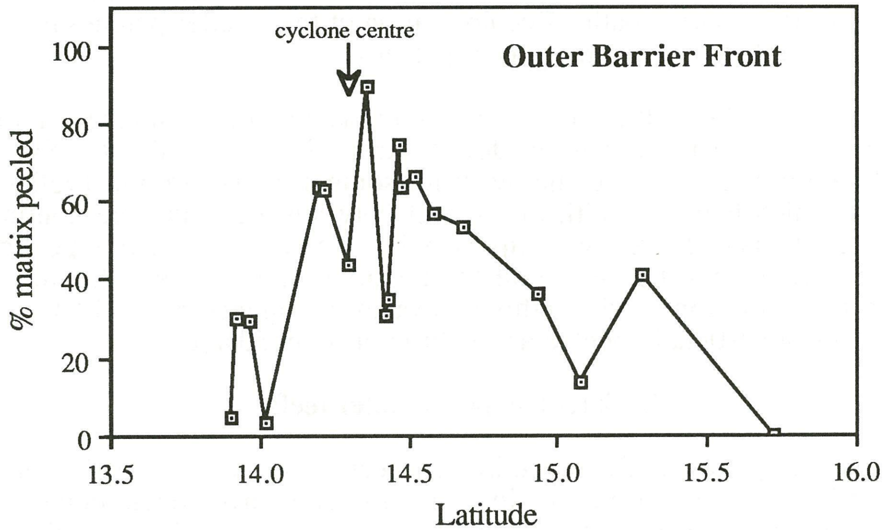
Latitudinal patterns of damage in back reef slopes of outer reefs were consistent with what might be expected based on wind direction and wave attack angle (Fig. 5). In all 5 back slopes on reefs on the cyclone path (reef 14-077; Jewell) or to the south of it (Ribbon 7; Ribbon 5), there was only 1 record of damage (a score of 1 for *Porites* dislodgement at Ribbon 7). In the case of Jewell, the absence of damage was particularly noteworthy, given the severe peeling, breakage and *Porites* dislodgement on the reef front less than 2 km away across the reef top. Similarly, M. Pichon (pers. com.) and two of us (RVW and AMA) observed very little damage on the backs of Yonge and Carter Reefs respectively, on separate visits. Both of these reefs were severely damaged on their seaward slopes.

On reefs to the north of the cyclone path (13-135; Davie; Scooterboot), there was considerable damage in the western sectors. To the south, by contrast, (on Pearl Reef - Site 2) there was significant damage in the north-west sector, including a score 2 for dislodgement of *Porites*. This probably resulted from swells generated from strong Northerly winds associated with the rain depression of 22-24 March.

**FIGURE 2. CYCLONE DAMAGE IN THE FRONT REEF HABITAT: REEF MATRIX PEELING**

A. Matrix peeling from video transects B. Estimated matrix peeling - peeling damage is ranked from 0 (no damage) to 5 (100% damage)

**A.**




**B.**

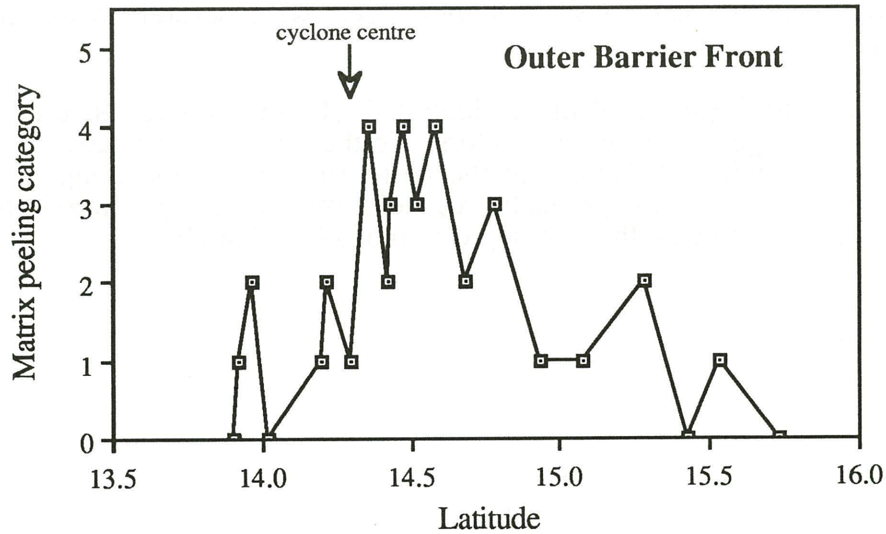
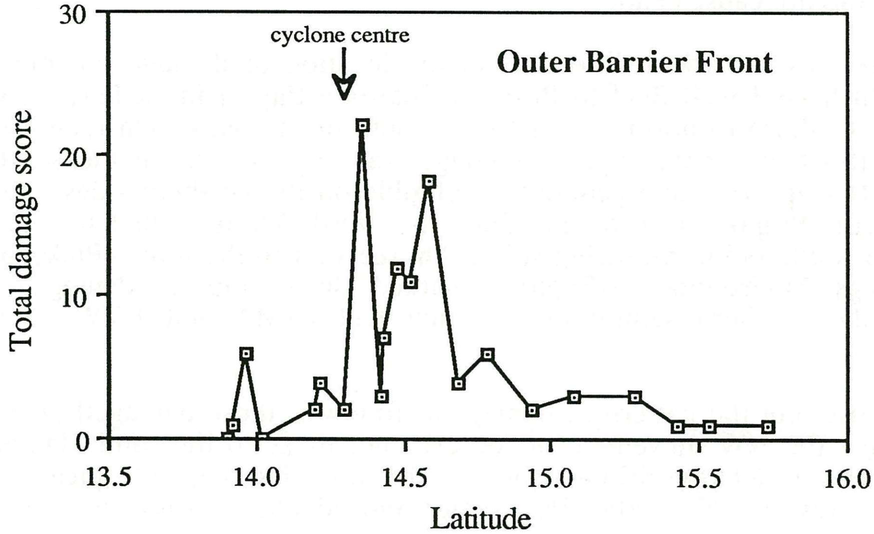


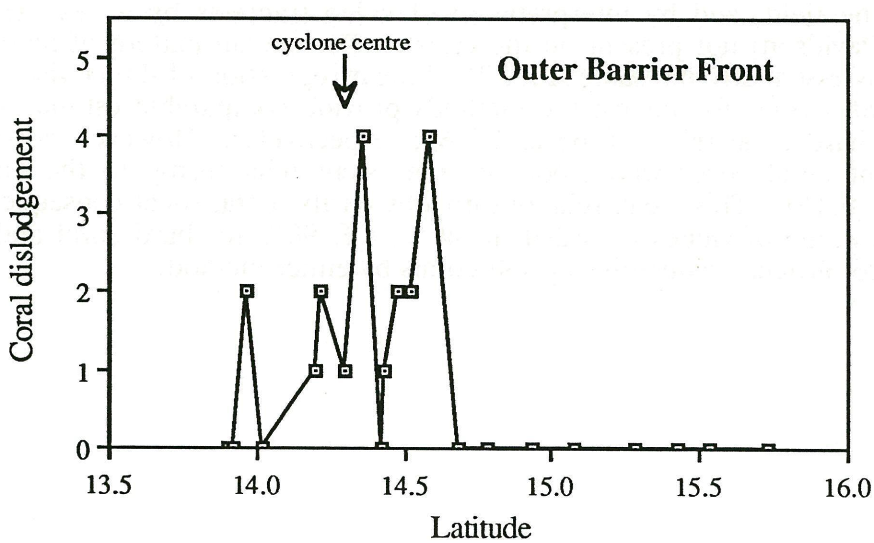
FIGURE 3. CYCLONE DAMAGE IN THE FRONT REEF HABITAT

A. Total damage score from all categories B. *Porites* dislodgement
Damage in each category is ranked from 0 (no damage) to 5 (100% damage)

A.




B.



## Mid-shelf reefs

The major categories of damage recorded on mid-shelf reefs were coral breakage, dislodgement of *Porites* and other large massive corals, and sediment transport. In contrast to the fronts of the outer reefs, we observed no cases of matrix peeling on the fronts of mid-shelf reefs. This observation reflects differences in the way mid-shelf and outer-shelf reef fronts accrete. There was no indication that any structures equivalent to the 1 - 1.5 m thick veneer of living and recently dead *in situ* corals so common on the fronts of the outer reefs had ever existed on the mid-shelf reef fronts. Rather, most corals had grown directly on a consolidated reef platform. In severely damaged areas, coral rubble had accumulated in level areas at the base of reef slopes, and the shallow slopes were free of loose rubble or sand. In less damaged places, there was high survival of corals, damage often consisting of no more than flattening of staghorn thickets, and branch breakage which did not cause death.

There was a marked difference in the location of damage on mid-shelf reefs close to the path from Jewell Reef to Princess Charlotte Bay or immediately south of the path, compared to those to north, or far to the south of the path. On reefs close to the cyclone's path (Switzer, Snake, Eyrie), damage was most severe on the south- to east-facing reef fronts (Fig. 4B), and generally negligible on the northern sides. Reefs to the north of the path (Pippon It, King Is, Clack Is, North Warden) had low to moderate damage on both south and north facing sides. On reefs far to the south (Pickersgill, Opal, Norman, Hastings, Michaelmas, Arlington - marked 'dn' on Fig. 1), damaged areas were exclusively in the northern semi-circle of each reef (AMA and RVW - unpublished observations).

We interpret the pattern of damage as follows: those damaged in the southern semi-circle reflect the NW movement of the cyclone: those to the south damaged in the northern semi-circle reflect the SE movement of the much less severe tropical low pressure system (central pressure 998-1008 hPa), which moved back across the coast on 23-24 March.

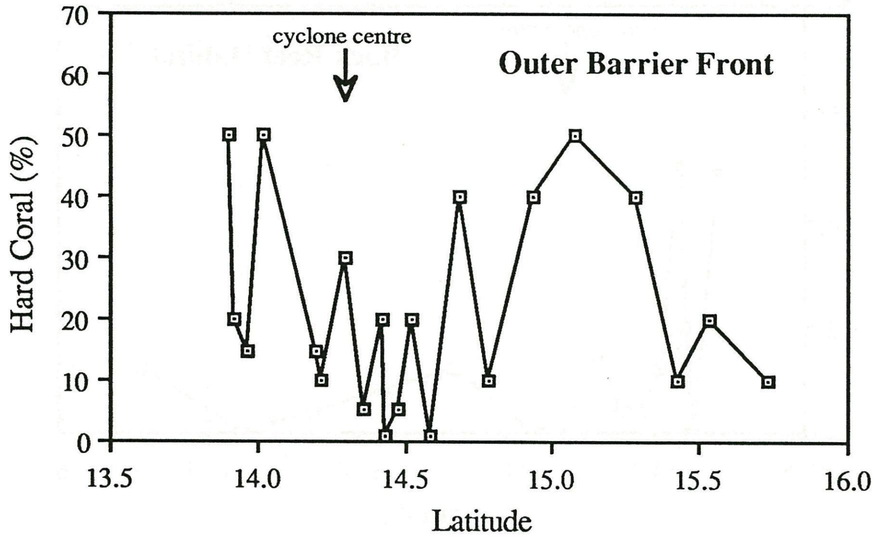
## Visual estimates vs video sampling

Similar gross patterns of damage were documented by both direct visual assessment in the field, and by interpretation of video transects by an experienced reef researcher (J. Davidson) not present on the cruise. The overall pattern of matrix peeling versus latitude is essentially the same (Fig. 2). Linear regression of direct visual estimates on video estimates (Fig. 6) suggest the methods provide comparable estimates of matrix peeling and % hard coral ($r^2$ = 0.65 and 0.67, respectively). However video provided estimates of soft coral cover which bore no consistent relationship to the direct visual estimates ($r^2$ = 0.16). This weak relationship was partly a statistical consequence of the relatively small range of values recorded (to 40%, c.f. 90% for hard coral and peeling), and partly due to difficulties quantifying soft corals by either method.

## FIGURE 4. EFFECT OF CYCLONE IVOR ON CORAL COVER

A. Outer barrier front reef sites B. Mid-shelf front reef sites
Estimates of hard coral cover are shown

A.

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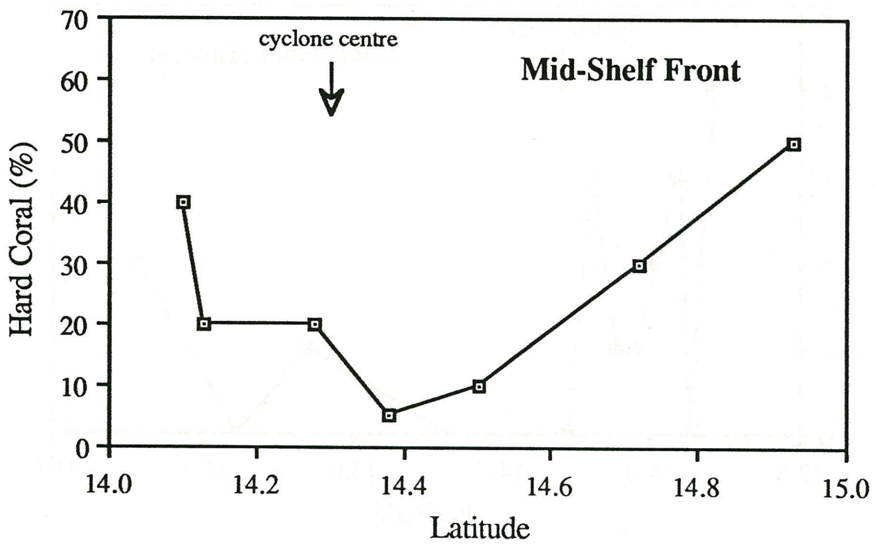
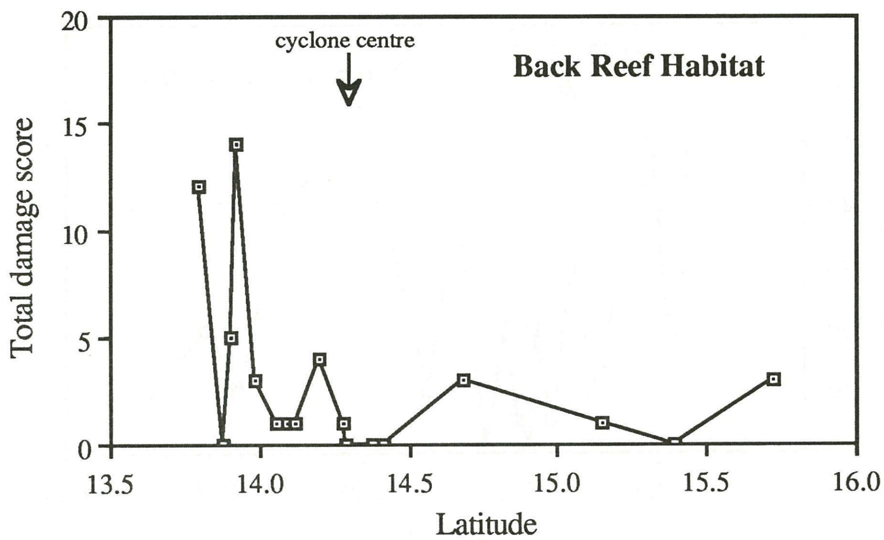


**FIGURE 5. CYCLONE DAMAGE IN THE BACK REEF HABITAT**

A. Total damage score from all categories **B.** *Porites* dislodgement
Damage in each category is ranked from 0 (no damage) to 5 (100% damage)

**A.**




**B.**

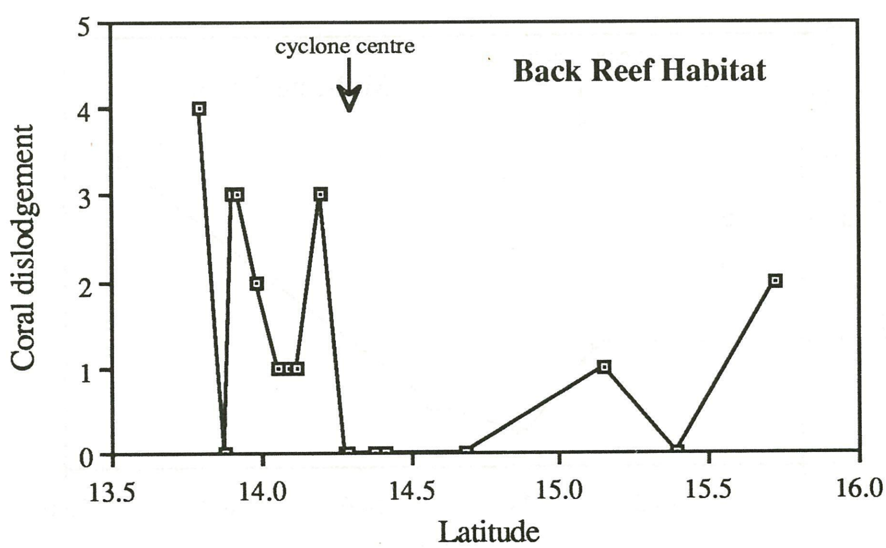
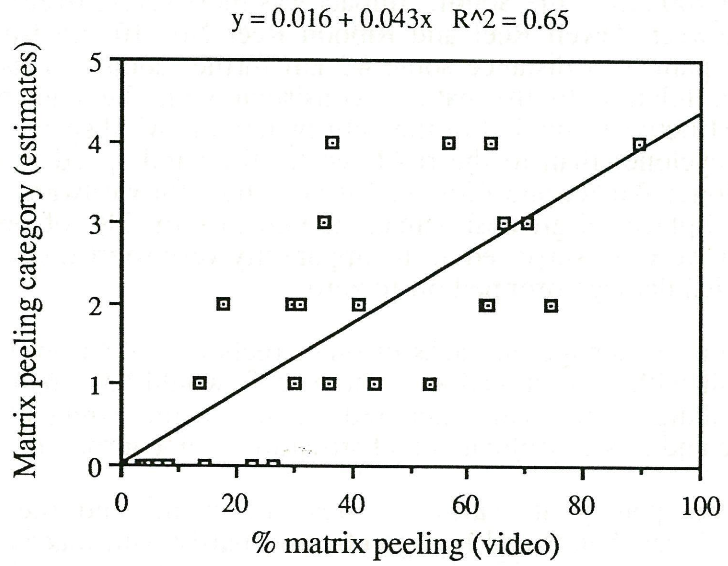


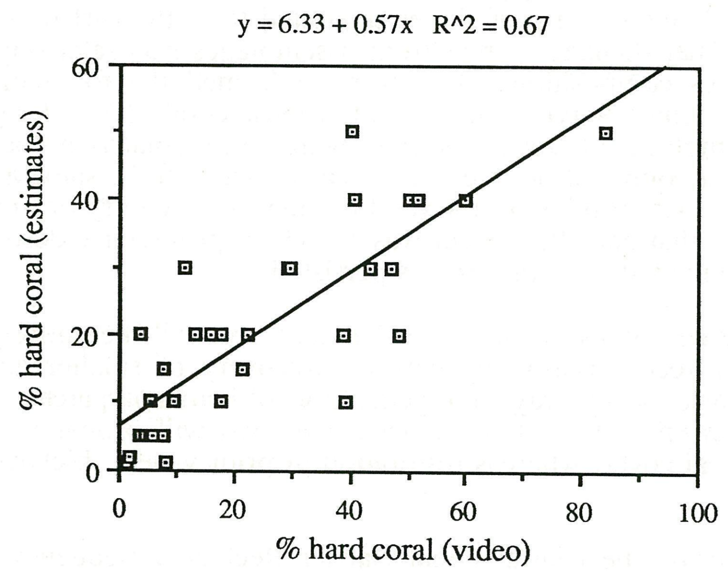
**FIGURE 6. COMPARISON OF CORAL COVER AND CYCLONE DAMAGE ESTIMATES WITH VIDEO TRANSECT DATA FROM SAME SITES**

A. Matrix peeling B. Hard coral cover C. Soft coral cover

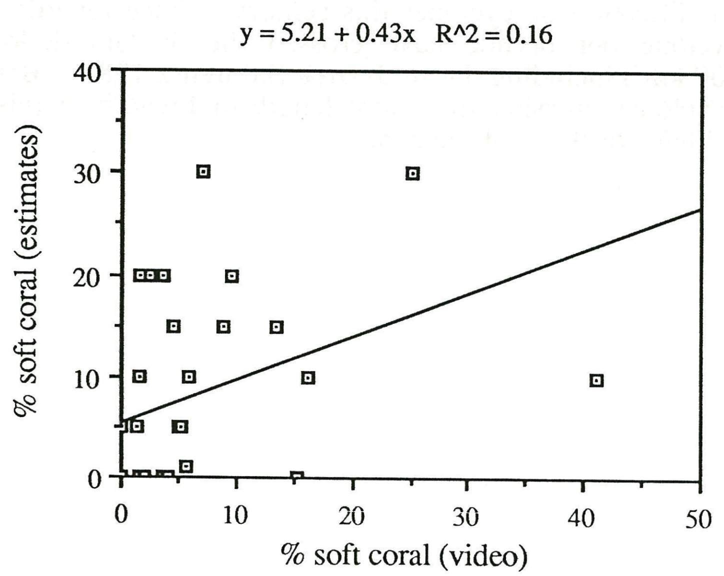
A.




B.




C.



## Discussion

This study documented destructive effects of Cyclone Ivor over a 140 km section of the GBR. Physical damage caused by the cyclone was recognised as far as 40 km to the North of the path and 100 km to the South. Impact was most severe over a 50 km section of the outer GBR between Jewell Reef and Ribbon Reef No. 10, i.e from close to the southern limit of the path to a distance some 40 km further south. This asymmetry of outer reef damage in relation to the path is consistent with the known property that cyclones are more destructive to the left of the path (where the wind speed = orbital speed + forward speed of cyclone) than to the right (where the wind speed = orbital speed - forward speed of cyclone; Walker and Riordan 1986). Thus, for westward moving parts of the path, the predicted places of greatest damage are on eastern sides of reefs to the south of the path. However we were surprised at the apparently very short distance north of the nominal path over which damage dropped off to zero.

The location of damage on backs of outer reefs (i.e north but not south of the path) is also consistent with wind-direction. These reefs would have had strong westerly winds and swells breaking on normally sheltered sides, and the extent of damage to the relatively more fragile and less consolidated reef structures is not surprising.

Damage was patchy at scales of 100s -1000s $m^2$ and the patchiness was associated partly with local shelter and topography and partly with matrix robustness, but less with coral community composition than age and size structure. Thus, given the aforementioned differences in wind speed and direction, we have shown that the reef can provide complete local shelter for reef slopes separated from the surf by the width of the reef. We concluded that damage to reef front assemblages was relatively indiscriminate with respect to species composition. However we formed the following impressions:- 1. Some of the areas which survived had small, robust corals (viz. *Acropora humilis / Acropora palifera* assemblages of Done, 1982) growing on reef matrix probably exposed in cyclones within the last couple of decades. 2. Areas in which these same assemblages had built up to a veneer 1 - 1.5 m thick over several decades to a century or more, were more vulnerable. It appears that once the veneer was breached, progressive destruction occurred from that breach so long as strong wave forces persisted.

Large denuded areas in the worst damaged area will be entirely dependent on larval recruitment for recolonisation by corals. Recovery of smaller and less severely damaged areas will also be by way of regeneration of remnant patches and growth of colonies on patch margins. Periods of a decade or two will probably be required for restoration of high coral cover, whereas restoration of prior veneer thickness will probably take many decades.

Cyclones cross the central Great Barrier Reef at a frequency which suggests that, if the width of the swathe caused by Cyclone Ivor is any indication, few reefs would have escaped major modification by cyclones this century. Since records began in 1909, an average of 13 cyclone per decade have crossed the 5° latitude/longitude square (approximately 290,000 $km^2$) including the study area (Lourensz 1981). Based on a swathe width of 40 km, 13 cyclones crossing the entire length or breadth of this square would severely affect 280,000 $km^2$, or 96 % of the area.

Much more research is needed to determine the significance of cyclones in relation to reef ecology and structure. Existing and proposed follow-up studies on coral recovery will do much to put the effect of cyclones and other disturbances in their proper perspective. Further broad scale studies of the present type would also be useful to improve our understanding of spatial patterns of damage.


## Acknowledgements

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# Plates

**Plate** 1. Peeling of reef matrix. Dark area is algal turf growing on freshly exposed reef matrix 0.3 to 1.0 m below original surface. Jewell Reef, site 19, 2m.

**Plate 2**. Peeling of reef matrix. A patch covering about 4 $m^2$. Carter Reef, site 13, 2 m.

**Plate** 3. Peeling of reef matrix. Detail. Yonge Reef, site 19, 2 m.

**Plate** 4. Peeling of reef matrix. Recently exposed surface is on the bottom left. Recolonization of a surface exposed in the past on the right. Jewell Reef, site 19, 2 m.

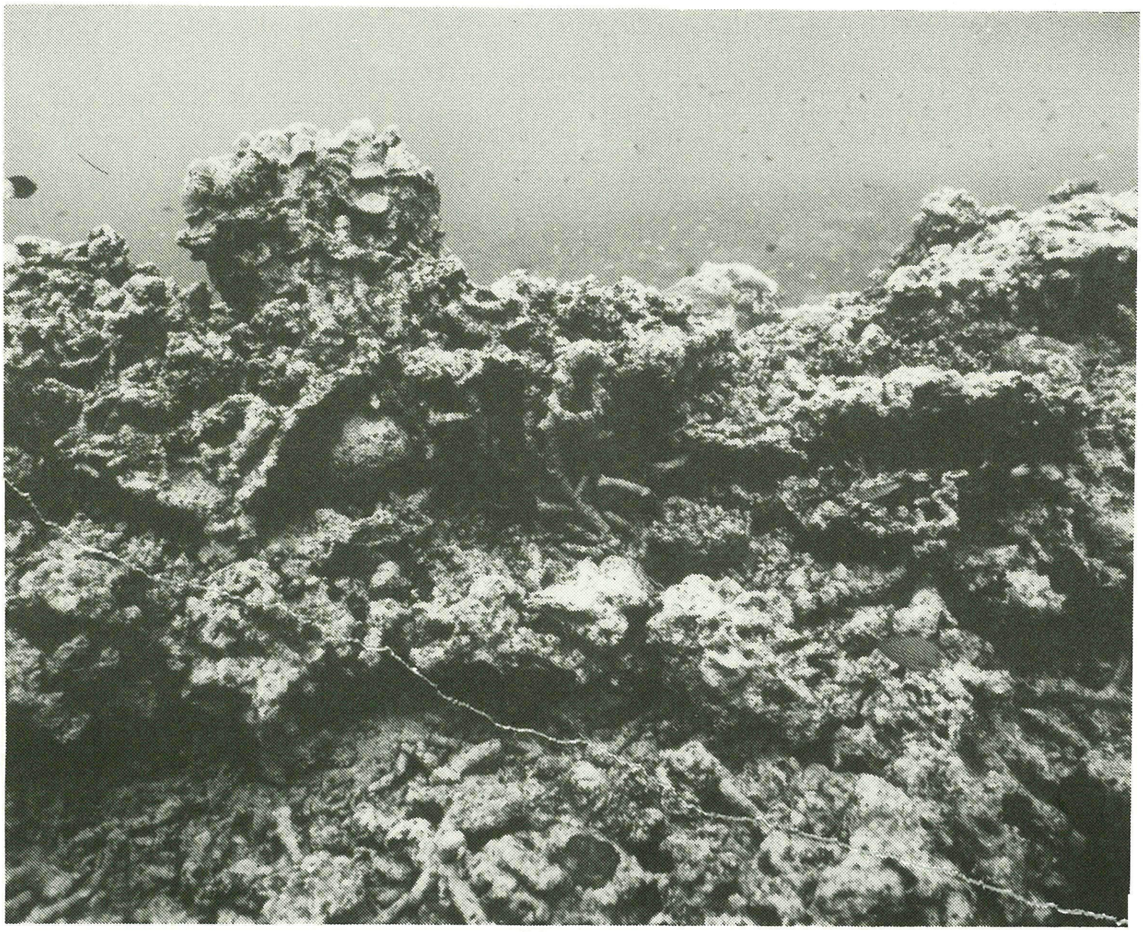

**Plate** 5. Peeling of reef matrix. Side of a 'cutting' caused by matrix peeling showing layers of corals in position of growth. Yonge Reef, site 12, 10 m.

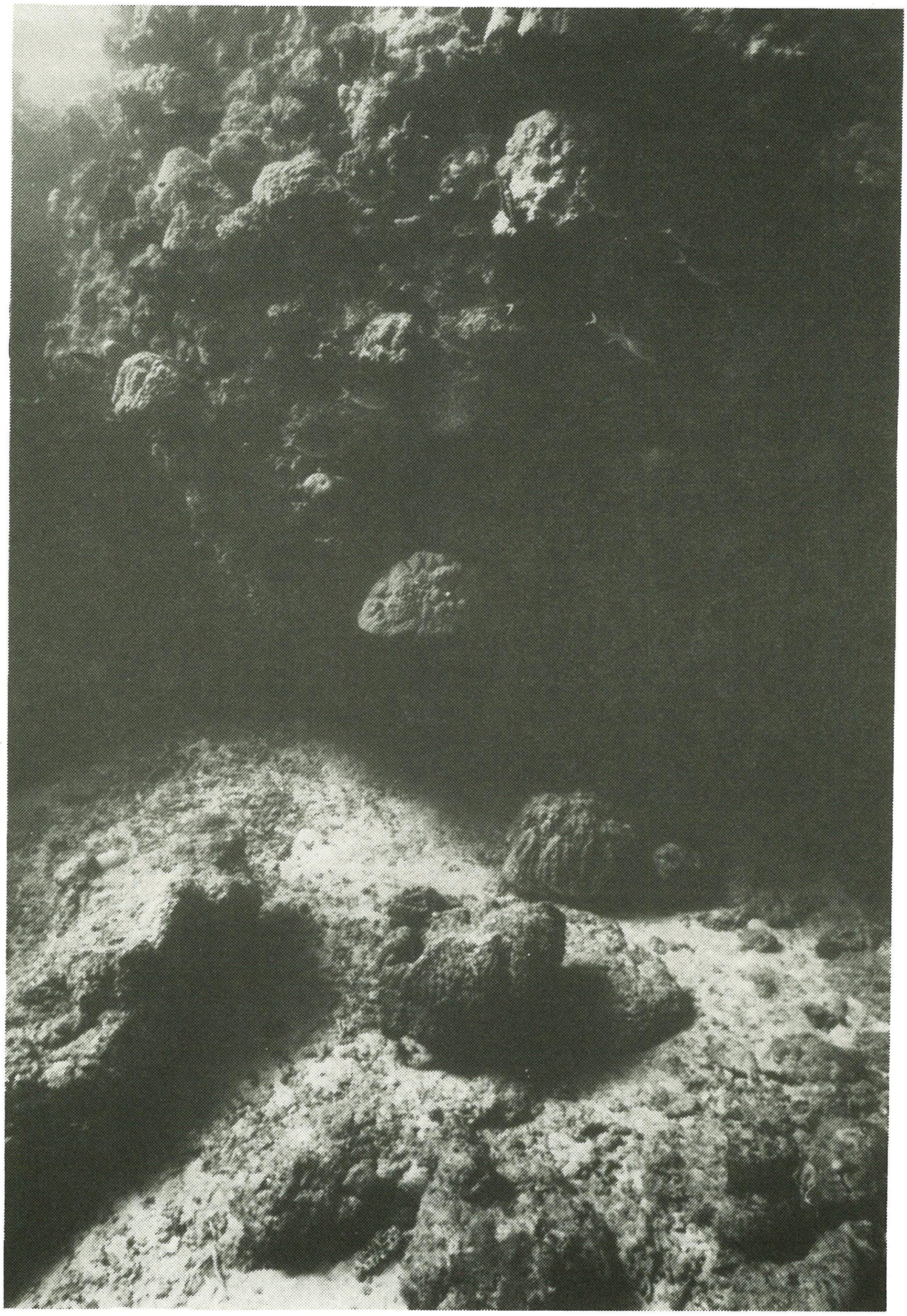

**Plate** 6. Dislodgement of massive *Porites* corals. Davie Reef W, site 28, 4 m.

**Plate** 7. Dislodgement of massive *Porites* corals. Davie Reef N, site 27, 6 m.

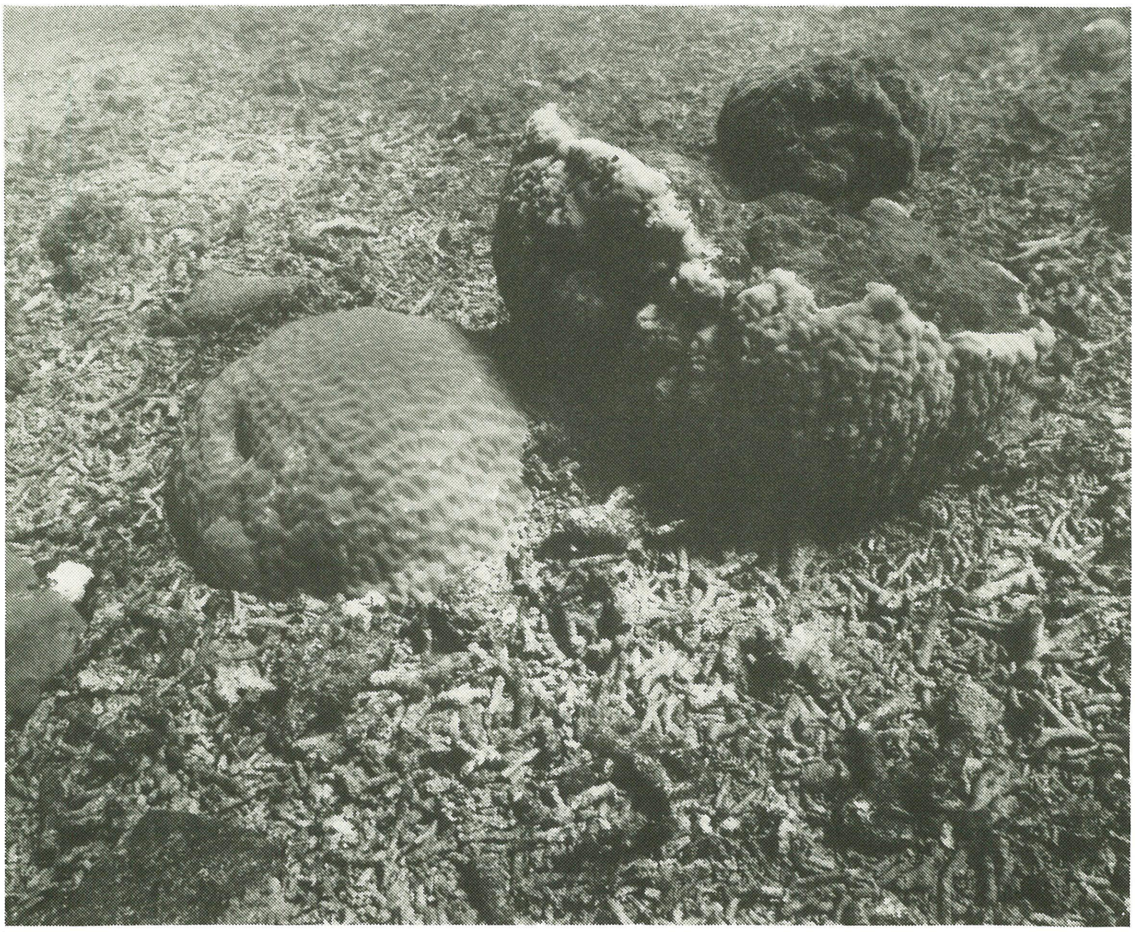

**Plate** 8. Dislodgement and burial of massive *Porites* corals. Davie Reef, site 29, 4 m.

**Plate** 9. Dislodgement of massive *Porites* corals. Jewel  Reef, site 19, 10 m.

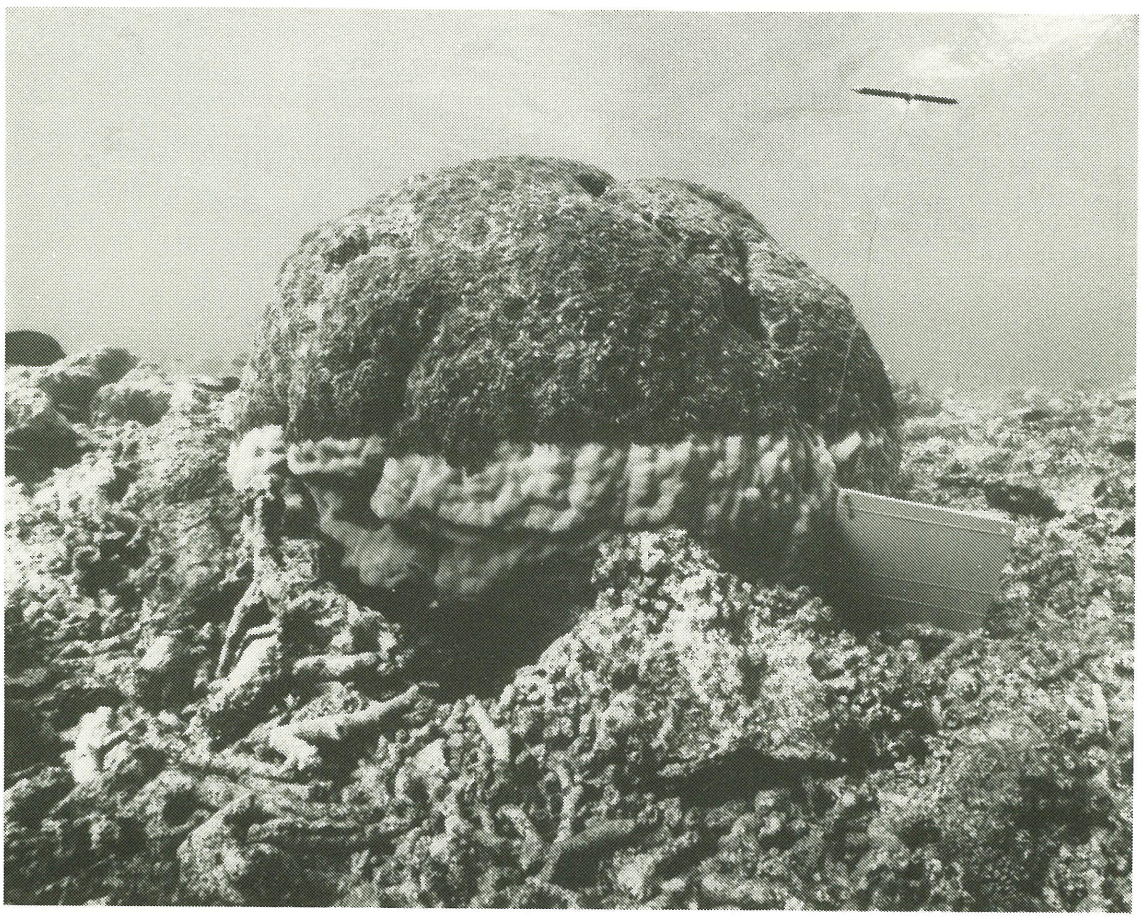

**Plate** 10. Dislodgement of massive *Porites* corals. Reef 13.142, site 35, 0 m. Colony (around 1 m diameter) has been lifted into the intertidal zone, killed on top by desiccation, and colonized by algal turfs.

**Plate** 11. Stripping of soft corals. Pipin Islet Site 36 0.5 m. Smooth area is composed of spicule mass laid down by the soft coral *Sinularia* sp, which has been partially stripped off by the cyclone.

**Plate** 12. Breakage of hard coral. Jewell Reef, site 19, 5 m. This *Galaxea fascicularis* has been split in half by storm waves.

**Plate** 13. Breakage of hard corals. Switzer Reef, site 40, 2 m. About one third of this 1.5 m diameter *Acropora hyacinthus* has been broken off by storm waves.

**Plate** 14. Area of low coral damage. Ribbon Reef 6, site 6, 2 m.

**Plate** 15. Area of low coral damage. Yonge Reef , site 19, 1 m.
This area was adjacent to areas where the same coral assemblage had been stripped off, exposing reef matrix below (see plates 1-5).

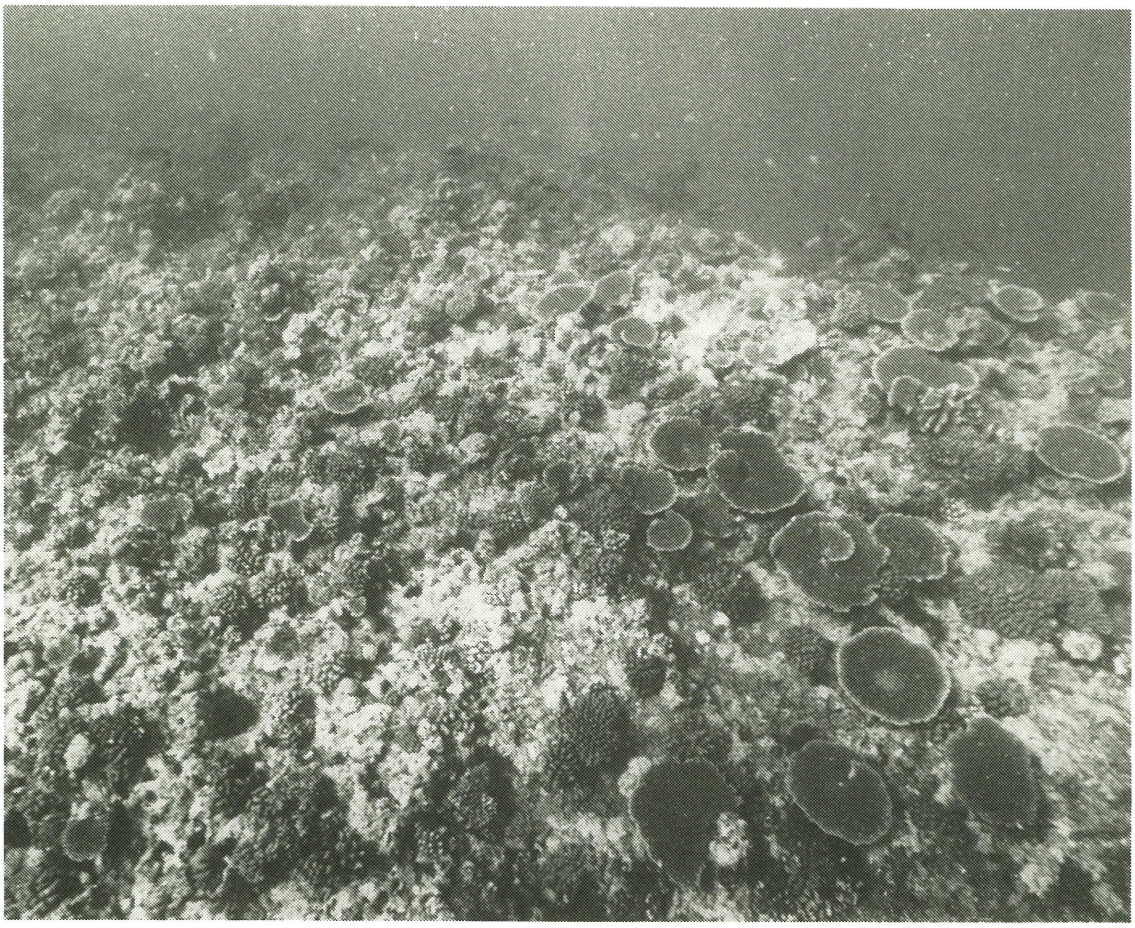

**Plate** 16. Area of low coral damage. *Acropra* plates on the southern margin of Jewel Reef , site 18, ≈ 2 m.

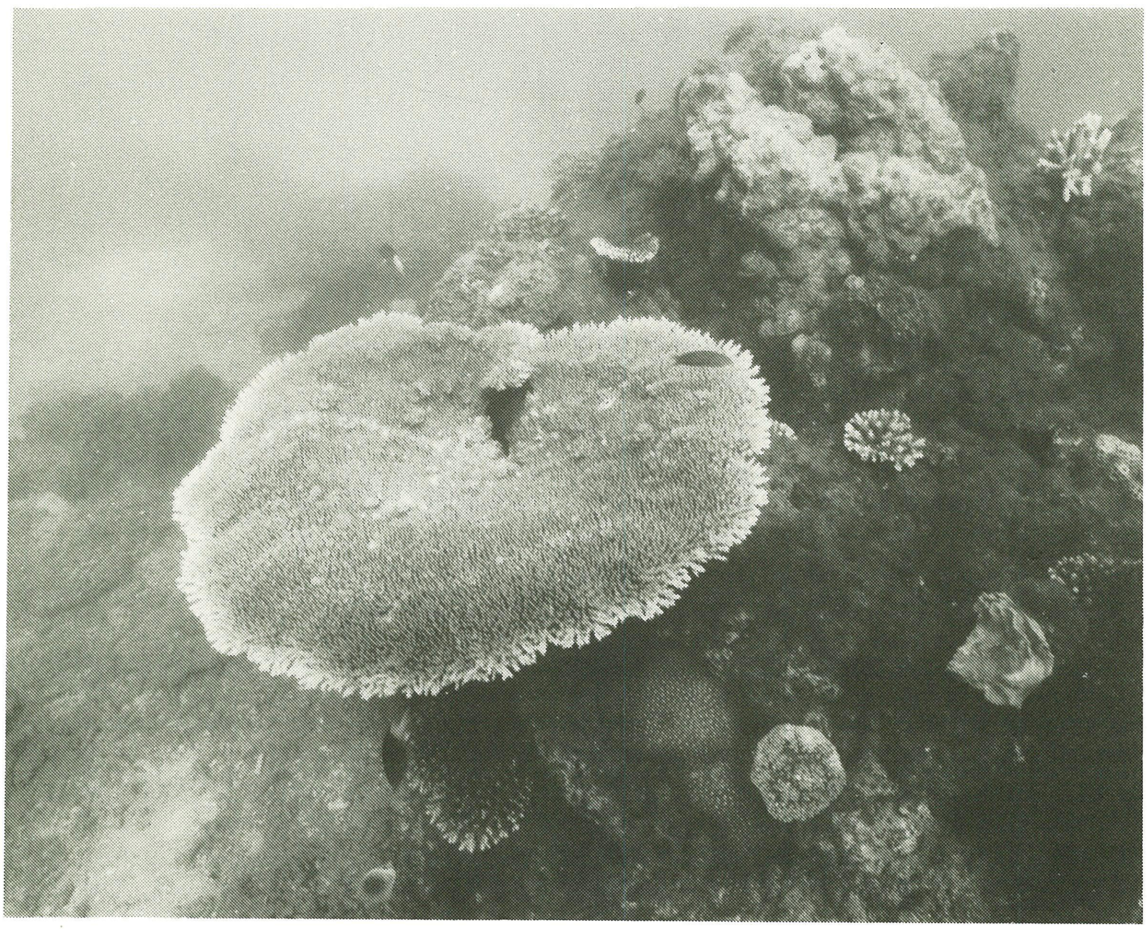

**Plate** 17. Area of low coral damage. Switzer Reef, site 40, 2 m.

**Plate** 18. Sediment transport. N. end of Scooterboot Reef, site 26, 2m. Sand wedge is around 1.5 m thick.

**Plate** 19. Sediment transport. N. end of Scooterboot Reef, site 26, 2 m. Sand has almost buried this colony, estimated height overall approx 2 m (visible height ≈ 0.4 m).

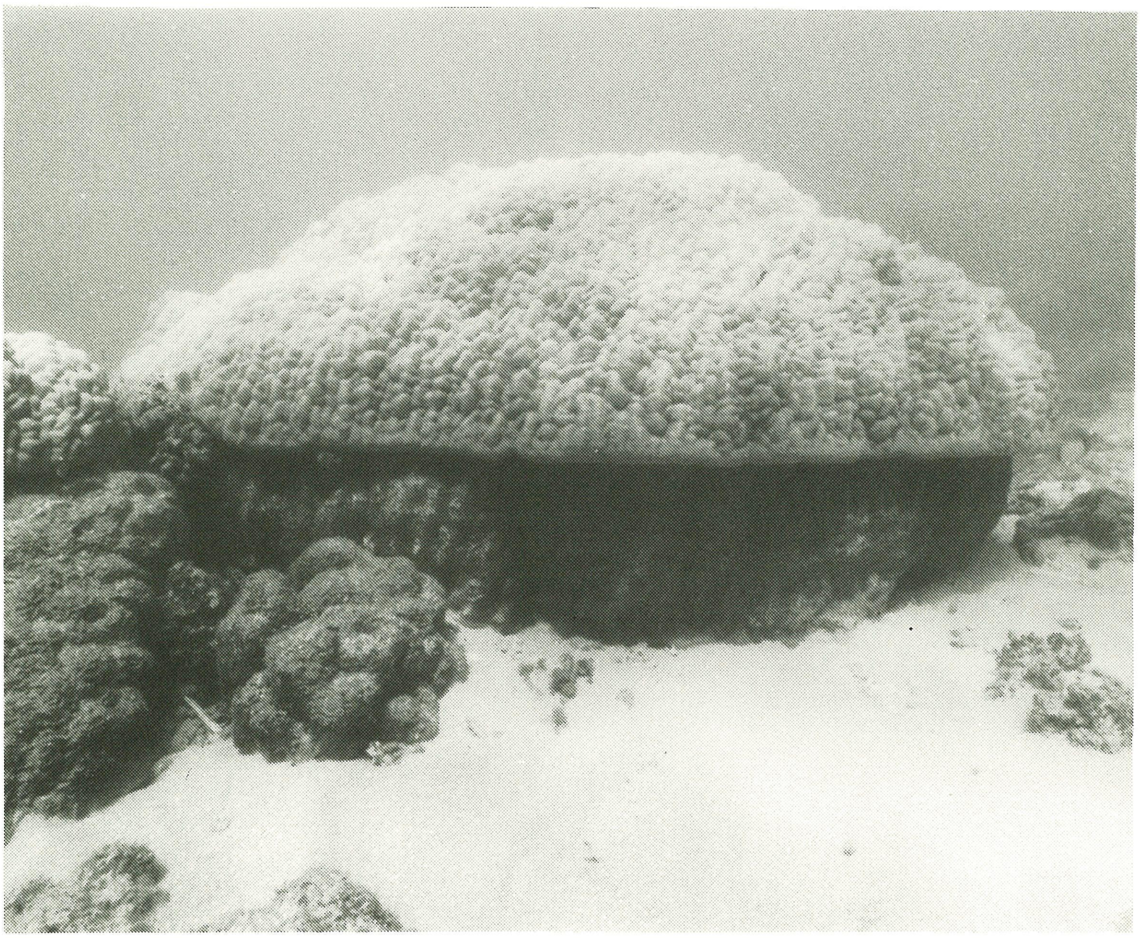

**Plate** 20. Sediment transport. Switzer Reef (site 40) 4 m. Sand has been washed away from this *Porites* colony. The morphology shows that the sand had been dumped in a single episode around 20 years before.

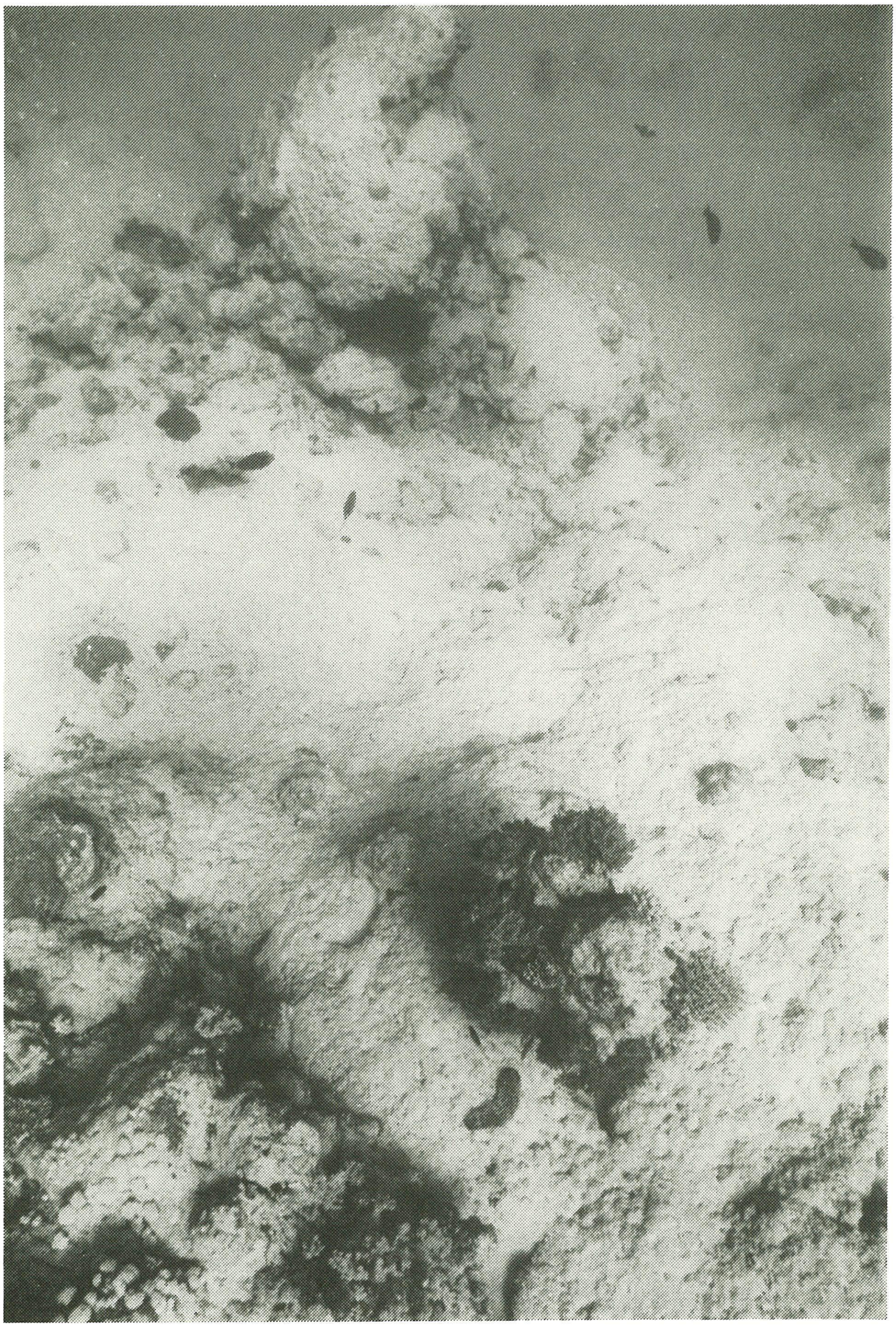

**Plate** 21. Sediment transport. Reef 14-077 (site 21). Sand has been washed off the reef top and has fallen down onto the slope.

**Plate** 22. Sediment transport. Eirie Reef (site 44). Bed of staghorn rubble with upturned plate *Acropora* colonies.