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I.N. Baxter

Great Barrier Reef Marine Park Authority

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A REPORT TO THE GREAT BARRIER REEF MARINE PARK AUTHORITY

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EXECUTIVE SUMMARY

The Green Island Information Review was commissioned by the Great Barrier Reef Marine Park Authority for the purpose of reviewing the available information pertaining to Green Island contained in published studies, books, theses and unpublished reports.

The draft review was utilised as an information resource by participants at the Green Island Workshop conducted by the Authority on October 16 and 17, 1990. This workshop was attended by representatives from the Authority, Queensland National Parks and Wildlife Service, James Cook University, Australian Institute of Marine Science, Queensland Department of Primary Industries' Fisheries Branch, University of Queensland, Cairns City Council, Mulgrave Shire Council and Reef Research and Information Services. While the final review incorporates comments from workshop data presented at the workshop.

This review supersedes the report 'Green Island: review of current knowledge' (Baxter, 1987), which was commissioned as a pilot study for a multidisciplinary research and monitoring program related to Acanthaster planci infestations at Green Island - the Green Island Reef Multidisciplinary Study.

The history of human activity at Green Island, from the late 19th century usage by beche-de-mer fishermen to the heavy tourist visitation of the present day, is reasonably well documented. Recent projections of future visitation rates for Green Island were not located and these may well be influenced by the extent of redevelopment of the Green Island Reef Resort.

The is little data pertaining to the reef biota prior to the 1962/67 infestation by the crown-of-thorns starfish. Coral cover was first estimated subsequent to this infestation and recolonisation studies were undertaken between 1967 and 1970. It appears no further surveys were conducted between 1967 and 1970. It appears no further surveys were conducted until 1979, subsequent to the second A. Planci outbreak. Surveys of live and dead hard coral cover have been conducted from 1979 to the present are schedule to continue, primarily the Reef Research and Information Services and the Australian Institute of Marine Science. The former are also conducting research into hard coral recruitment and juvenile population dynamics.

As the site of primary observation of crown-of-thorns starfish on the Great Barrier Reef, Green Island was the focal point for much of the early Australian work on the biology of the starfish. A variety of control measures were attempted during each infestation. Starfish abundance was surveyed frequently over the 1966/70 period, on a couple of occasions between 1970 and 1979, and again frequently during the 1979/82 infestation. Post-infestation abundance has been periodically determined since 1982 and the current status of the resident starfish population at Green Island is monitored by Reef Research and information Services.

There has been a recent increase in awareness of the need to prevent degradation of coral reef communities as a result of deterioration in water quality within the Great Barrier Reef region. At Green Island, attention has been focussed on the possible effects of effluent discharge from the cays sewerage system and on the potential influence of fluvial discharge from the adjacent mainland. Water quality monitoring is likely to be undertaken by the Sir George Fisher Centre for Tropical Marine Studies, James Cook University.

While work associated with the Green Island Reef Multidisciplinary Study provided some date on hydrodynamic processes occurring under certain tide and wind conditions, a more extensive study is required to model current patterns on the temporal and spatial scales necessary to make recommendations regarding the discharge of sewage to minimise impact on the reef.

There are some differences in opinion regarding the causes of an apparent increase in seagrass meadow area over the past 45 years. While some researchers consider this to be a true increase fuelled by nutrients from the sewerage effluent, others consider the meadows to be naturally occurring features with an ecological succession towards species forming meadows which are more visually apparent in aerial photographs. Seagrass biomass and abundance of the associated biota are the focus of research programs conducted by the Northern Fisheries Research Centre (Queensland Department of Primary Industries).

The work of D. Kuchler and the Beach Protection Authority in documenting historical shoreline and beach profile changes should be valuable as baseline data should the protective structures at the western end of the cay be removed to allow the 'natural' shoreline to be re-established. Again, a detailed hydrodynamic study would be necessary to predict possible effects of such action.

As it is unlikely I have uncovered full details of the vast array of unpublished research conducted at Green Island, this review may well have overlooked certain studies. Information on any additional studies will be gratefully accepted by the Research and Monitoring Section, Great Barrier Reef Marine Park Authority.

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INTRODUCTION

Green Island and its surrounding reef have a reasonably well documented history, as one would expect for a location which has been a major tourist attraction in the Cairns region for over fifty years. It is home to reputedly the world's first glass-bottomed boat service and to Australia's first coral cay resort and underwater observatory.

The most recent major repositories of general information on Green Island cay and reef are Baxter (1987) and the Great Barrier Reef Resource Inventory (Australian Littoral Society, 1990). The current report is intended to supersede Baxter (1987), while the latter is an updated version of the 1982 Resource Inventory (Australian Littoral Society, 1982). Both the Green Island Management Plan (Green Island Management Committee, 1980) and the 1982 Resource Inventory were valuable compilations of current knowledge, although inadequate referencing meant it was not possible to determine whether specific information originated from the published scientific literature, preliminary reports based on 'inferred data and broad assumptions' (see Chapter 1) or from local knowledge. While the 1990 Resource Inventory overcomes this deficiency and omits some of the more dubious 'facts', information attributed to the Green Island Management Committee (1980) should be treated with some caution.

Within the Great Barrier Reef region, Green Island has experienced a unique combination of natural and anthropogenic disturbances. Infestations of the crown-of-thorns starfish, Acanthaster planci, have been recorded twice in the past three decades. Nutrient input occurs from the sewage discharge of the resort and the water outlet from the marine zoological gardens, and the reef may also lie within the discharge plume of the Barron River (van Woesik in Baxter, 1988). Beach replenishment programs and revetments intended to reduce erosion around the western end of the cay have led to an unnatural redistribution of sediments in this area (Beach Protection Authority, 1989).

It has been suggested (Gourlay, 1983; Hopley, 1989) that some of these disturbances have, over the past four decades, led to a marked increase in area of the seagrass meadows to the north-west of the cay. However, a reviewer of McCormick and Choat (1989) believed there was no evidence to support such a suggestion as there was little information on expansion of seagrass areas elsewhere in the region. They noted that many uninhabited coral cays and reefs between Cairns and the Torres Strait also supported large seagrass meadows, so Green Island was not unique in having sizeable areas of seagrass.

The first of the A. planci infestations at Green Island was the first to be recorded on the Great Barrier Reef (Moran, 1986), and both infestations have preceded successions of outbreaks on reefs further south (Kenchington, 1977). This led to suggestions that Green Island may be near the epicentre of A. planci outbreaks on the Great Barrier Reef (Talbot and Talbot, 1971), although recent hydrodynamic models have predicted that A. planci larvae at Green Island reef are derived from more northern reefs (Dight *et al.* unpubl. ms.).

During the first A. planci infestation, Green Island hosted the first detailed Australian study of the biology, ecology and impact on the reef communities of A. planci (Pearson and Endean, 1969). This study, along with subsequent surveys to evaluate the recovery of the Green Island reef communities (Woodhead, 1971; Endean and Stablum, 1973a,b; Nash and Zell, 1981; Ayling, 1983), provides some historical data on coral abundance at certain localities on the reef. These are complemented by the current extensive coral surveys of Harriott and Fisk (1988, 1989) and the regular broadscale surveys of the Australian Institute of Marine Science (Bradbury *et al.*, 1987; Bass *et al.*, 1988, 1989a,b).

More recently, attention has been focussed on water quality and nutrient levels in the waters surrounding Green Island, with some attention being paid to the fate of sewage released from the cay's sewerage system (Steven *et al.*, 1989; van Woesik, 1990).

The broad scope of the Green Island Information Review should ensure its usefulness to anyone conducting research at Green Island in the near future. However, I stress the importance of updating the review on a regular basis to maintain its current status.

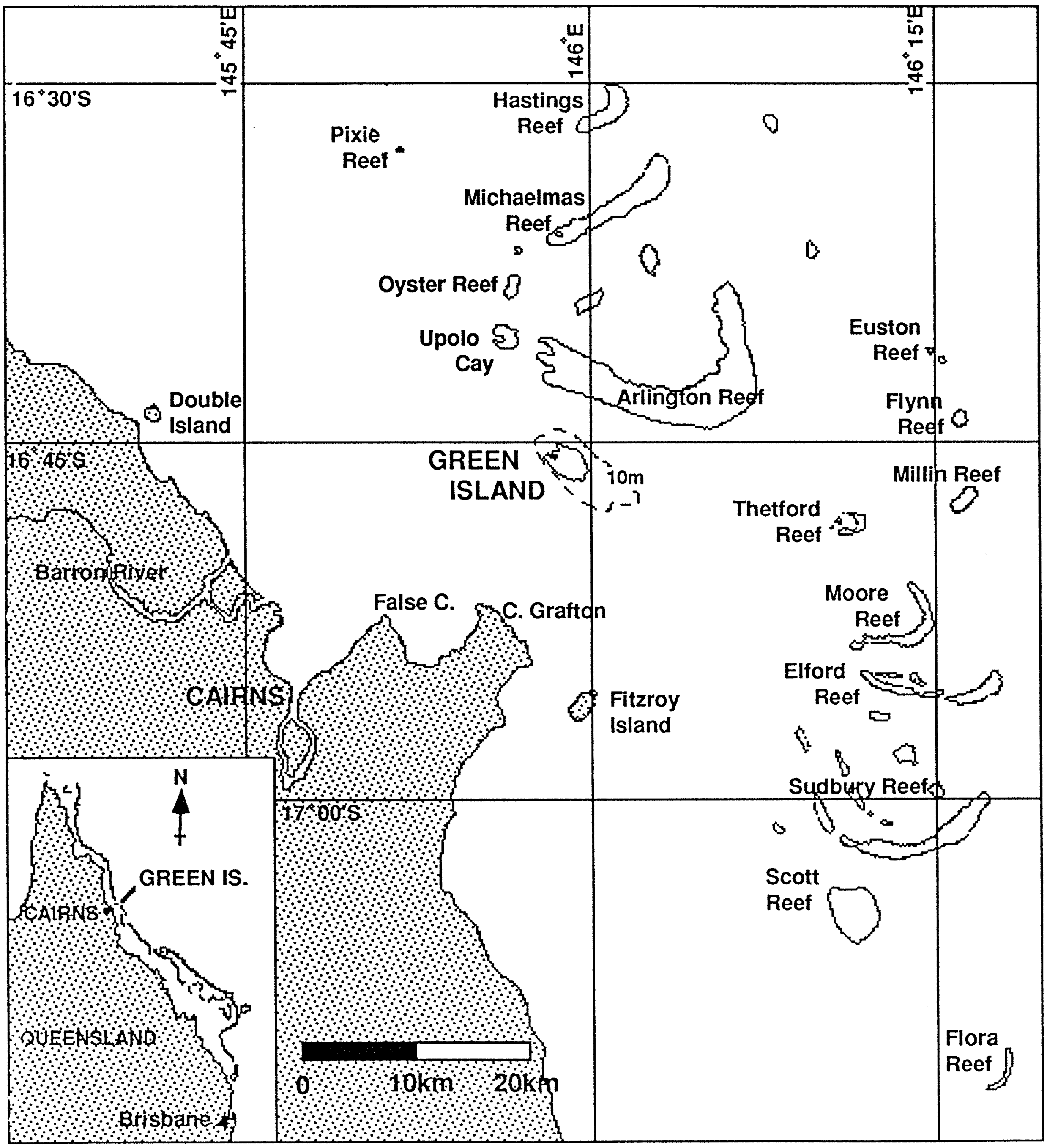


FIGURE 1.1 Locality plan, Green Island

Chapter 1 THE CAY

LOCATION AND DIMENSIONS

Green Island ($16^{o}45$'S, $145^{o}59$'E), 27 kilometres north-east of Cairns [Fig.1.1], is a vegetated sand cay on a planar reef (Hopley, 1982). The dimensions of the cay vary between publications, which is probably due in part to real changes in sediment distribution and in part to the adoption of differing definitions of the cay's boundary between authors.

Stoddart *et al.* (1978) utilised a compass-and-pacing method to survey Green Island in 1973 and estimated the total sand mass forming the cay to have maximum dimensions of 690m x 300m, covering an area of 13.91ha. Kuchler (1978) adopted the extent of an undefined parameter - the nearshore sand accumulation shoreline - as a measure of cay size. From aerial photographs, nearshore sand accumulation areas were estimated for several years within the 1936 - 1978 period [Table 1.1]. Both the Green Island Management Committee (1980) and the Australian Littoral Society (1982) list the cay's area as approximately 12ha, with a circumference of about 1.6km and maximum dimensions of 660m x 260m (the long axis lying roughly east-west). These dimensions appear to be derived from a Lands Department of Queensland report and thus would be relative to Mean High Water Level. The Australian Littoral Society (1990) lists an undated area of 12ha.

The Beach Protection Authority (1989) give the cay dimensions as a maximum length of 650m and a maximum width of 300m (with the major axis oriented approximately east-south-east to west-north-west), with an area of approximately 15ha above Mean Sea Level and a circumference of 1.6km. From a study of the behaviour of Green Island, the Beach Protection Authority (1989) concluded that there had been a progressive and steady loss of sand from the cay between 1980 and 1988, with about $1000m^3$ per year lost. Some of this loss was attributed to accretion occurring in deeper water at the north-western corner of the cay, with the other possible losses to the reef flat west of the cay and into the navigation channel and swing basin.

Table 1.1 Areas and dimensions of Green Island cay and associated features

VEG = vegetated area; B'ROCK = exposed beachrock area; MAX DIM = maximum cay dimensions. K = from Kuchler (1978); S = from Stoddart *et al.* (1978); GIMC/ALS = from Green Island Management Committee (1980) and Australian Littoral Society (1982); BPA = from Beach Protection Authority (1989), ALS90 = from Australian Littoral Society (1990).

YEAR	CAY (ha)	VEG (ha)	B'ROCK (ha)	MAX DIM (m)
1936 (K)	15.6		0.006	
1945 (K)	16.5	10.8		
1946 (K)	15.6			
1950 (K)	15.6		0.025	
1959 (K)	14.4	10.8	0.039	
1963 (K)		10.8		
1964 (K)	16.1			
1969 (K)	16.2			
1972 (K)	16.5	11.6	0.069	
1973 (K)			0.068	
1973 (S)	13.9	11.7	0.854	690x300
1975 (K)	17.5	11.5		
1976 (K)	19.1			
1976 (K)	18.2			
1978 (K)	19.1	11.7	0.085	
Undated:				
GIMC/ALS	12			660x260
BPA	15			650x300
ALS90	12			

Variations in datum levels adopted by authors may also lead to some confusion when comparing elevations listed in different publications. The Australian Littoral Society (1982) gives the maximum elevation as 4.5m above Mean High Water Springs, while Stoddart *et al.* (1978) refer to distinct terraces at 3.5-4.0m and 4.3m above Mean Lower Low Water Springs. There is a considerable difference between these datum levels - the Department of Harbours and Marine (1989) lists the level of Mean High Water Springs at Green Island as 2.2m above Local Low Water Datum (Mean Lower Low Water Springs). The Australian Littoral Society (1990) gives the elevation as 5m, with no reference to datum level.

GEOMORPHOLOGY

The Green Island Management Committee (1980) described soil on the cay as calcareous sandy loam, with the top 10 - 20m of the cay surface a fairly porous layer of dead coral and algae overlying a reasonably consolidated older reef surface. However, the source of this information is not given and I have been unable to locate any specific investigation into the geological structure of Green Island cay. Gourlay (pers. comm.) suggests it is the Holocene reef deposits which are likely to be 10 - 20m thick and overlie the consolidated Pleistocene reef surface. Stoddart *et al.* (1978) noted the presence of superficial broken phosphorites under the 'dense broadleaf woodland' in the centre of the cay.

Beachrock has formed through lithification along most of the southern and north-eastern sides of the cay [Fig.1.2] (Green Island Management Committee, 1980; Beach Protection Authority, 1989). Kuchler (1978) calculated the areas of exposed beachrock apparent in a number of aerial photographs in the 1936 - 1978 period [Table 1.1]. Using their compass-and-pacing method, Stoddart *et al.* (1978) estimated the 1973 beachrock cover to be 0.85ha - an order of magnitude higher than the estimates of Kuchler (1978). While beachrock is exposed and covered regularly due to wind and wave action, thus leading to seasonal and annual variations in exposed area, I suspect that one of the above publications carries a typographical error.

Kuchler (1978) noted that the lower of the terraces described by Stoddart *et al.* (1978) was absent on the windward (southern) side of the cay, where the beach was steep with extensive well-cemented beachrock. On the leeward (northern) side, the beach profile was slightly convex with patchy less-cemented beachrock formed lower into the inter-tidal zone.

The Beach Protection Authority (1989) described the southern side of the cay as exposed beachrock, partially covered by sand at the eastern end. At the eastern end of the northern shoreline, the sandy shoreline landward of the exposed beachrock had eroded to the extent that High Water Mark was beneath overhanging vegetation including established trees. The western end of the northern shoreline was described as an accreting sandy beach, with a sandy bulge or spit at the north-western tip of the cay. The western side comprised a sandbag and rubble seawall approximately 150m in length, with the nearshore sand seaward of the wall sloping gradually towards the mooring basin adjacent to the jetty.

A dredged channel led in a westerly direction from the head of the jetty to the reef edge and a small beach existed to the north of a groyne at the south-western corner of the cay.

VEGETATION

The Green Island Management Committee (1980) describes the vegetation on Green Island as that of a closed vine forest similar to those of tropical mainland Queensland.

Stoddart *et al.* (1978), from their compass-and-pace survey, estimated the 1973 vegetation coverage to be 11.7ha (84% of the cay area). Table 1.1 includes the vegetated areas for several years within the 1936 - 1978 period, as estimated from aerial photographs by Kuchler (1978). Although Stoddart *et al.* (1978) recorded 114 species of vascular plants at Green Island, the published species lists I have located - in Kuchler (1978), Green Island Management Committee (1980) and Cornelius (1982) - cover a maximum of 90 species (listed in Appendix 1). There is no indication within these reports of the relative abundances of the various species.

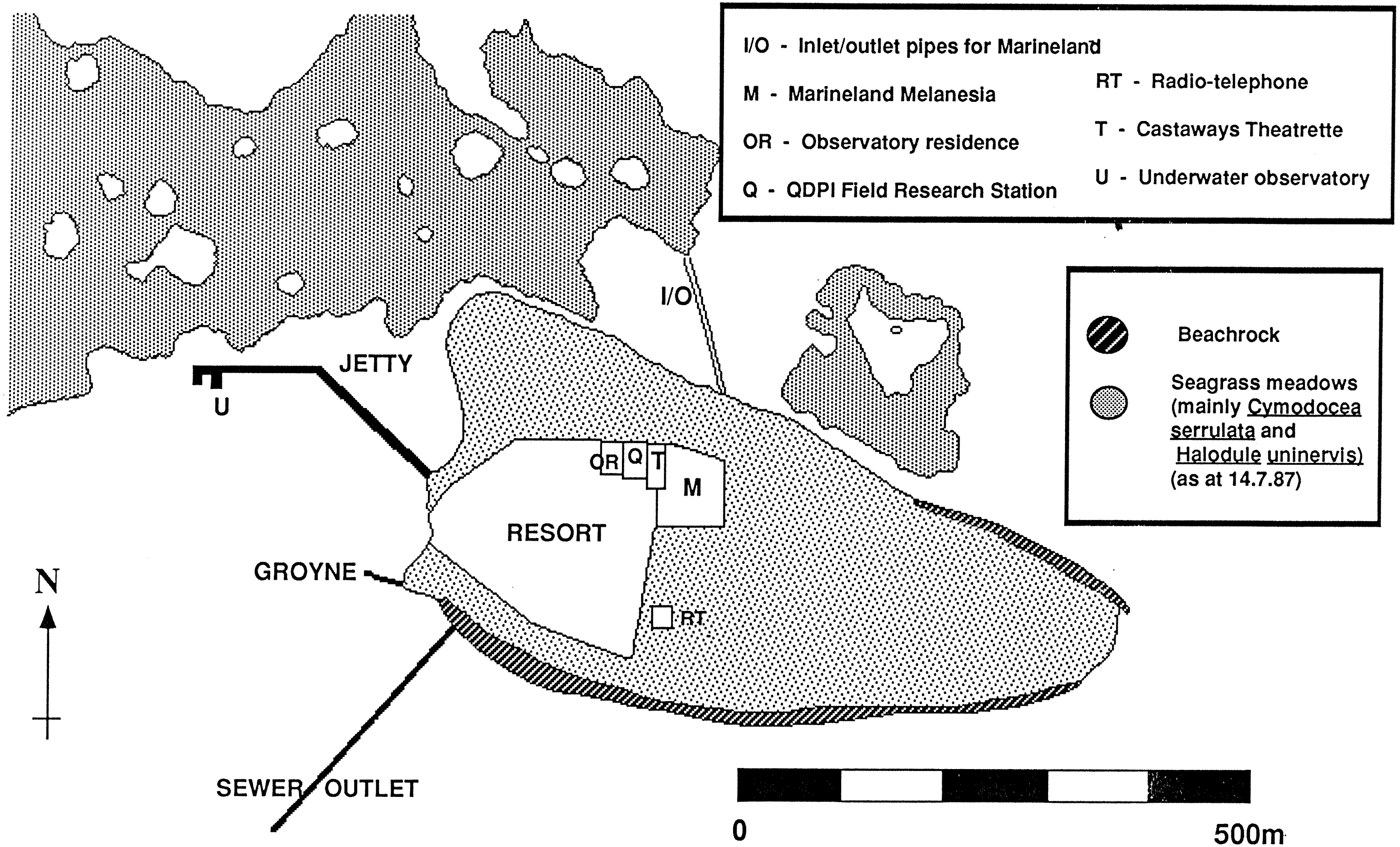


Figure 1.2 Green Island, showing leases and geomorphological features

The majority of the cay's present-day vegetation has presumably developed only since the late 1850s. According to Jones (1976), one of the first settlers on the cay cleared its centre in 1857 and planted seeds from the Sydney Botanical Gardens. By the 1880s, beche-de-mer fishermen had apparently accounted for all the timber and shoulder-high burrs covered the cay, making it possible to overlook the whole area (Jones, 1976). Coconuts were planted in 1889 (Green Island Management Committee, 1980). In 1937, Green Island was declared a National Park (Jones, 1976) but the Park's caretaker subsequently felled some of the vegetation and is reported to have set fire to the whole cay in a very dry year (Kuchler, 1978).

FAUNA

Birds

Appendix 2 lists the species of birds recorded for Green Island in Kikkawa (1976), Kuchler (1978) and Australian Littoral Society (1982). Thirteen species of seabirds were recorded, with no significant breeding taking place on the cay. Of the 38 species of land and shore birds occurring, 7 breeding colonies were identified. These were the Reef Heron, White-breasted Sea Eagle, Torres Strait Pigeon (estimated 3500 - 4500 birds), Grey-breasted Silver-eye, Yellow-breasted Sunbird, Mangrove Honeyeater and White-breasted Wood-swallow (Australian Littoral Society, 1990). King (1983) describes bird surveys conducted on the northern Great Barrier Reef islands, including Green Island, by the Queensland National Parks and Wildlife Service - a species list is not given.

Other vertebrates

The Australian Littoral Society (1982) lists 3 species of skink for Green Island:

- Lepidodactylus lugubris
- Carlia rhomboidalis
- Cryptoblepharus virgatus

Also listed by the Australian Littoral Society (1982) are a colony of the spectacled flying fox (Pteropus conspicillatus) and introduced cats and rats.

Invertebrates

Terrestrial invertebrates recorded for Green Island are the Capaneus butterfly (Papillo fuscus capaneus) (Australian Littoral Society, 1982) and the ant Pheidole megacephala (Heatwole, 1976). The latter is an African species which Heatwole concluded had 'almost certainly' reached the cay via human agency and was the only ant species occurring on the cay - presumably through elimination of the original ant fauna (Heatwole, 1976).

HYDROLOGY

The average annual rainfall (1949 - 1989, using all available data) at Green Island is 2111mm (Australian Bureau of Meteorology, pers. comm.). The monthly averages for this period are given in Table 1.2. Brandon (1973) compared rainfall data for Green Island and Cairns Airport over an unspecified sixteen year period and found Green Island to have a 9.4% higher average annual rainfall.

Table 1.2: Monthly average rainfall data for Green Island (1949 -1989, using all available data). Source: Australian Bureau of Meteorology (pers. comm.).

MONTH	AV. (mm)
January	419
February	398
March	424
April	217
May	129
June	84
July	60
August	43
September	33
October	33
November	96
December	175

Annual av.	2111

The Green Island Management Committee (1980) referred to the existence of a shallow lens of fresh groundwater overlying more dense saline water during the wet season, with the lens almost entirely utilised by the native vegetation during the dry season. Consequently, in the dry season the groundwater would become quite saline due to seawater intrusion. However, inquiries made of the Queensland Water Resources Commission by Dr. M. Gourlay (University of Queensland) revealed this information to be 'a preliminary statement on the basis of inferred data and broad assumptions and allegedly factual data, some of which has since been shown to be incorrect' (Gourlay, pers. comm.).

WIND REGIME

In December 1982, the Queensland Beach Protection Authority installed an automatic wind recorder on the telecommunications tower at Green Island at a height of approximately 30m above Mean Sea Level. The device measured both wind speed and direction each minute, and a data logger recorded minimum, mean and maximum wind speed and average wind direction over each 60 minute period (Beach Protection Authority, 1989). While wind data from the Green Island recorder was analysed by the Beach Protection Authority (1989), data from a recorder at Low Isles was used in their analyses of shoreline dynamics as data from both stations showed comparable patterns and the Low Isles station had a longer history of operation. The Green Island wind recorder was still in operation at August 9, 1990 (Beach Protection Authority, pers. comm.).

From the Low Isles data, the Beach Protection Authority (1989) describe the predominant winds throughout the year to be south-easterly, to a greater degree from April to October and predominantly in the afternoon. In the mornings, south-westerly winds occurred to some degree throughout the year, north-westerly winds occurred to some degree from October to March and north-easterly winds were found to occur rarely. In the afternoons, north-easterly winds occurred significantly during the October to March period with south-westerly and north-westerly winds a rare occurrence.

SHORELINE DYNAMICS

Coral cays, the products of complex physical, geological and biological processes, are geologically temporary features of considerable instability which may respond dramatically to fluctuations in their environment (Gourlay, 1983). This inherent instability is well illustrated at Green Island, which has a long history of shoreline construction and erosion.

Kuchler's study

Kuchler (1978, 1979) studied the shoreline movements of Green Island on long-term and seasonal scales, identifying an approximate cyclic oscillation of the western end of the cay with periodicity of 30 years duration. Just prior to 1938 the main depositional area was to the north-west; from 1938 to 1964 it was the south-west corner, and from 1964 onwards it had again been the north-west corner. The primary agents for sediment transport appeared to be wind and waves, with wind velocity and angle of incidence of wave approach considered important parameters. Accordingly, most long-term changes in the nearshore sand accumulation had been due to cyclones. On a seasonal scale the pattern was one of windward recession and leeward advance, the windward shoreline being the southern in winter and the northern in summer. However, most probably due to anthropogenic influences described below, there was an overall pattern of erosion of the south-western corner and accretion of the north-western corner (Kuchler 1978, 1979).

Pannell Kerr Forster (1971) felt the jetty was responsible for erosion around the cay end of the jetty and recommended the construction of a marina to stabilise the erosion. However, Kuchler (1978, 1979) found the construction of various groynes and jetties to have had little apparent impact on the shoreline movements on a historical scale.

The expansion of the north-west spit on a scale not evident in the historical data was deemed by Kuchler (1978, 1979) to be due to the beach replenishment programs of 1973 and 1975. In these programs sand was pumped from the nearshore lagoon to the beaches of the cay's south-western corner, an action which proved ineffective due to inadequate protection from the strong south-easterly winds prevalent during winter. The added sand was rapidly transported to the north-west corner of the cay (Hayles, 1982) and the resultant extensive spit disrupted the northerly wind-generated waves which had previously been responsible for sediment transport to the south-western corner during summer. As a result, the south-western corner experienced winter erosion without summer accretion (Kuchler, 1978).

There are several other factors which may have been responsible for retarding overall sediment accumulation by the cay. Devastation of the hard coral community by the crown-of-thorns starfish, A. planci, may have reduced the rate of sediment production within the reef system (Kuchler, 1979; Gourlay, 1988). Seagrass beds, with their associated mats of blue-green algae, are known to accumulate sediment, and at Green Island they may have done so at the expense of the cay by trapping the fine sediment normally transported to shore by northerly winds during summer (Kuchler, 1978; Gourlay, 1983, 1988). The dredged navigation channel and swing basin may have been partially responsible for non-replenishment of the cay's beaches through their potential to act as sediment traps (O'Keeffe, 1979) or by changing the sediment flow and movement (comment from reviewer of draft Green Island Information Review). Gourlay (1988) proposed that climatic variations influencing hydrodynamic conditions, and rising sea level associated with the 'greenhouse' effect, may also have contributed to the net loss of sand from the cay.

Beach Protection Authority surveys

In 1972 the advice of the Queensland Government Beach Protection Authority was sought on erosion problems at Green Island and they became involved in collecting data on coral cay behaviour (Beach Protection Authority, 1987, 1989). Between November 1972 and July 1977, beach profile surveys were conducted at four stations on the south-western corner of the cay [P1, P2, P12, P13: Fig.1.3].

From July 1977 to September 1980, beach profiles were monitored at a total of thirteen stations around the cay [P1 - P13: Fig.1.3]. A further five survey lines [P1.5, P2.5, P3.5, P11.5, P13.5: Fig.1.3] were added to the beach monitoring program in September 1980 to monitor the effects of a newly constructed groyne at the south-western corner (Beach Protection Authority, 1989).

Profiles extended from several metres landward of the vegetation line to the toe of the beach slope at its interface with the underlying reef platform. Vertical datum for the surveys was Local Low Water Datum and horizontal datum was arbitrarily chosen at the time of the initial survey to be 'several metres landward of the vegetation line' (Beach Protection Authority, 1989).

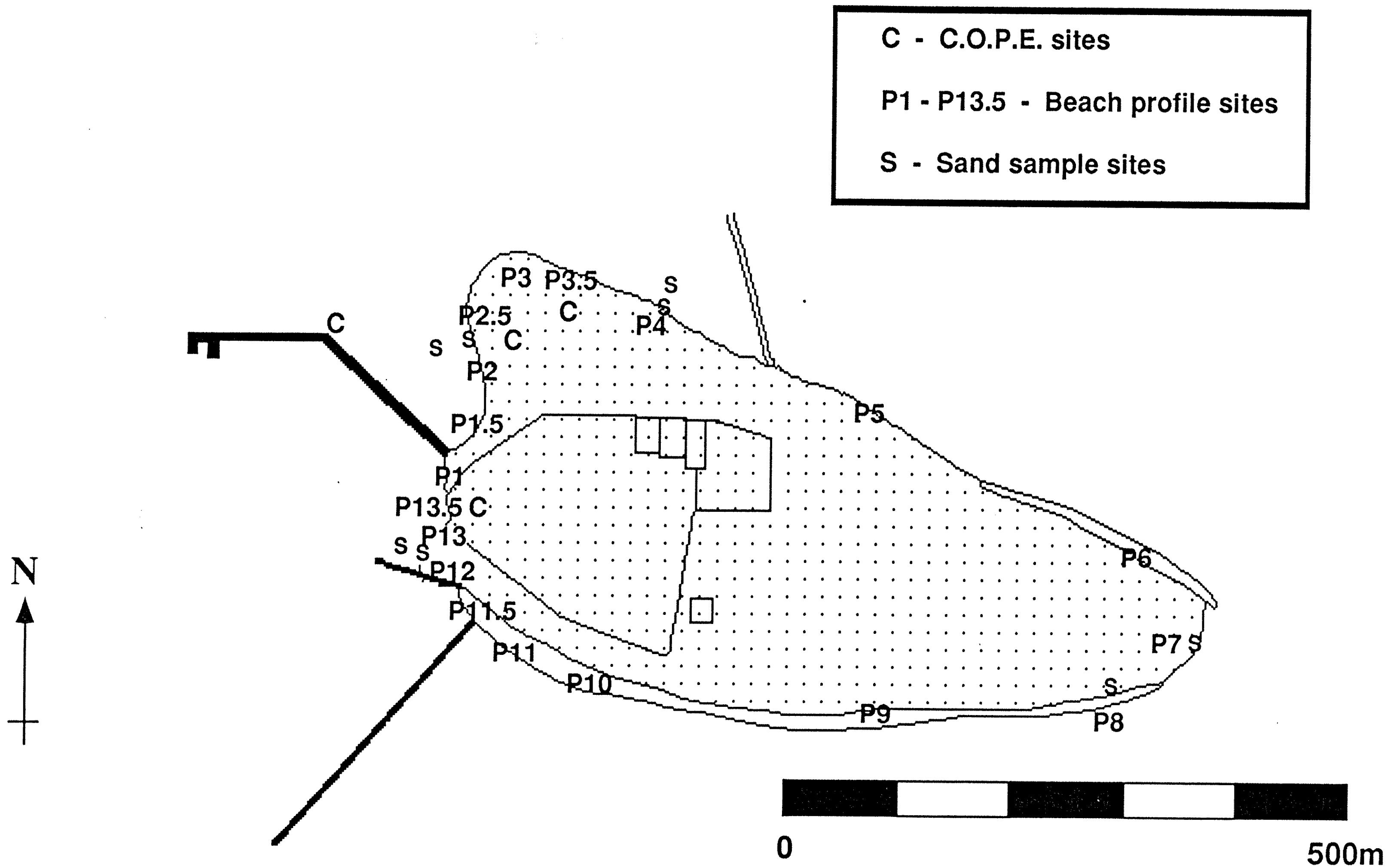


Figure 1.3 Location of Beach Protection Authority survey sites

Until September 1979 the surveys were undertaken by officers of the Queensland Boating and Fisheries Patrol. From November 1979 to March 1986 officers of the Queensland National Parks and Wildlife Service monitored beach profiles on a monthly basis, continuing on a twice yearly basis (before and after the cyclone season) from March 1986 to February 1989. In addition, annual surveys were conducted by surveyors from the Queensland Department of Harbours and Marine, who also checked and re-established control points where necessary (Beach Protection Authority, 1989).

Vertical aerial photographs were taken 'as near as practicable to low water' in 1972 and annually from 1978 to 1987 at low level (455m), medium level (915m), high level (1830m) and very high level (7600m). Details of the photographs are included in Chapter 12. Photogrammetric analysis of seven series of aerial photographs (4/72, 6/78, 10/80, 9/81, 9/82, 10/83 and 8/85) was undertaken to provide beach contours relative to Australian Height Datum (Derived) (Beach Protection Authority, 1989).

Erosion or accretion of the beaches was quantified in terms of changes in sand volume and horizontal movement of the beaches. Changes to the cay as a whole were quantified in terms of changes in sand distribution and changes in total sand quantity (Beach Protection Authority, 1989).

Between April 1972 and June 1978 there was little net change in sand volume in the southern sector of the cay, losses from the south-western and eastern sectors, a net increase in the northern sector and a very large increase in the north-western sector. Dramatic changes in the western sector took place during this period as a consequence of the beach replenishment programs undertaken by the Queensland Department of Harbours and Marine (Beach Protection Authority, 1989).

Between July and September 1977 an estimated 3000m^3 of sand was lost from above low water mark (Green Island Management Committee, 1980). From July 1977 to September 1980 the western side and eastern tip of the cay experienced erosion while the northern beach accreted at its western end. The southern shoreline showed only slight erosion and accretion in parts during this period (Beach Protection Authority, 1989).

From September 1980 to July 1986 the shoreline from the newly constructed groyne to the jetty remained relatively unaltered following the initial build up of sand to the north of the groyne, apart from erosion at the jetty abutment. The beach to the north of the jetty eroded substantially during this time and the north-western spit moved to the north. The western part of the northern beach accreted while the eastern half had slowly eroded, and the eastern tip of the cay continued to erode. The southern side of the cay remained relatively stable over this period, with only slight erosion and accretion in parts (Beach Protection Authority, 1989).

In August 1986 and December 1987, sand samples were collected by the Beach Protection Authority (1989) at eight sites around Green Island [Fig.1.3]. At five sites the samples were collected from the 'beach ramp' approximately half way between normal high water level and mid-tide level. At three more seaward sites, samples were collected from the nearshore slope approximately 20m seaward of the toe of the beach ramp. The sand samples were graded as fine (particle size diameter 0.06 - 0.2mm), medium (0.2 - 0.6mm) or coarse (0.6 - 2.0mm) on the basis of predominant particle size. Between the two sampling dates the Beach Protection Authority (1989) found the sand retained by the groyne and the sand at the eastern end of the cay had become coarser, while the sand around the north-western spit had become finer.

Muir's study

Muir (1986) compared beach profiles before and after Cyclone Winifred had passed in the vicinity in February 1986. When compared with the November 1985 survey, the post-cyclone survey showed the north-west corner had up to 17m of beach crest removed, with a corresponding net foreshore beach face erosion of 60m. Accretion in the nearshore intertidal zone was greatest at the south-west corner, with a 20m net change (Muir, 1986).

Shoreline construction and erosion history

This summary is based on information in Kuchler (1978), Green Island Management Committee (1980) and Beach Protection Authority (1989). The information on cyclones in these publications appears to have been derived from Lourensz (1977) which has since been superseded, with some corrections, by Lourensz (1981) and I have made the appropriate corrections here. While the cyclones listed all passed within approximately 100km of Green Island, not all have had their effect documented in the published literature.

1906 - First jetty built by Cairns Harbour Board.

1912 - Cyclone (998mb) passes to east during April.

1918 - Cyclone (928mb) passes to south in March.

1931 - Jetty constructed by Cairns City Council.

1932 - Cyclone (994mb) passes to south-west in January.

1934 - Three cyclones: 984mb to south in January, 1002mb to east in February and 968mb to north-west in March.

1936 - New jetty built. Sandy beach around entire western end of the cay, with vegetation line truncated on the south-western corner.

1939 - First groynes built to protect foreshore - one major and four minor on western side, constructed mainly of timber.

1945 - Sandy beach from the jetty around the north-western corner of the cay, but a lack of sand on the south-western corner. Beach rock exposed in the centre of the northern beach.

1946 - Cyclone (996mb) passes in very close proximity - groynes damaged and jetty destroyed, all reconstructed within the year by the Cairns Harbour Board. New jetty to the north of the original and almost a mirror image in shape.

1950 - Cyclone (994mb) passes to north-east

1956 - A Queensland Department of Harbours and Marine report refers to cyclone damage during the year (Gourlay, pers. comm.), but there are no cyclones recorded in Lourensz (1981).

1957 - Restoration of existing groynes.

1959 - Two cyclones in the immediate vicinity, in January (980mb) and December (990mb). Slight recession of north-western corner of cay (relative to 1945) and a significant accretion to the south of the original jetty abutment.

1960/61 - Present (1990) jetty constructed by the Cairns Harbour Board immediately adjacent to the northern side of the previous jetty.

1962 - High water mark at south-west corner was 90m from the main building of the Coral Cay Hotel.

1963 - Inshore end of major groyne re-instated, remainder of groyne and four minor groynes in state of disrepair.

1966 - Queensland Department of Harbours and Marine surveys reveal recession of High Water Mark at south-western corner to be 25m landward since 1959. Evidence that some of eroded sand migrated northwards along beach.

1970 - Construction of retaining wall to protect resort approved.

1971 - Severe erosion around retaining wall construction site, work suspended to permit reappraisal. Old timber groynes removed.

1972 - Accretion commences on north-western corner of cay and on western part of northern beach.

1973 - Sand replenishment program (2,300m^3) on beach at south-western corner undertaken by Queensland Department of Harbours and Marine.

1974 - Sand used for beach replenishment eroded.

1975 - Cyclone Gloria (980mb) passes to north-east in January.
Old dining room of Coral Cay Hotel begins to collapse due to erosion.
Sand replenishment program (16,000m^3) on beach adjacent to hotel complex undertaken by Queensland Department of Harbours and Marine, extends beach approximately 30m seaward of 1972 position. Short experimental sand-bag groyne constructed at south-western corner.

1976 - Cyclone Dawn (988mb) in immediate vicinity in March.
Sand-bag groyne ineffective in protecting south-western corner from erosion. Erosion near jetty head, concrete pathway collapses.

1977 - Cyclone Keith (992mb) passes to south-west in close proximity in January - top layer of groyne washed off by wave action.
High water mark at south-western corner 3m from main building of Coral Cay Hotel (cf. 1962).
State Cabinet decides no further funds are to be made available for shore protection works.
Construction of sandbag revetment commenced by Hayles Pty Ltd.
Queensland National Parks and Wildlife Service commences beach monitoring program for the Beach Protection Authority.

1979 - Application by Hayles Ltd to install groyne on south-western side of cay approved by the Marine Board of Queensland.

1980 - Concrete groyne constructed by Hayles Pty Ltd at south-western corner of cay, just south of the 1975 sandbag groyne.

1982/83 - Progressive extension and rebuilding of the seawall along the western side of the cay.

1986 - Cyclone Winifred (970mb) passes to south-east at a distance of about 100km in February.
Some erosion, particularly on the north-west spit.

Comments made on an earlier draft of this review indicated that most of the current cement bag wall around the jetty base was constructed after 1985/86.

RESERVES AND LEASES

Green Island Management Committee (1980), Economic Associates Australia (1983) and Australian Littoral Society (1990) provide detailed information on the public reserves and private leases shown in Figure 1.2.

The eastern end of the cay is occupied by a 7ha National Park (N.P.836 Trinity, declared 1937) administered by the Queensland National Parks and Wildlife Service. A 20m esplanade, under the control of the Cairns City Council, was provided around the western perimeter of the cay to separate private lease development from the beach foreshore. The date of provision of the esplanade is unspecified in both reports, but they do note that sand movement has led to the disappearance of the esplanade in the south-west corner and its considerable extension in the north-west corner.

There are three perpetual and three special leases held on Green Island, all within the western half of the cay [Fig.1.2]. The largest of the perpetual leases (2.9ha) is the site of the Green Island Reef Resort (formerly the Coral Cay Hotel) owned by Great Adventures Pty Ltd., a division of the Dreamworld Corporation. The first lease for a tourist resort development was a 20-year special lease (S.L. 11234) granted to Hayles Magnetic Island Pty Ltd in 1938. The current lease (N.C.L. 2048), was granted to the Hayles company on January 1 1965, replacing a 30-year special lease (S.L. 25519) granted in 1961. The Cairns operations of the Hayles company were bought by the Dreamworld Corporation in 1988, and in 1989 the Dreamworld Corporation was placed in the hands of receivers. At present, a change in ownership of the resort is still to be finalised.

The other perpetual leases cover a marine zoological garden (Marineland Melanesia, N.C.L. 2590, 0.4ha, granted 1 January 1974) and a theatrette (Castaways Theatre, N.C.L. 2331, 0.08ha, granted 1 October 1968).

Two of the special leases cover an underwater observatory (S.L. 25496, 0.1ha, granted for 30 years from 1 March 1961) and an associated residence (S.L. 40190, 0.06ha, granted for 15 years from 1 March 1976). The third (S.L. 36573) covers a 0.04 ha area of National Park excised on 1 March 1972 for use by the Commonwealth Government as a radio-telephone installation under a 30-year lease.

The remaining development is situated within a 0.06ha reserve (R. 1695) voluntarily acquired by the Queensland Department of Primary Industries in 1979. This lease contained the residence of pioneer underwater photographer Noel Monkman and his wife Kitty, who held a perpetual residential lease (N.C.L. 2551). The lease was to be developed by the Queensland Fisheries Service (now the Fisheries Branch of the Queensland Department of Primary Industries) as a marine park ranger station, interpretive centre and reef biological research base (Haysom, 1981), but is currently used only as a field research station.

WATER SUPPLY AND DRAINAGE

The Green Island Management Plan (Green Island Management Committee, 1980) provides the following information, which is derived from a 1979 report by Gutteridge, Haskins and Davey Pty Ltd for the Queensland Department of Works. From a conversation in July 1988 with Mr D. Rogers, a former engineer at Hayles' Coral Cay Hotel, it appeared the water supply, sewerage and drainage works had changed little since the report.

Fresh water supplies for Green Island's lessees were derived from rainwater storage, with that of the Hayles lease supplemented by water carted from the mainland by their ferries. Additional groundwater was obtained by Hayles from a well on their lease and used for general cleaning and toilet flushing at the resort and for the toilets, hand basins and showers in the public toilet block on the esplanade. The other lessees pumped sea water to supplement fresh water used in toilet flushing. There were no underground storm-water drains on Green Island and drainage was by run-off and by natural infiltration into the groundwater.

A desalination plant operated on the Hayles lease for about two years around the period 1978 to 1980 (Rogers, pers. comm.). It was located in a generator shed, with a feeder tank adjacent to the bore. Initially, bore water was used for the desalinator but this was found to be contaminated with bacteria (probably from septic tank seepage) and minerals (notably sulphur) which were presumed to originate from the coral substrate. Subsequently, salt water was pumped to the feeder tank from the end of the jetty. Operation of the plant ceased when the expensive filters for the reverse-osmosis system were cleaned with kerosene and consequently badly damaged. There have been no other desalination plants in operation on Green Island since (Rogers, pers. comm.).

SEWERAGE

All buildings on the Green Island Reef Resort lease are connected to a sewerage system which also incorporates input from the public toilet block on the esplanade. The system, constructed by the Queensland Department of Works in 1972, consists of a main sewer line leading to a detention and chlorination tank with an outfall pipe crossing the reef flat in a south-westerly direction from the cay [Fig.1.2]. According to the Green Island Management Committee (1980), the discharge from the outfall pipe is below maximum low water level at the south-west reef edge. Through discussions with long-term residents of Green Island, Kuchler (1978) found that over the years the sewerage outlet may have had several positions around the reef, including one to the north of the cay. However, Kuchler was unable to gain confirmation of this from any government department.

The toilets associated with the theatrette, marineland, observatory residence and Queensland Department of Primary Industries research facility have conventional septic tanks with soakage trenches (Green Island Management Committee, 1980).

Water inlet and outlet pipes for the Marineland Melanesia aquarium system lie on the reef flat to the north of the cay [Fig.1.2]. These are identifiable in some aerial photographs and are marked on lease maps held in the Great Barrier Reef Marine Park Authority library.

WASTE DISPOSAL

In 1979, Hayles employees were collecting and disposing of wastes from the hotel lease, National Park, esplanade, beaches and jetty. Wet wastes (edible food wastes) were tipped off the jetty each morning and consumed by birds and fish. Combustible waste was incinerated and the residue, along with non-combustible waste, was transported to the mainland and dumped. Wastes from the other leases were either buried, dumped at sea or returned to the mainland for disposal (Green Island Management Committee, 1980).

Mr T. Steven of the Queensland National Parks and Wildlife Service at Cairns conducted a survey of fish feeding and garbage dumping activities around Green Island in late 1987 (Hunnam, pers. comm.). He estimated that almost 30 tonnes per year of wet waste were dumped from the jetty by Hayles employees and the crew of the Coral Seatel vessel. In addition, an estimated 18 tonnes per year of bread were being deposited into the water through fish feeding. About 40% was scattered on the water surface in an area known as 'Patches' [area B5: Fig.3.1] by the crew of glass-bottom boats associated with the Hayles ferries and the Coral Seatel. Sub-surface release by the underwater observatory operators accounted for a further 30%, while around 20% was released by snorkellers on the northern and north-western reef flat. The remaining 10% was released from the jetty by the Hayles Activities Officer or at the northern reef edge by the dive tender operated by Peter Tibb's Dive Shop.

Following the survey, fish feeding activities noticeably declined (Hunnam, pers. comm.). Current practice is for all rubbish to be returned to the mainland (Queensland National Parks and Wildlife Service, 1990), although feeding of fish from the jetty was continued until at least November 1989 (comment by reviewer of draft Green Island Information Review).

Chapter 2 THE REEF

DIMENSIONS AND MORPHOLOGY

The published dimensions of Green Island reef [Fig.2.1] are as variable as the cay dimensions outlined in the previous chapter. Kuchler (1978) determined its longest axis to be 4.6km and its shortest 2.8km, while the Beach Protection Authority (1989) described the reef as approximately 4km along its longest axis and 2km along its shortest axis.

Following the system of Maxwell (1968), Green Island reef was classified by Fisk *et al.* (1988) as a ring platform reef. Both the Green Island Management Committee (1980) and Australian Littoral Society (1982) described the reef as a 1200ha lagoonal platform reef. The former did not cite a reference for this information, while the latter gave its source as the Great Barrier Reef Gazetteer (a database prepared by the Geography Department of James Cook University for the Great Barrier Reef Marine Park Authority). However, it is currently listed in the Great Barrier Reef Gazetteer (and in Australian Littoral Society, 1990) as a planar reef with an area of 7.1km^2 (only 710ha). This variation between editions of the Gazetteer may reflect a change in definition of the reef boundary (e.g. the exclusion of the eastern shoal area), or it may be indicative of mathematical or typographical errors.

The Green Island Management Committee (1980) gives the cay's position as the extreme north-west corner of a reef flat composed almost entirely of dead coral, with a shallow and indistinct lagoon lying to the north of the cay. Fisk *et al.* (1988) describe the north-west corner as a shallow shelf area with large patch reefs and sand. The northern reef slope is described by Fisk *et al.* (1988) as a gently sloping shelf 200-400m wide with scattered coral patches.

There are some discrepancies in the literature regarding locations of some of the morphological elements of the Green Island reef flat. Steers (1929) describes a belt of 'negro-heads' - 'masses of coral cast up onto the reef flats by waves' - on the flat just to the north-west of the cay. However, the Green Island Management Committee (1980) refers to 'nigger heads' on the reef crest to the south-west of the cay, while Nash (1985) notes the presence of a boulder zone there. Unless there has been a substantial redistribution of these coral boulders since 1928, it would appear Steers was slightly disorientated.

I initially suspected a typographical error, but Steers later refers to 'the north-western sides, from which direction heavy weather often comes'. Personal observations indicate the more recent reports are certainly descriptive of the current location of the boulder zone.

In another contradiction, Nash (1985) identifies the reef slope as most steep on the south-western reef face, with ill-defined edges on all other faces shelving-off gradually over some distance, while Bradbury *et al.* (1987) describe the reef slope as 'steep to the north-west but more gradual around the remainder of the perimeter'. This conflict in description may have come about through differing interpretations of the 'shallow (less than 4m deep) shelf extending from the boulder zone to the edge of the drop-off' described by Nash (1985) for the south-western edge. Alternatively, the description by Bradbury *et al.* (1987) may be the result of another typographical error or another example of muddled orientation (see Chapter 4). Fisk *et al.* (1988) note the presence along the southern reef slope of a 'shallow, narrow shelf, 3-4m deep and up to 50m across, which then grades more steeply to a 10-12m deep sandy floor'.

Kuchler (1978) gave a detailed description of the reef's physiography. From the most recent aerial photographs available, it appears this description is still valid. Zonation was most clear on the eastern and southern windward sides of the reef where the reef edge, algal rim and reef flat were readily discernible. In these regions, the reef edge had a spur-and-groove structure and a steep reef slope, while the junction between the algal rim and the coral zone of the reef flat tended to be obscured by a zone of coral rubble. The windward flat was clearly divisible into coral and sand zones [Fig.2.1], with the latter more extensive than on the leeward flat. Similarly, the zone of coral rubble to windward did not extend to leeward. The reef flat was generally at or near tidal datum, except to the north-west where there was a downslope dip (Kuchler, 1978).

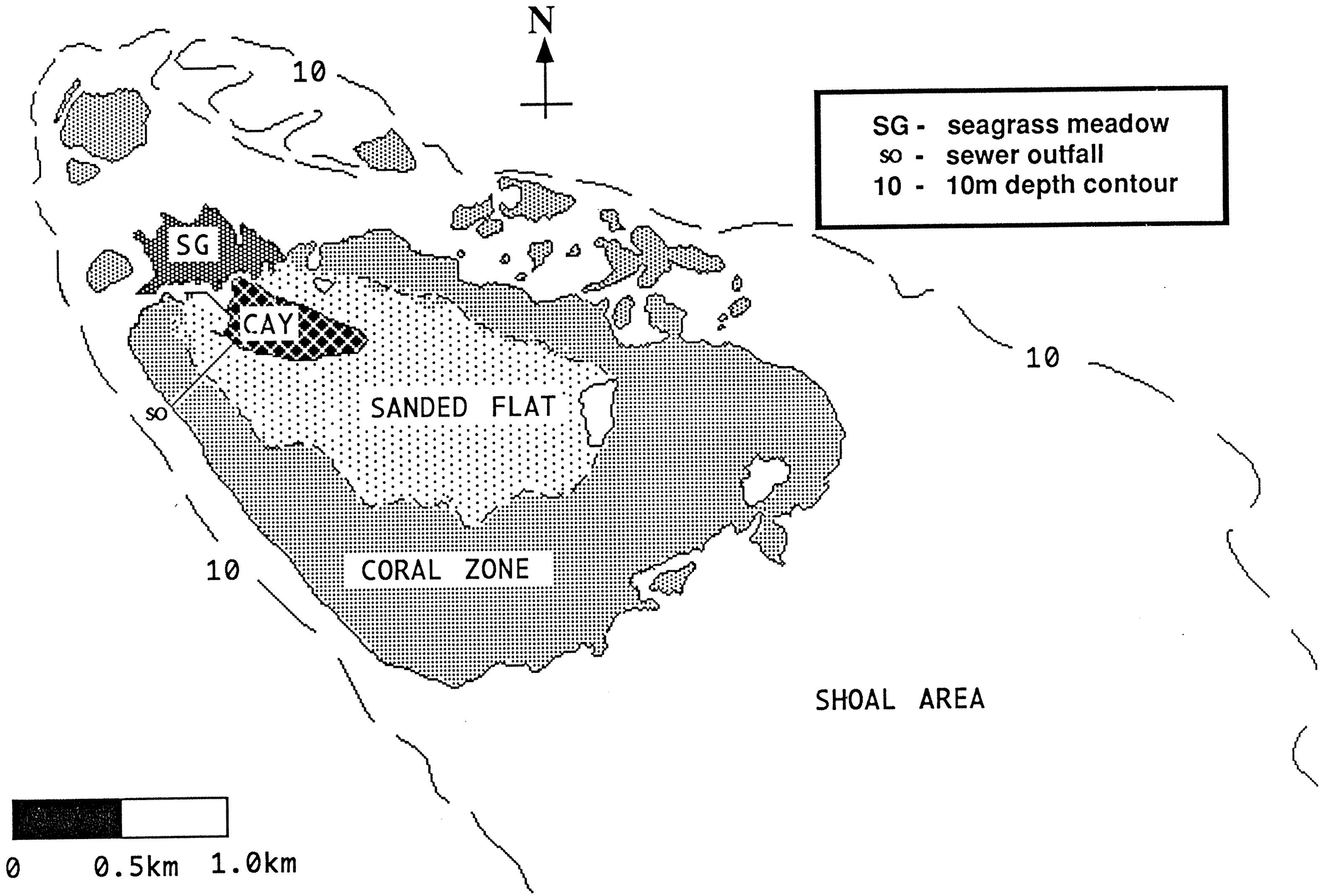


Figure 2.1 **Green Island reef, showing general morphological features**

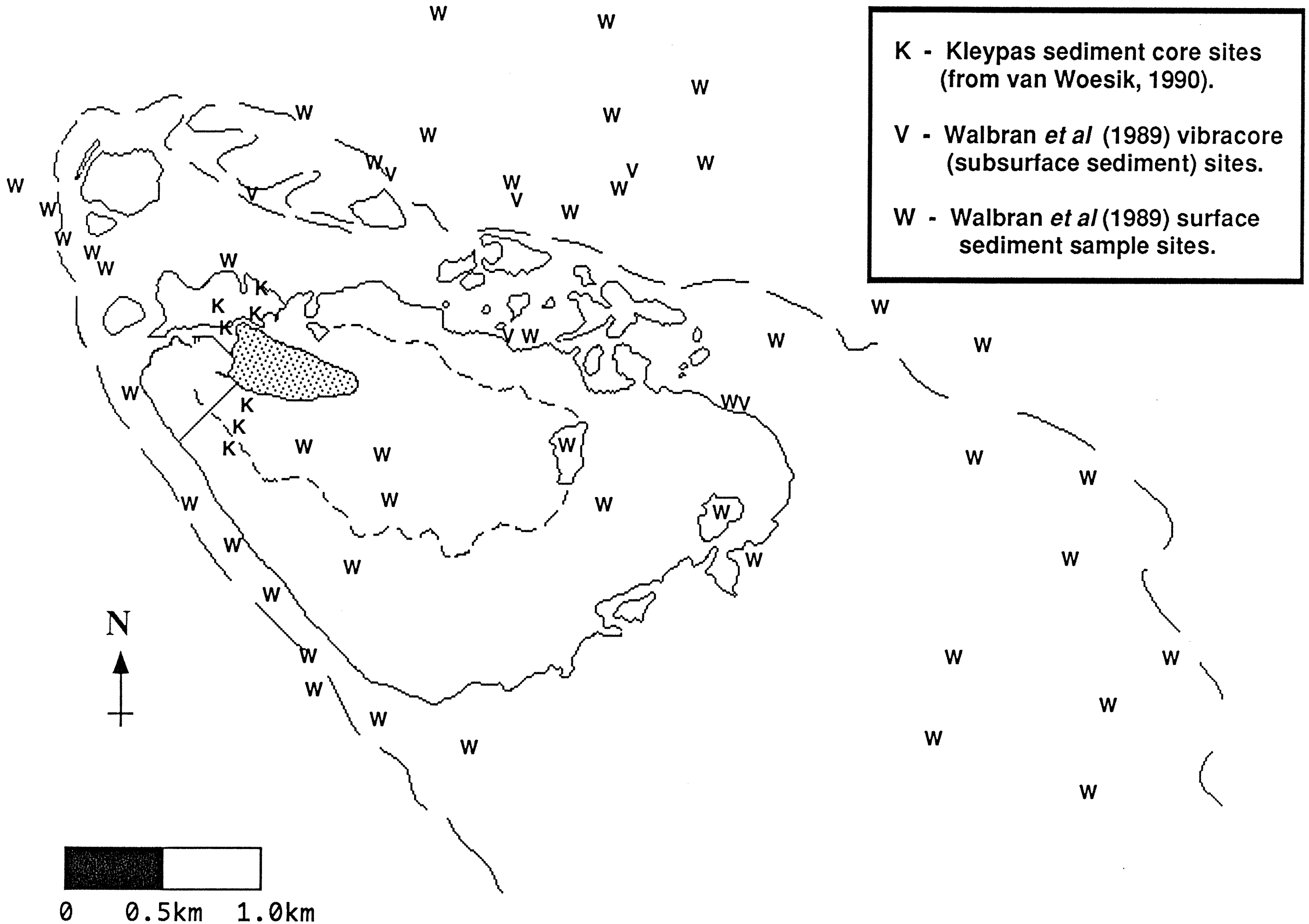


Figure 2.2 Location of sediment sample sites

Fisk *et al.* (1988) note the presence of a double reef front along the south-east face of the reef leading to an extensive shoal area approximately 3km long and 3km wide. The shoal area is described by Fisk *et al.* (1988) as consisting of large numbers of unconsolidated rubble mounds, with the area surrounded by a ring of more consolidated patches associated with large Porites colonies. It is not clear whether this area was included in the published estimates of reef area previously mentioned.

SEDIMENTS

Grab samples of surface sediments at 46 sites around Green Island reef and cores of the sub-surface sediments at six sites off the northern edge of the reef flat were taken in January 1986 by Walbran *et al.* (1989) [Fig.2.2]. These were analysed only for A. planci fragments and no further analyses of the samples or cores were anticipated (Walbran, pers. comm.).

As part of the Green Island Reef Multidisciplinary Study (Baxter, 1988), J. Kleypas of James Cook University used push cores to examine the sediments within the seagrass beds adjacent to the cay [Fig.2.2]. The sediments were found to be thoroughly mixed by the abundant burrowing shrimp Callianassa, and no sedimentary structure or horizons were evident. Samples taken to the south-west of the cay had coarser sediments with less silt than those from the north-west. Cores from the northernmost transect had a noticeably stronger hydrogen sulphide odour than the others (Baxter, 1988).

RESOURCE PROTECTION

In 1932, the Cairns Town Council granted a licence for the removal of coral from within a one mile radius of low water mark around Green Island (Green Island Management Committee, 1980; Australian Littoral Society, 1990). The coral was used as a source of lime for the canfields of the adjacent mainland (Jones, 1976). The foreshore and reef within the same area were protected by the Queensland Fish and Oyster Acts in 1937, although the licence to remove coral was not revoked until 1945 (Green Island Management Committee, 1980; Australian Littoral Society, 1990).

An area of 3000ha, extending from high water mark to 1.6km beyond the outer edge of Green Island reef, was declared a Marine National Park by the Queensland Government in February 1974 (Green Island Management Committee, 1980; Claringbould *et al.*, 1984). In 1975, management of the Park was assumed by the Queensland Fisheries Service (Green Island Management Committee, 1980; Cornelius, 1982).

Provisions applying to the Park included:

- no removal of or interference with any material, whether living or dead.
- line fishing prohibited in the jetty area and the area known as 'Patches' [area B5: Fig.3.1].
- spearfishing prohibited.
- no deposition of rubbish. (Cornelius, 1982)

Despite these regulations, spearfishing and use by shell collectors was still heavy in 1978 (Australian Littoral Society, 1990).

The Cairns Section of the Great Barrier Reef Marine Park was declared in 1981, with Green Island reef zoned in November 1983, within the Cairns Zoning Plan, as a Marine National Park 'B' with a Marine National Park Buffer Zone extending 500m out from the reef edge. The reef edge of Green Island reef is considered at present to be the shallowest edge of the reef flat and therefore does not extend to the eastern shoal area (comment on draft of this review).

Prohibited within the Marine National Park 'B' are:

- fishing (defined as the taking of fish, echinoderms, crustaceans or molluscs).
- collecting (the taking of any animal, plant or marine product declared in the regulations made under the Great Barrier Reef Marine Park Act).

The Marine National Park 'B' and Marine National Park Buffer Zone may only be entered for:

- recreational activities other than fishing or collecting (aside from trolling for pelagic species within the Buffer Zone, which is permitted).
- navigation and operation of vessels with gross tonnage less than 500 tonnes.
- construction, conduct and servicing of navigational aids.
- operation of aircraft at altitudes above 500ft or within an aircraft landing area.
- the removal of wrecked, stranded, sunk or abandoned vessels (ships, boats, rafts, pontoons or any other thing capable of carrying persons or goods through or on water, but not including hovercraft).

Permits from the Great Barrier Reef Marine Park Authority are required within the Marine National Park 'B' and Marine National Park Buffer Zone for:

- research.
- construction and conduct of underwater observatories, mooring facilities for boats and aircraft landing areas.
- provision of tourist or educational facilities and programs.
- navigation and operation of tourist cruise ships (gross tonnage exceeding 500 tonnes).
- operation of aircraft on the water surface and at an altitude of less than 500ft above the water, other than within an aircraft landing area.
- use of hovercraft.
- harbour works, beach protection works or other works.
- discharge of wastes from fixed structures.

(Great Barrier Reef Marine Park Authority, 1983)

In 1979, the Marine National Park declared around Green Island reef by the Queensland Government in 1974 was amalgamated into the Cairns Marine Park, also declared by the Queensland Government. Zones adopted for the Cairns Marine Park were complementary to the zones of the Cairns Section of the Great Barrier Reef Marine Park and therefore carried similar conditions.(Department of Environment and Conservation, 1989).

The Zoning Plan for the Cairns Section of the Great Barrier Reef Marine Park is currently under review, with proposed zoning of Green Island as Marine National Park (Great Barrier Reef Marine Park Authority, 1989). As such, it is anticipated that zoning conditions for Green Island reef will not change significantly (D. Briggs, G.B.R.M.P.A., pers. comm.).

Green Island reef has been subjected to two major periods of infestation by the crown-of-thorns starfish, A. planci - in 1962-67 and 1979-81. The 1962 outbreak was the first to be reported on the Great Barrier Reef. and preceded an extensive series of infestations of reefs throughout the Great Barrier Reef region which continued until 1977. Similarly, the 1979 outbreak was the first recorded for two years and marked the beginning of another series of reef infestations (Moran, 1986).

Talbot and Talbot (1971) and Kenchington (1977) suggested the primary A. planci outbreaks had occurred on reefs to the north of Green Island in the mid-1950s, as outbreaks generally progressed in a southerly direction during the 1960s and 1970s. However, Moran (1986) could find no direct evidence to support this and Fisk *et al.* (1988) noted that reefs in the Green Island area had been proposed as the location of primary outbreaks of A. planci on the Great Barrier Reef. More recently, hydrodynamic models have predicted that A. planci larvae at Green Island reef are most likely derived from reefs to the north, where coral cover was reduced before starfish were present at Green Island reef (Fisk *et al.*, 1988). This is considered by Fisk *et al.* (1988) to support the idea that Green Island is a site of primary observation rather than primary outbreak.

Oral history projects relating to human experiences of crown-of-thorns starfish on the Great Barrier Reef were conducted by Dalton and Reynolds (1984) and Ganter (1987). The former acknowledged that dates given for various events would vary in accuracy, and this should be kept in mind when considering information from these publications.

A comprehensive review of the course of events during the Green Island infestations is given by Raymond (1986). Fortunately, it appears the accuracy of his information improves following his introduction of Green Island as a 3km long, 2km wide cay which stands only a metre above high tide!

EARLY SIGHTINGS

Raymond (1986) reported that a crown-of-thorns starfish was first filmed on Green Island by biologist and film-maker Noel Monkman in 1930. In 1935 another film enthusiast, Bruce Cummings, saw and filmed A. planci at Green Island but not at Michaelmas Cay or Low Isles (Dalton and Reynolds, 1984). Despite their frequent filming around Green Island, he and his wife saw only about six more over the ensuing three years (Raymond, 1986). All were reportedly small - six or seven inches in diameter (Dalton and Reynolds, 1984).

Dalton and Reynolds (1984) interviewed a diver, Scott, who frequented Green Island reef in the period 1942 - 1960 and saw no A. planci until 1960. Vlasoff and Grigg - builders of the underwater observatory - were interviewed by Dalton and Reynolds (1984) and Ganter (1987) respectively. Grigg commented that the Cairns Harbour Board first noticed crown-of-thorns starfish at Green Island in 1959 and that he had collected some in November of that year, noting that they were gradually increasing in number (Ganter, 1987). Vlasoff recalled starfish 'in numbers' on the reef in 1960, while Scott related that removal of the starfish by hand had commenced in 1960 when Grigg realised they were eating the coral (Dalton and Reynolds, 1984).

Dr John Barnes, a practicing doctor and renowned marine biologist, was reported by Raymond (1986) to have seen his first A. planci on the reef flat to the south-east of Green Island in 1960. The white, circular patches of dead coral nearby were regarded as 'long-term resting places' (Barnes, 1966). While no more specimens of the starfish were sighted during inspections of the reef in 1961, Barnes (1966) reported many more dead patches of coral on the reef flat to the south-east and south of the cay [B1, B2: Fig.3.1].

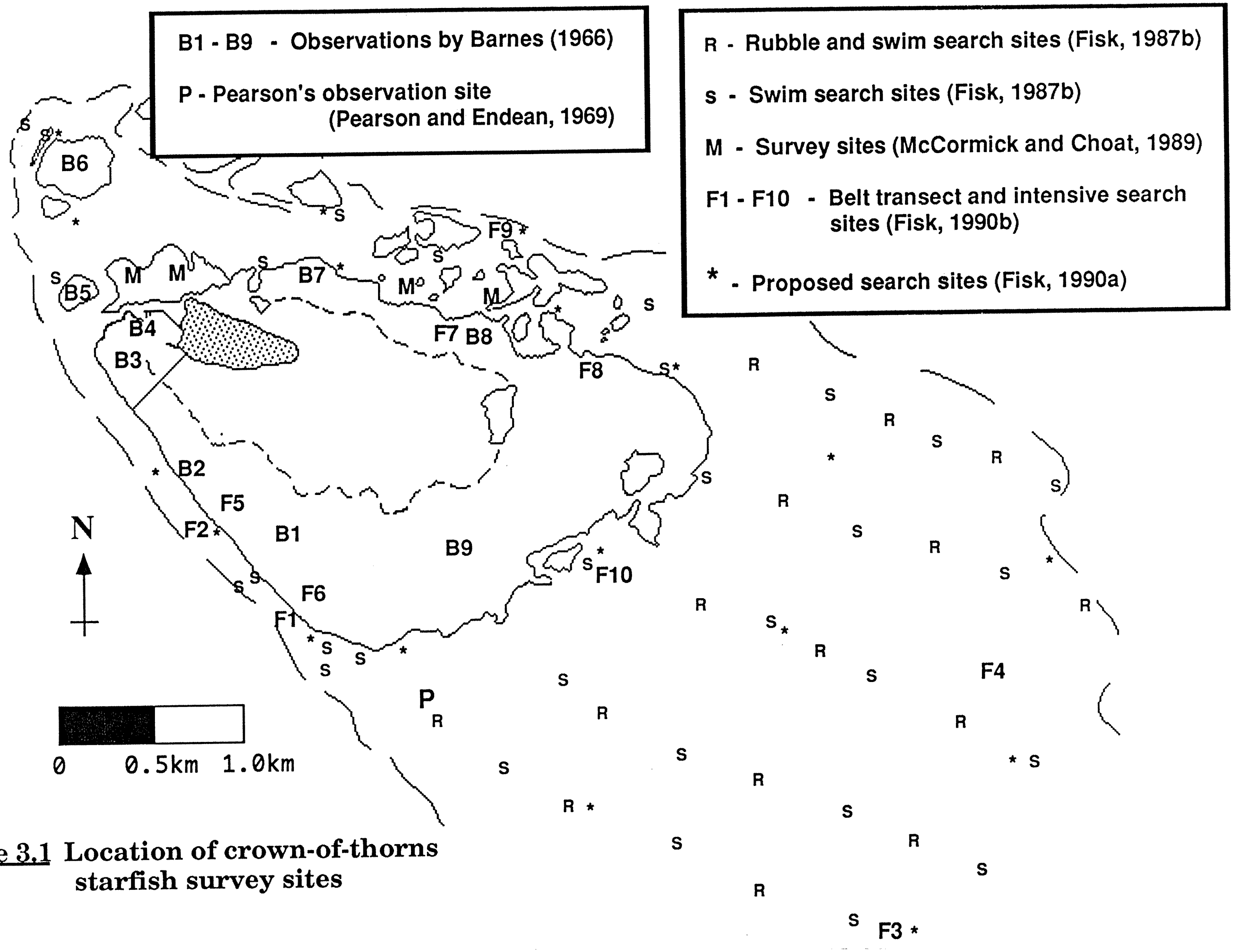


Figure 3.1 Location of crown-of-thorns starfish survey sites

1962 - 1967 INFESTATION

The outbreak

In early 1962 more A. planci sightings were reported to Barnes, including numbers around the underwater observatory by Vlasoff and Grigg (Raymond, 1986). Grigg subsequently collected five specimens in less than an hour and found a large number to the south of the observatory apparently moving northwards in a distinct front [B2: Fig.3.1] (Barnes, 1966). By 1963, the starfish had reached the observatory [B4: Fig.3.1] and Grigg was able to study them at night, discovering that coral damage was actually due to their feeding on the coral polyps (Raymond, 1986). The A. planci infestation at Green Island rated a passing mention in Barnes and Endean (1964).

Control measures, 1964-65

During 1964 the starfish continued to advance in a clockwise direction around the reef, spreading rapidly over the north-western corner [B5, B6: Fig.3.1] where their widespread destruction of the coral prompted the first concerted effort to remove them (Barnes, 1966). This was largely ineffective and coral destruction continued to increase until, by the end of 1964, the area was denuded (Raymond, 1986).

In 1965, a diver employed by Hayles Ltd was stationed to the north-east of the cay [B7: Fig.3.1] to remove the starfish in one small area. Despite his removal of 27,000 A. planci over a 15-month period, at rates of up to 373 a day (Barnes, 1966), considerable damage did still occur and not even the 4ha coral-viewing site could be saved (Moran, 1986).
Birkeland (1982) reported a total of 44,000 starfish were killed by control measures. An interviewee of Dalton and Reynolds (1984) reported the removal of 'about 150,000' starfish during the first period of infestation.

Surveys, 1965-66

A team of fisheries biologists from the Queensland Department of Primary Industries, led by N. Haysom, surveyed portions of Green Island reef in 1965 (Kenchington, 1978). The results of this survey are not available in the published literature.

The first scientific study of A. planci on the Great Barrier Reef was by Barnes (1966), who gave a detailed description of starfish movements around the reef [Fig.3.1]. At this time, they were still highly active in the region due east of the cay [B8: Fig.3.1], but the south-eastern corner of the reef flat showed little evidence of A. planci activity (Barnes, 1966).

Pearson's study, 1966-69

A more extensive study of A. planci on the Great Barrier Reef - conducted by R. Pearson of the Queensland Department of Primary Industries - was based at Green Island from May 1966 to March 1967, after which it was based in Cairns, continuing until March 1968. Studies included visual surveys of starfish numbers, observations of feeding rates, starvation experiments, determinations of fecundity, plankton hauls for larvae and surveys of coral regeneration. Results from these studies are presented in detail by Pearson and Endean (1969), while unpublished size frequency data was used by Kenchington (1977) to derive growth curves for A. planci. Clare (1971) refers to a steel-framed dredge which, in November 1968, was to be used between reefs 'to pick up any crown-of-thorns starfish ... migrating from reef to reef', but the results of its usage are not given.

In a $100m^2$ area on the south-eastern reef slope (marked in September 1966) [P: Fig.3.1], the starfish numbers increased from 219 to 350 within fifteen days and live coral cover decreased from 47% to 15% in two months (Pearson and Endean, 1969).

Visual surveys of A. planci abundance were made by observers swimming for a known length of time over an area of reef. Where large numbers of starfish were encountered only the readily apparent ones were counted, while more detailed searches for concealed starfish were made in areas where they were less abundant. Numbers of A. planci counted during swims of varying duration were standardised to numbers per 20-minute period to give a measure of relative abundance (Pearson and Endean, 1969).

Specific locations of the Green Island reef visual surveys are not given by Pearson and Endean (1969), although counts were generally made in water depths of less than 10m along the 'reef margin'. In May 1966 abundances of up to 351 per 20-minute swim were recorded, increasing to up to 1150 per 20-minute swim by September, after which numbers began to decline (Pearson and Endean, 1969). By January 1967 maximum abundance was 28 per 20-minute swim (Pearson and Endean, 1969) with a total of 36 starfish recorded from 3 sites surveyed (Fisk *et al.*, 1988). In March 1968 no more than two were found per swim (Pearson and Endean, 1969) with a total of five starfish recorded from 4 sites surveyed (Fisk *et al.*, 1988). No starfish were recorded during a survey of 8 sites in November 1968 (Fisk *et al.*, 1988). In August 1969 only one was found in each of two 30-minute and one 20-minute swims (Pearson and Endean, 1969).

Following the two year study, Endean (1969) recommended implementation of hand-harvesting of A. planci and importation and large-scale breeding of the giant triton shell (Charonia tritonis), which he identified as a major predator of the starfish. However, Pearson subsequently disagreed with several of Endean's interpretations of the results and recommended examination of the report by population ecologists (Report of the Committee, 1971). When interviewed by Dalton and Reynolds (1984) Vlasoff commented that triton shells were a deep water species, while tourists were restricted to the reef top and would not have removed sufficiently large numbers of the shells to have precipitated the starfish infestation.

BETWEEN INFESTATIONS

Endean and Stablum's survey, 1970

Endean and Stablum (1973a) surveyed sectors of Green Island reef for A. planci in May and November 1970. Green Island reef was one of a series of reefs surveyed, with several survey methods being employed during the series - snorkelling, scuba diving, use of a glass-bottomed box from a boat and manta towing. The methods employed at Green Island are not specified. During the survey series, visual estimates were generally made over 20-minute periods, with more detailed searches only made within the vicinity of 'freshly killed' hard corals - duration and thoroughness of the Green Island surveys are also unspecified.

An estimated 35,000m^2 of Green Island reef was surveyed, covering areas of reef flat to the west of the cay [B4: Fig.3.1] and on the north-western side of the reef [B5: Fig.3.1], seaward slopes on the south-western [B2, B3: Fig.3.1] and southern sides [B1: Fig.3.1], and 'submerged reef' on the south-eastern side [B9: Fig.3.1]. No specimens of adult or juvenile A. planci were found during the survey.

Pearson's surveys, 1970 - 1976

As reported in Fisk *et al.* (1988), Pearson conducted 20-minute swim surveys at sites around the perimeter of Green Island reef in June 1970 (3 starfish from 6 sites), August 1972 (4 starfish; 8 sites) and August, 1976 (48 starfish; 13 sites). Precise locations of the survey sites are not given by Fisk *et al.* (1988).

1979 - 1982 INFESTATION

The outbreak

In August 1979 Queensland Fisheries Service staff, acting on reports from fishermen and scuba divers, observed a large population of small starfish (about 14cm in diameter) at 10m depth at the 'deeper eastern end' of the reef (Kenchington and Pearson, 1981). A belt transect survey by Pearson in August 1979 yielded 456 starfish from 29 sites around the reef perimeter and two sites within the eastern shoal area (Fisk *et al.*, 1988). Further reports by skindivers and fishermen indicated the population appeared to be spreading up the reef slope and advancing around both sides of the cay towards the western end of the reef (Raymond, 1986). The main advancing front of the A. planci aggregation followed much the same path as in the first outbreak, while a second smaller front advanced more slowly from the eastern end of the reef and along the northern reef face. Both aggregations converged on the north-west patch reefs before dying or disappearing (Kenchington and Pearson, 1982; Fisk *et al.*, 1988).

Surveys, 1979-80

Following an initial survey in December 1979, Endean (1982) estimated that 60% of the hard corals had been killed and that the A. planci population comprised 350,000 individuals. While Endean's estimate of coral mortality was derived from transect surveys, the method employed in estimating starfish abundance is not specified by Cameron and Endean (1981) or Endean (1982). Cameron and Endean (1981) further report that 'Government scientists' concurrently estimated 400,000 starfish to be present, which was 'subsequently' raised to 2 million. I have been unable to locate the surveys which may have given rise to these estimates.

During 1980, Pearson (1980) estimated, using a belt transect technique, that there were 1,642,000 (± 871,351) starfish on the reef. Individual surveys were conducted in March (420 starfish from 16 reef perimeter sites and 2 shoal sites) and September (2142 starfish; 33 perimeter and shoal sites) (Fisk *et al.*, 1988). In September, Pearson also observed many adult starfish up to several hundred metres from the south-western reef edge. These were moving in a north-west direction over the sandy floor at 20m depth. Further observations in October 1980 revealed starfish in depths of 50m up to 1.5km from the reef perimeter (Fisk *et al.*, 1988).

Analysis by Fisk *et al.* (1988) of starfish diameters recorded during this outbreak revealed an assemblage in the eastern shoal area to have a greater number of small starfish than a spatially separated assemblage in the northern reef area. This was considered to be indicative of greater recruitment of starfish to the shoal area, supported by Pearson's observations of movements of starfish from this area along the southern reef slope to the western end of the reef (Fisk *et al.*, 1988).

Control measures, 1980

In mid-1980, the Queensland Fisheries Service tested a series of control measures at Green Island, including hand collecting (removal rate of 38/hour), compressed air injection (21/hour) and injection of chemicals such as copper sulphate (132/hour), formalin and ammonia (Blakey, 1980; Hicks and Blackford, 1981). Of the chemicals tested, 10ml of copper sulphate per starfish was found to be the most effective (Hicks and Blackford, 1981). Despite the collection of 1800 starfish and the injection of 6700 more, there was no discernible effect on the A. planci population in the area (Raymond, 1986).

Shortly afterwards, two divers working in a 2ha coral viewing area at the western end of the cay with copper sulphate injection guns killed 25,850 starfish over 35 days at a rate of 115 per hour (Kenchington and Pearson, 1981). However, the starfish still managed to invade and denude the area, completing the destruction of hard corals to an even greater extent than did the 1962/67 infestation (Raymond, 1986). In total, over 29,000 starfish were killed during the second outbreak (Zann and Weaver, 1988).

POST-INFESTATION SURVEYS

Nash and Zell, 1980

The number of A. planci on Green Island reef declined during 1980, and a manta tow survey by Nash and Zell (1981) in the period between March and May revealed high dead coral cover but relatively few starfish. They surveyed the entire reef margin, some of the reef flat and much of the back-reef lagoon, although specific locations are not given. Observers were towed for 20-minute periods at speeds of around 1.5 knots, thus covering up to 1km of reef per tow. It would appear from this methodology that only the readily apparent individuals would have been counted. Of the twenty-four 500m-unit tows conducted, 10 revealed no A. planci, 6 had one or two starfish, 4 had three to ten individuals and 4 revealed between eleven and forty starfish (Nash and Zell, 1981). The total number of starfish found and their distribution around the reef is not presented.

Cannon and Goeden, 1980

Benthic hauls were undertaken by Cannon and Goeden (1983) in October 1980 to assess the abundance of A. planci in the inter-reefal areas surrounding Green Island reef. Hauls of 5 or 10 minutes duration were taken using a single rigged 5.4m try net. The sampling stations encircled Green Island reef and did not encroach into the south-eastern bommie field. An A. planci specimen was recovered at only one station- approximately 2km south-west of the south-western reef edge at a depth of 40m.

Nash *et al.*, 1981

Specimens of A. planci were collected from Green Island reef in July 1981 by Nash *et al.* (1988). Starch gel electrophoresis was used to genetically compare the Green Island population with other populations of A. planci on the Great Barrier Reef. Distinct differences between the Green Island population and the others sampled were attributed to selection, with the selective pressures probably based on low food availability. It was observed that many of the starfish collected were feeding on a species of the soft coral Sinularia, and one was observed with its stomach everted over the silty bottom at the base of the reef (Nash *et al.*, 1988).

Ayling, 1983

In the period January to March 1983, Ayling (1983) surveyed Green Island reef for A. planci. Five 50m x 10m belt transects were positioned 'randomly' and neither the precise locations nor the degree of search effort utilised are given. No crown-of-thorns starfish were recorded in this survey.

Harriott, 1984

A manta tow survey of the reef perimeter by Harriott in March 1984 located no starfish (Fisk *et al.*, 1988). Precise details of the survey technique (tow speeds, duration of tows etc.) are not given by Fisk *et al.* (1988).

A.I.M.S., 1986

In January 1986, Green Island reef was surveyed by the Australian Institute of Marine Science (Bradbury *et al.*, 1987). Manta tows were utilised, with observers towed for two minute periods at speeds of about 1.5 knots. A total of 38 tows were used to survey the reef margin, and no A. planci were observed (Bradbury *et al.*, 1987; Moran *et al.*, 1988).

Walbran et al., 1986

Walbran *et al.* (1989) sampled the surface sediments at 46 sites on and around Green Island reef in January 1986 [Fig.2.2]. A jawed grab sampler was utilised to retrieve 3-4kg samples which were examined for A. planci skeletal elements. There was no obvious pattern of element distribution, although abundance was low in the reef flat samples. Radiocarbon dating using carbon-14 accelerator mass spectrometry confirmed the elements to be Modern (within the last 200 years) to >Modern (post-1954) in age.

Subsurface sediment cores were obtained at six sites [Fig.2.2] using a pontoon-supported vibracorer. Core results indicated a more uniform geographic distribution of elements than that displayed in the surface sediment, which was ascribed to the reworking and dispersal of elements prior to their internment in the sediment body. They also noted substantial biological reworking of the sediment pile, predominantly by callianassid shrimp. This physical and biological reworking precluded recognition of individual outbreaks in core stratigraphy. The down-core distribution of A. planci elements was considered to be consistent with repeated A. planci outbreak cycles over a period of at least 3000 years. An apparent increase in elemental abundance below 200cm core depth suggested a decrease in the prevalence of A. planci at Green Island reef over the last 1000-2000 years (Walbran *et al*,,1989).

Fisk, 1986

The abundance and distribution of A. planci on Green Island reef was estimated by Fisk (1987b) in July/August 1986. Swim surveys of 5 minutes duration were undertaken at 46 sites on the reef slope and within the bommie field to the south-east of the reef flat [Fig.3.1]. Patches of recently dead coral were searched for starfish, unlike the manta tow surveys of other researchers in which only readily visible starfish were recorded.

The initial survey (one swim at each site) revealed 47 A. planci, while a second survey (two swims at each of a subset of 12 sites within the bommie field) revealed 14. An additional 6 starfish were observed during the course of other activities. The highest number of A. planci observed during a 5-minute swim was 12, the next highest 6 - each on only one occasion. Four or fewer starfish were found during each of the remaining 68 timed swims, with no starfish found in 43 of these.

The distribution of A. planci across the reef slope and bommie field was considered to be apparently random, with the possible exception of the seaward margin of the reef where very few starfish were detected. The size distribution of the juvenile population detected was consistent with that of an 18-month old starfish population, suggesting a single year class probably recruited from the 1984/85 summer. Smaller numbers of younger and older starfish were also found.

Fisk *et al.* (1988) reported a total of 30 starfish found in September 1986 during 5-minute swim surveys of 45 sites around the reef perimeter and within the shoal area. When feeding scars were seen, additional time was taken to search the nearby area for starfish, the number so found being added to the number of non-cryptic starfish sighted.

Detailed rubble searches were also undertaken in September 1986 at 15 of the bommie field sites, within four 0.5m x 0.5m quadrats at each site. Rubble was removed to a depth of approximately 0.5m, with each piece scrutinised for small (>1cm) starfish. In this manner, almost $2m^3$ of rubble was searched and only one starfish - 2cm in diameter and most probably about 9 months old - was found (Fisk, 1987b). This survey appears to be the same survey referred to by Fisk *et al.* (1988) as an October/November survey of 20 sites searching for >0.5cm starfish.

Black and Gay, 1987

Dispersal of A. planci larvae on and around Green Island reef was modelled by K. Black of the Victorian Institute of Marine Sciences utilising the hydrodynamic model detailed in Black and Gay (1987). Data from the numerical dispersion study are unpublished.

A.I.M.S., 1987

Australian Institute of Marine Science personnel surveyed Green Island reef in February 1987 (Bass *et al.*, 1988). Manta tows were utilised, with observers towed for two minute periods at speeds of about 1.5 knots. A total of 51 tows were used to survey the reef margin, with deviations through the patch reefs to the north-west of the cay and at the southern edge of the eastern reef tip. No A. planci were observed.

The reef was resurveyed in June 1987 utilising the same technique, but with the scope of observations expanded to include feeding scars (presumed to be due to A. planci feeding). A total of 62 tows were used to survey the reef perimeter, with the exception of the eastern tip, and no A. planci or feeding scars were observed (Bass *et al.*, 1989a).

Fisk and Harriott, 1987-88

Fisk (1988) and Fisk *et al.* (1988) give data from 5-minute surveys conducted by Fisk and Harriott in May 1987 (15 starfish from 45 sites), November 1987 (9 starfish; 46 sites) and April 1988 (8 starfish; 43 sites). Sites around the reef perimeter and within the eastern shoal area were surveyed utilising the same search effort as the September 1986 survey of Fisk and Harriott.

Searches for 0-1year old starfish were conducted in October/November of 1987 and 1988, using the survey technique described for the October/November 1986 survey of Fisk and Harriott (Fisk *et al.*, 1988). No starfish in this age class were found in 1987 (Fisk, 1988), and results of the 1988 survey are not given by Fisk *et al.* (1988).

Size class data from the 1986-88 surveys revealed the low density population present to be predominantly small starfish, with a decrease in abundance and average size over time (Fisk *et al.*, 1988). The decline in abundance may have been indicative that there was insufficient coral on Green Island reef to support larger starfish once their diet had changed from calcareous algae (Fisk *et al.*, 1988).

McCormick and Choat, 1988-89

During surveys of reef fish abundance within and outside the Green Island reef seagrass beds [Fig.3.1] in May 1988 and April 1989, observations of crown-of-thorns starfish were recorded by McCormick and Choat (1989). No A. planci were recorded within sixty 10x4m strip transects searched in detail on each occasion, and only one starfish was seen during each of the surveys.

A.I.M.S., 1989

Green Island reef was surveyed by the Australian Institute of Marine Science in February 1989 (Bass *et al.*, 1989b). A manta tow technique was utilised, with observers towed for two minute periods at speeds of about 1.5kn, recording abundance of A. planci and of feeding scars . A total of 48 tows were used to survey a clockwise path through the seagrass beds and across the sanded reef flat at a distance of about 150m from the cay until adjacent to the eastern tip of the cay; then around the reef perimeter and back across the reef flat to the south-west of the cay. A feeding scar observation (category <10 scars) was made during the first two-minute tow, apparently in the vicinity of the seagrass beds. No assumptions are made in this report as to the origins of feeding scars (cf. Bass *et al.*, 1989a, in which they are assumed to be 'A. planci feeding scars'), and no A. planci were observed (Bass *et al.*, 1989b).

Fisk, 1989

Two techniques were used by Fisk (1990b) to sample juvenile crown-of-thorns starfish during a survey in November 1989. A total of 10 survey stations were established [F1 - F10: Fig.3.1] in the eastern bommie fields, the south and south-west flanks of the reef edge, the reef flat and the back reef.

Intensive searches of dead coral substrata with a high component of encrusting coralline algae were conducted to locate 0+yr individuals. The searches covered two substratum types where such individuals had previously been located - rubble and rubble/porous substrata under or adjacent to live coral and within 0.25m of plate coral colonies. Within each station, four replicate 0.5m square areas at each of two sites were searched. Only one 0+yr individual was located, at station F2 [Fig.3.1].

Belt transect surveys were utilised to locate 1+yr individuals. At each site, a 20m x 4m belt transect was searched for feeding scars on live coral or visible crown-of-thorns starfish. An area within a radius of 0.25m from each feeding scar was searched down to bedrock. Only one 1+yr individual was located, at station F1 [Fig.3.1]. One individual of 18cm diameter was found outside the belt transects, feeding on a colony of Acropora grandis (Fisk, 1990b).

A.I.M.S., 1990

Green Island reef was surveyed in January 1990 as part of the continuing series of broadscale surveys of crown-of-thorns starfish on the Great Barrier Reef conducted by the Australian Institute of Marine Science. Data is currently in preparation for publication (Moran, pers. comm.).

Chapter 4 CORAL

CORAL ABUNDANCE

Pearson's surveys, 1967 - 1969

The earliest published estimates of coral cover on Green Island reef were made subsequent to the 1962-67 infestation by the crown-of-thorns starfish, Acanthaster planci, and were therefore expressed mainly as proportions of dead coral. Pearson and Endean (1969) subjectively estimated that by November 1968 A. planci had killed over 80% of hard corals from the reef flat to the sea floor (at about 40m). They found most of the commonly occurring genera in the surviving corals, with many colonies of Pocillopora damicornis and Millepora undamaged. Surviving corals ranged in size from single colonies to clumps as large as $100m^2$. It was also observed that the outermost tips of several otherwise-dead staghorn Acropora colonies were left untouched (Pearson and Endean, 1969).

Coral recolonisation studies through mapping of four distinct study areas [P1, P4, P5, P6: Fig.4.1] were commenced by Pearson in March 1967 (Pearson and Endean, 1969). Areas P1, P4 and P5 measured 30m x 2m while area P6 was 10m x 10m. It was apparent from brief re-examinations of the study sites in November 1968 that recolonisation was taking place, but at a very slow rate. In August 1969 the corals in areas P1, P4 and P5 were again mapped and recently-established corals, particularly of Stylophora, Acropora and Seriatopora species, were found growing on dead coral surfaces in all three areas. Pearson and Endean (1969) do not give any quantitative coral cover data from the mapping exercise, and area P6 was apparently not remapped in 1969.

Cursory examinations of several hundred square metres of reef in the vicinity of areas P1 - P5 [Fig.4.1] were also made in August 1969. At site P5 on the north-eastern reef flat, Pearson estimated approximately 50% dead coral cover (mostly Acropora and Porites), 20% live coral cover (likewise) and 1% new hard coral growth. Site P4 was judged to have a similar coral cover [Table 4.1].

Site P3 on the north-western reef flat had similar coral cover to site P2 [Table 4.1], with Acropora dominating the dead coral cover. Acropora and massive Porites colonies accounted for most of the live coral cover. New hard coral cover was again estimated to be about 1%.

The dead coral cover at site P1 [Fig.4.1; Table 4.1] was mainly Acropora, Stylophora and Seriatopora, with live coral mainly recently established colonies of the same three genera. At greater depths (3 - 6m) in the same area they found far less coral regeneration (about 1% new growth). Pearson concluded that the growing colonies were those which had not been attacked during the infestation (Pearson and Endean, 1969).

Woodhead's survey, 1970

In June 1970, Woodhead and Pearson quantitatively surveyed coral abundance in the vicinity of Pearson's sites P1, P2 and P4 [Fig.4.1] (Woodhead, 1971). A quadrat technique was used in which a one metre square quadrat was placed at every second metre along a transect line of unspecified length. The number of coral species, number of coral colonies and total area covered by living hard and soft corals were measured for each quadrat. Pearson and Woodhead conducted separate surveys at sites P1 and P2, but co-surveyed site P4. Their estimates are listed in Table 4.1.

Site P1 was found to have the highest living coral cover of the three, with branching colonies of Acropora, Seriatopora, Stylophora and Pocillopora predominant and very large Porites heads common. Despite the absence of comparable baseline data, Woodhead concluded that the area, where A. planci had been very abundant in 1966, was recolonising and regrowing very well. The back-reef area around site P4 was also judged to be recovering well, with Pocillopora damicornis the dominant species. From the size and distribution of the Pocillopora damicornis colonies, Woodhead felt they had appeared after A. planci had left the area.

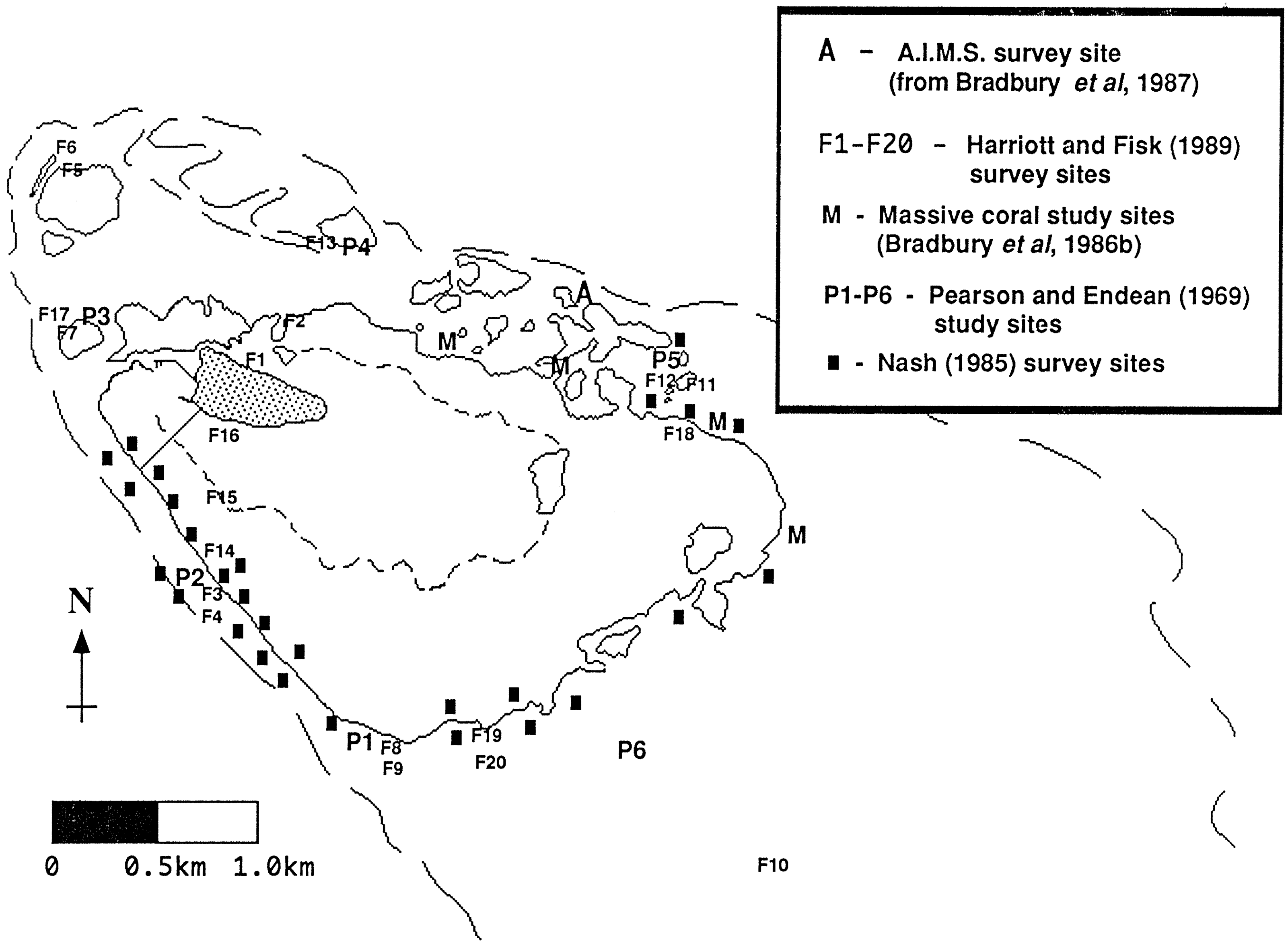


Figure 4.1 Location of coral cover survey sites

Table 4.1:
Coral cover data from surveys of three locations on Green Island reef. Direct comparisons between the surveys are not valid as different survey techniques were used and they were possibly conducted at different locations within the three general areas. Site locations are given in Fig.4.1.
PE = Pearson and Endean (1969); W = Woodhead (two surveys conducted: (P) = Pearson's survey, (W) = Woodhead's survey);
ES = Endean and Stablum (1973b) (two surveys conducted on 'south-western side, seaward slope'); HF = Harriott and Fisk (1989); B = Bradbury *et al.* (1987).

SITE P1	PE	W	HF
Date	8/69	6/70	9/85
Depth	<3m	1 - 8m	3 - 5m
Dead coral	60%	-	-
Live coral	30%	15% (P) 29.5% (W)	16% (3m) 11% (6m)
Soft coral	10%	5% (P) 11.5% (W)	3% (3m) 14% (6m)

SITE P2	PE	W	ES	HF	B
Date	8/69	6/70	11/70	9/85	1/86
Depth	1-6m	<6m	0-15m	3-6m	3-12m
Dead coral	50%	-	-	-	20% (3m) 24% (6m) 26% (12m)
Live coral	5%	2.5% (P) 4% (W)	2% 5.5%	5.5%(3m) 4% (6m)	<1% (3m) 4% (6m) <1% (12m)
Soft coral	15%	21%	9.5% 6%	5% (3m) <1% (6m)	18% (3m) 7% (6m) <1% (12m)

SITE P4	PE	W	HF
Date	8/69	6/70	9/85
Depth	5m	1-6m	5m
Dead coral	50%	-	-
Live coral	20%	14%	3%
Soft coral	-	8%	15%

By contrast, there was little evidence of recovery or recolonisation by hard corals at site P2, where there was considerable sediment movement. Similarly at site P3, where they examined the area but did not conduct a quantitative survey, the greater part of the coral was still dead and regrowing staghorn Acropora branches were on insubstantial or loose bases. Again, high water turbidity appeared a major factor inhibiting the settlement and subsequent growth of young colonies.

In all, Woodhead noted 34 genera and subgenera of corals during this survey, compared with 39 recorded before the starfish infestation. Neither the pre- infestation list nor the list from this survey appear to have been published. Woodhead considered the species assemblage resembled those of two reefs in the same region which had not been infested by A. planci (Low Island and Nymph Island). Although the overall living coral cover at Green Island reef was only about half that of the uninfested reefs (which had been surveyed using a similar technique), he concluded that good recovery was under way, particularly at the southern tip of the reef (Woodhead, 1971).

Endean and Stablum's survey, 1970

Hard coral cover at Green Island reef was surveyed by Endean and Stablum (1973a,b) in May and November 1970. While Endean and Stablum (1973a) conceded that visual estimates of hard coral damage could lack precision and be misleading as they did not take into account 'the overall extent of coral cover or the amount of dead coral normally found on the reef', they proceeded to make visual estimates of the respective amounts of living and recently killed coral present. Several techniques were employed during their series of surveys on a number of reefs - snorkelling, scuba diving, use of a glass-bottomed box from a boat and manta towing - and the methods used at Green Island are not specified.

The proportion of reef surface covered by live hard corals plus the skeletons of recently killed hard corals still *in situ* (termed the 'total hard coral cover') was categorised as 'sparse', 'moderate' or 'dense', while the proportion of recently killed hard corals within the total hard coral cover was categorised as 'low', 'marked' or 'high'. The extent of soft coral cover was also assessed (Endean and Stablum, 1973a). Survey areas were located so as to correspond with areas at which A. planci observations were made by Barnes (1966).

At two reef flat sites - one to the west of the cay [B4: Fig.3.1; 0-5m depth] and the other on the north-west side of the reef [B5: Fig.3.1; 0-3m depth] - hard coral destruction was considered almost total, soft coral cover was extensive and hard coral recolonisation was negligible. On the seaward slope along the south-west and southern sides [B2, B3, B1: Fig.3.1; 0-15m depth] there was extensive destruction of hard coral, with a high proportion of dead coral rubble plus algal covered coral skeletons *in situ* . Hard coral recolonisation was minimal along the south-western slope, while at B1 there were scattered surviving corals in shallow water with some apparent regeneration. On a submerged reef along the south-east side of the reef [B9: Fig.3.1; 3-10m depth], patches of soft coral were interspersed with hard coral, some of which had apparently survived predation and others appeared to be recolonisers. Total hard coral cover at the latter site was categorised as moderate, while at all other sites it was considered sparse. At all sites the proportion of recently killed hard corals was categorised as high (Endean and Stablum, 1973a,b).

Quantitative data on the proportions of living hard coral, recently established coral colonies and soft corals was obtained by Endean and Stablum (1973b) along transects at sites B1, B2, B3 and B9 [Fig.3.1]. Quadrats were placed along the 100m transect lines and photographed, the images of the various benthic components later being excised and weighed to determine the relative cover of each component. Data from transects along the seaward slope on the south-western side of the reef [B2, B3: Fig.3.1] are included in Table 3.1. At site B1, live hard coral cover was estimated as 15.6% and soft coral cover was estimated as 11.6%. At site B9, live hard coral cover was estimated as 18.3% (although this was reduced to 10.1% if one of the quadrats covering an atypically large coral colony was omitted from the analysis) and soft coral cover as 20.8%. At sites B1 and B9, about half of the living hard coral colonies were considered to be recently established (Endean and Stablum, 1973b).

Endean's survey, 1979

Following the second reported A. planci outbreak in 1979, Endean (1982) conducted transect surveys at certain unspecified locations on Green Island reef in December that year. The survey techniques employed were those used by Endean and Stablum (1973a,b). From the surveys, he estimated that approximately 60% of the reef's hard coral cover had been recently killed by the starfish.

Nash and Zell's survey, 1980

Green Island reef was surveyed by Nash and Zell (1981) at some time between March and May 1980. The survey utilised the manta tow method, with observers towed on a manta board for 20 minute periods at a speed of about 1.5 knots, thus covering a distance of 1km or less of reef. Data recorded included the numbers of A. planci present, percentage cover by hard coral, soft coral, macroalgae and dead standing hard coral, substrate type, depth, slope, colony size, coral species diversity and the visually-dominant benthic organisms. The entire margin, some of the reef flat and much of the back reef lagoon was surveyed, although specific locations are not given.

It appears the only data from Green Island to be published is A. planci abundance and percentage dead standing hard coral cover. Manta tow data were standardised for a 500m tow unit, with 24 tow units undertaken at Green Island. Of these, exactly half showed 51 - 100% of colonisable substrate to be occupied by dead standing hard coral, nine showed 16 - 50% occupation and three showed 6 - 15% occupation. None of the tows fell within the lowest occupation category (0 - 5%) and dead coral cover was very high relative to the other reefs in the vicinity which were surveyed over the same period (Nash and Zell, 1981).

Cameron and Endean's survey, 1981

In January 1981, Cameron and Endean (1981) resurveyed Green Island reef, possibly utilising the same technique as Endean's 1979 survey, and estimated that approximately 90% of the reef's hard coral cover had been killed. They noted that destruction of the remainder, including massive corals, was in progress (Cameron and Endean, 1981; Endean, 1982).

Ayling's survey, 1983

As part of a survey of reefs conducted between January and March 1983, Ayling (1983) estimated the overall cover of live hard and soft corals on Green Island reef. Estimated hard coral cover was less than 5%, with soft coral cover between 5% and 10% and coral rubble the dominant feature.

Nash's observations, 1984

Nash (1985) saw little evidence of hard coral regrowth during his 1984 trochus shell survey, which incorporated sites on the south-western reef edge and slope, the reef edge and slope at the southern tip and the slope around the eastern extremity of the reef [Fig.4.1]. He noted that the tabular corals which had once covered a large proportion of the shelf between the boulder zone and drop-off on the south-western reef edge were nearly all dead and covered by an algal turf. Remaining colonies on the shelf were predominantly Pocillopora damicornis and branching Acropora species. He found the south-western slope at about 20m depth to be devoid of living hard and soft corals, with the macroalga Padina the only conspicuous species (Nash, 1985).

A.I.M.S. study, 1985

Colonies of the massive corals Porites and Diploastrea were surveyed at four sites [Fig.4.1] around the perimeter of Green Island reef in April 1985 (Bradbury *et al.*, 1986b). The level of damage to various size classes of the corals caused by the A. planci infestations was assessed and some Porites colonies were cored to establish the date of coral damage. The height difference between the scarred surface and living surface of each colony was measured and there was a high correlation of infestation date with peak level of scarred surface (Bradbury *et al.*, 1986b).

Harriott and Fisk's surveys, 1985

Twenty transect sites were established by Harriott and Fisk (1989) between July and September 1985 to assess the status of the Green Island coral community following the 1979/81 A. planci infestation. The sites [Fig.4.1] were located both on the reef flat (0.5m depth) and on the reef slope (2m - 6m depth). Within each site, four 30m line transects were randomly placed and the intercepts of hard and soft corals recorded.

The 1985 surveys showed high hard coral cover at sites F16 (20% cover) and F15 (28% cover) on the reef flat directly south of the cay [Fig.4.1], where Montipora digitata colonies were dominant and there was no evidence that A. planci predation had occurred (Fisk *et al*,1988). Coral cover on the reef slope at the southern tip of the reef [F8 : Fig.4.1] is given in Table 4.1 - this site being an isolated patch dominated by Pocillopora damicornis and apparently undamaged by A. planci predation (Harriott and Fisk, 1989). Aside from a transect at 3m depth in area F7 [Fig.4.1] which had 11% hard coral cover, the remaining transects all yielded a hard coral cover of less than 10%. Highest soft coral cover (47%) and lowest hard coral cover (1%) were both recorded at F20 [Fig.4.1] at 6m depth. Photographs of some of the sites are included in Harriott and Fisk (1989).

A.I.M.S. survey, 1986

Green Island reef was surveyed in January 1986 by the Australian Institute of Marine Science as part of a study to assess the distribution and effects of crown-of-thorns starfish on the Great Barrier Reef (Bradbury *et al.,* 1987). The entire reef margin was surveyed using a manta tow technique with observers towed for two minute periods at speeds of 1.5kn. Cover of live and dead coral was recorded as one of six relative percentage categories (Bradbury *et al.,* 1986a).

Two sites - one fore-reef and one back-reef - were surveyed in detail using a line transect technique. Transect lengths of 100m were surveyed with benthic life forms recorded as one of 21 categories. Sampling was carried out along depth contours at 3m and 6m below the reef crest, with additional sampling along a 12m depth contour when possible. These depths were selected as they 'characteristically contain high coral cover and are subject to the most obvious damage and changes associated with Acanthaster outbreaks.'. Locations of the permanent line transect sites were noted on aerial photographs and pickets were positioned at 6m depth to assist in relocation of the sites (Bradbury *et al.,* 1986a).

Although no A. planci were found during the manta tow survey, the effects of previous outbreaks were apparent. Small live colonies of branching and tabulate Acropora were noticeable along the north-western and south-western slopes, but live coral cover over the reef as a whole was low (less than 10%). Dead coral cover was generally moderate to high (10-50%), rising to 50-75% in the south-west, and consisted 'mainly of dense patches of branching and massive Porites' (Bradbury *et al.,* 1987). Concern was expressed by an assessor of Baxter (1987) over the accuracy of this statement - comment was made that dead branching Porites is very difficult to distinguish from dead branching Acropora, and that live branching Porites is rare at Green Island and may have been confused with the more common Heliopora. It appears the statement should read 'branching Acropora and massive Porites'

Confusion also arises when the locations of the detailed transect sites are considered. A figure depicting the locations shows the 'front' site to be on the north-eastern reef slope [A: Fig.4.1], with the 'back' site on the south-western reef slope in the vicinity of Pearson's site P2 [Fig.4.1]. These locations correspond well with the site descriptions given in the text - the 'front' site in 'a relatively broken and undulating area, consisting of patch reefs rising from a gently shelving substrate' with the 'back' site 'more steeply sloping'. However, it is inconsistent with other literature on Green Island reef to refer to the generally more exposed south-western slope as the 'back reef'. It appears also that the 'tow numbers' have been reversed. If it is assumed that the 'front' and 'back' sites have been reversed in the report, then the detailed surveys were carried out at three depths on the south-western slope and at two depths on the north-eastern slope.

Live hard coral cover was low (13% at 3m; 14% at 6m) at the north-eastern reef slope site, being mainly remnant massive Porites and foliose corals. There was no evidence of recent A. planci predation, with all the dead coral colonies covered with algae. Dead coral cover was moderate (16% - 3m; 18% - 6m), algal cover was about 17% (3m) and 11% (6m) and from the data the dominant organisms were soft corals (34% - 3m; 21% - 6m) - not 'sponges' as the text suggests.

At the south-western reef slope site (see Table 4.1 for data), hard coral cover was lower and dead coral cover higher than at the other site. Soft corals were common only at 3m, while algae were dominant at all depths (30% - 3m; 32% - 6m; 51% - 12m) (Bradbury *et al.*, 1987).

Harriott and Fisk's surveys, 1986

Following the passage of Cyclone Winifred in February 1986, Harriott and Fisk (1986) resurveyed six of their transect sites [F1, F3, F5, F6, F7, F13: Fig.4.1] to assess its effect on coral cover. Hard coral cover was significantly reduced at only one site - the shallow (2m depth) coral transplant site at F5 [Fig.4.1] - and there was no significant change in soft coral cover at any site. The minor effect of the cyclone on the coral community may have been partly due to the reef's early stage of recovery from A. planci infestation, with small colonies contributing most of the live cover (Harriott and Fisk, 1986).

Harriott and Fisk (1989) resurveyed twelve of the 1985 transect sites [F1 - F12: Fig.4.1], in August/September 1986. There was no significant difference in hard coral cover between the surveys at any of the sites, while soft coral cover increased at one site [F8: Fig.4.1] and decreased at another [F10: Fig.4.1].

A.I.M.S. surveys, 1987

Australian Institute of Marine Science personnel surveyed Green Island reef in February 1987 (Bass *et al.*, 1988) utilising a manta tow technique, with observers towed for two minute periods at speeds of about 1.5 knots. A total of 51 tows were used to survey the reef margin, with deviations through the patch reefs to the north-west of the cay and at the southern edge of the eastern reef tip. Coverage of live and dead hard coral was categorised for each of the tows, with a median cover of both live and dead coral of 1-10% over the 51 tows. Highest cover of live hard coral (11-30% category) was recorded during one tow along the reef edge to the north of the cay and three tows around the eastern tip of the reef. Cover of dead hard coral was highest (31-50% category) in an area on the reef edge to the north of the cay, areas on the north-eastern and south-western reef edges and on the reef edge due west of the cay (Bass *et al.*, 1988).

A benthic line transect survey was also conducted, presumably at the north-eastern reef slope site [A: Fig.4.1] surveyed by Bradbury *et al.* (1987) as data was not collected at 12m depth. Three 100m transects were laid along the 3m and 6m contours and the benthos classified according to the 21 categories given in Bradbury *et al.* (1986). At 3m depth, total live hard coral cover was almost 5%, dead hard coral cover almost 6% and algal cover about 40%. Dead hard coral cover was similar at 6m, but live hard coral cover (almost 3%) and algal cover (about 29%) were lower (Bass *et al.*, 1988).

The reef was re-surveyed in June 1987 utilising the manta tow technique, but without the benthic line transect survey. A total of 62 tows were used to survey the reef perimeter, with the exception of the eastern tip, and the scope of observations was expanded to include estimates of soft coral and sand/rubble cover on each tow. Median categories over the 62 tows were determined, with both live and dead hard coral cover included in the 1-10% cover category, and soft coral and sand/rubble categorised as 11-30% cover. Highest live hard coral cover (31-50% category) was observed at the southern tip of the reef. Cover of dead hard coral was highest (11-30% cover) in areas along the reef edge to the north of the cay, the reef flat at the eastern tip and along the slope at the southern tip of the reef. Soft coral cover was highest (31-50% category) in areas along the northern reef edge and on the reef flat at the eastern tip of the reef (Bass *et al.*, 1989a).

Endean *et al*'s survey, 1987

Massive coral colonies within an unspecified region of Green Island reef were surveyed in February 1987 by Endean *et al.* (1988). Nine belt transects, each 30m long (along slope) and 10m wide (downslope) were located at random within the region and each massive coral colony present was measured at its maximum diameter. Each colony was also assigned to a 'damage' class: intact - 1/3 dead; 1/3 - 2/3 dead; >2/3 dead or recently killed.

From analyses of size distributions, it was concluded that recruitment of massive corals at Green Island was very low. Further, more than 50% of Porites colonies larger than 20cm diameter, and 2/3 of other massive colonies in the 21 - 50cm size class, fell in the highest damage category (Endean *et al.*, 1988).

Harriott & Fisk's surveys, 1987

The twelve sites surveyed in August/September 1986 were resurveyed in November 1987, with eight additional sites across the eastern bommie field also surveyed. Fisk *et al.* (1988) give the coral cover estimates from this survey and describe the coral community as predominantly large numbers of small (<20cm mean diameter) colonies with significant contributions from colonies regenerating following partial mortality. The dominant genus in the community was Acropora, as it was following the first outbreak, and most regeneration was from the tips of branching staghorn colonies. Small patches of tissue on massive colonies also made a significant contribution (Fisk *et al.*, 1988).

McCormick and Choat's surveys, 1988-89

In conjunction with surveys of fish abundance in May 1988 and April 1989, McCormick and Choat (1989) quantified the sessile organisms and substrata on the tops of bommies both within and outside the Green Island seagrass beds [Fig.3.1]. One 20m and two 10m line intercept transects were sampled on each of five bommies at each site, with the organisms placed into broad life-form categories. Soft corals and macroalgae were found to be the dominant components, although specific data is unpublished at present.

A.I.M.S. survey, 1989

Green Island reef was surveyed by the Australian Institute of Marine Science in February 1989 (Bass *et al*, 1989b). A manta tow technique was utilised with observers, towed for two minute periods at speeds of about 1.5kn, categorising cover of live and dead hard coral, soft coral and sand/rubble. A total of 48 tows were used to survey a clockwise path through the seagrass beds and across the sanded reef flat at a distance of about 150m from the cay until adjacent to the eastern tip of the cay; then around the reef perimeter and back across the reef flat to the south-west of the cay.

Median categories over the 48 tows were 1-10% cover for live and dead hard coral, 11-30% for soft coral cover and 51-75% for sand/rubble cover. Highest live hard coral cover (31-50% category) was observed at the southern tip of the reef. Cover of dead hard coral was highest (11-30% cover) at the eastern tip of the reef and within areas along the south-western reef edge. Soft coral cover was highest (31-50% category) in the first tow (apparently within the seagrass beds to the north-west of the cay) and at the southern tip of the reef (Bass *et al.*, 1989b).

Harriott & Fisk's surveys, 1989

The sites surveyed in November 1987 were resurveyed again in October/November 1989, although data is unpublished at present (Fisk, 1990a). In conjunction with a survey in November 1989 on the distribution of juvenile crown-of-thorns starfish at Green Island reef, Fisk (1990b) obtained estimates of hard coral cover, soft coral cover and proportion of rubble at 10 stations [F1 - F10: Fig.3.1]. These estimates, obtained using line intercept transects of 20m length, are also unpublished.

HARD CORAL TRANSPLANTS

Tibbs' transplants, 1984

In 1984, about 200 colonies of hard coral were transplanted by Mr. P. Tibbs (operator of the Green Island dive shop) from Arlington Reef to an area adjacent to the north side of the Green Island jetty. A 4m x 4m site within the transplant zone was mapped and photographed before and after the transplanting exercise. While the hard coral cover increased by only 1.3% (from 5% to 6.3%) the area was visibly different due to the presence of branching corals, which had been rare prior to the transplant operation (Harriott, 1984).

Harriott and Fisk's studies, 1985-86

In May 1985 Harriott and Fisk (in press) transplanted hard corals from Arlington and Middle Cay Reefs to a site at the north-western extremity of the reef [F5: Fig.4.1]. Both whole colonies (genera Favia, Favites, Leptastrea, Platygyra and Porites) and fragments (staghorn Acropora, plate Acropora, branching Porites, Pocillopora damicornis, Seriatopora hystrix and Stylophora pistillata) were transplanted into 2m square quadrats. Three quadrats were mapped about ten days after transplantation and 28 were mapped in July 1985. All 40 quadrats were remapped in October 1985 and surviving coral cover calculated. The experiment was terminated by the passage of Cyclone Winifred in February 1986, during which virtually all transplants were removed.

A number of further studies relating to aspects of coral transplantation to enhance rehabilitation of damaged coral reef communities were conducted by Harriott and Fisk (in press) utilising corals from Middle Cay Reef. At some time in 1985, and again between February and September 1986, the survival rates were tested of different sizes of Acropora fragments transplanted to site F5 [Fig.4.1].

An experiment was conducted over a two month period from September 1985, and again for a seven month period from February 1986, to examine differences in survival rates of branched and unbranched Acropora fragments transplanted to both fore-reef and back-reef sites on Green Island reef (specific site locations not given). Survival of fragments was higher at the back-reef than the fore-reef site during the first period, while there was no clear relationship between location and survival during the second period.

In February, May and July 1986, transplants were established at site F5 (with the May transplants in slightly deeper water) to examine the effect on survival rates of staghorn Acropora branches of varying degrees of aerial exposure during transportation. Similarly, transplanted fragments of Pocillopora damicornis were established in February (along with massive faviid colonies) and July 1986 at site F5 [Fig.4.1] following varying degrees of aerial exposure. These transplants were monitored at one or two month intervals until September 1986.

Harriott and Fisk (in press) concluded the most practical way to accelerate regrowth was by the transplantation of large (>30cm diameter) coral pieces. The use of pieces of large, branched staghorn Acropora was recommended, with pocilloporid and faviid corals also suitable. Branching poritid coral was considered unsuitable for aesthetic reasons.

HARD CORAL RECRUITMENT

Harriott and Fisk (1988) commenced a coral recruitment study in May 1985 utilising cut coral blocks as settlement plates. Plates were located at 3 - 5m depth at one fore-reef and one back-reef site at Green Island reef and at nearby Michaelmas and Upolo Reefs. At each site two wire racks were positioned 20 - 40m apart, each rack supporting eight plates which were inspected at six-monthly intervals. Plates were bleached and inspected using a dissecting microscope, with coral spat identified to family level.

Following collection and replacement of the plates in October 1985 and March and September 1986, there was evidence for a summer dominance of Acroporid recruits subsequent to the mass coral spawning period, and a winter dominance of Pocilloporid recruits. More unexpected, in the light of the reef's relatively depauperate coral fauna, was the higher recruitment at Green Island reef than at Michaelmas or Upolo Reefs, suggesting Green Island reef was not totally self-seeding and coral planulae were transported between reefs in the interval between spawning and settlement (Harriott and Fisk, 1988). In addition, spawn from Michaelmas and Upolo Reefs may have been transported away more effectively or thoroughly than spawn from Green Island reef (reviewer's comment, draft of this review).

In October 1986 the number of sites was increased to four fore-reef [R5 - R8: Fig.4.2] and four back-reef [R1 - R4: Fig.4.2] sites, with 15cm square ceramic tiles used in place of the cut coral blocks (Fisk, 1987a). At two fore-reef [R6, R8: Fig.4.2] and two back-reef [R1, R3: Fig.4.2] sites, racks were also deployed at 6m depth to determine whether coral spat settlement was depth-related (Fisk, 1990a).

Settlement plates were recovered in November 1987 and a replacement set deployed. A winter dominance of Pocilloporid recruits was again observed, with Pocilloporid spat abundances at Green Island reef about 30% of those at Upolo and Michaelmas reefs (Fisk, 1988). For the summer period, spat abundance was again higher at Green Island reef than the other two reefs, with a dominance of Acroporid recruits (Fisk, pers. comm.). Settlement plates were deployed in October 1989 and retrieved in March/April 1990 and are currently under analysis (Fisk, 1990a).

JUVENILE HARD CORALS

In November 1985, Harriott and Fisk (1989) marked-out natural substrata at sites R1, R3, R6 and R8 [Fig.4.2] to study the population dynamics of juvenile hard coral colonies (defined as colonies with mean diameters of less than 20cm). Five replicates of two substrate types - dead standing Acropora spp. plates (0.23 - 1.0m^2) and smoother limestone substrata (e.g. consolidated substrata and dead massive Porites colonies, 1.0m^2) - were studied at two depths (3m and 6m) at each site.

Juvenile coral colonies on the substrata were mapped, identified to genus level and their dimensions measured. Their presence or absence was noted in May 1986 and colonies were re-mapped and measured in September 1986.

Juvenile coral colonies were more abundant and recruitment was higher at the back-reef site, while growth rates were consistently higher at the fore-reef site. Acropora species were the most dominant and successful recruits, with greatest abundances, recruitment rates and growth rates (Harriott and Fisk, 1989).

Colonies were remapped and measured on an annual basis - in November 1987 (Fisk, 1988), November 1988 (Fisk, pers. comm.) and November 1989, with this data added to an established database (Fisk, 1990a).

CORAL SPECIES

Appendix 3 lists the coral genera and species appearing in the published literature on Green Island reef. Cornelius (1982) includes species lists of both hard and soft corals in the Cairns region from surveys conducted by members of the Queensland Fisheries Service (now the Fisheries Branch of the Queensland Department of Primary Industries) and the Queensland National Parks and Wildlife Service. While he considers the list to be directly applicable to Green Island reef he does not denote the species actually recorded there, so these lists have not been included in Appendix 3.

The soft coral species list compiled by R. Garrett (Queensland Fisheries Service) for the Cairns region, which is included in Cornelius (1982), shows high soft coral diversity - 6 orders, 22 families, 47 genera and 114 species recorded, 16 of which were new to science when listed. However, this list applies to the entire Cairns region and not specifically to Green Island reef as suggested by the Green Island Management Committee (1980) and the Australian Littoral Society (1982, 1990).

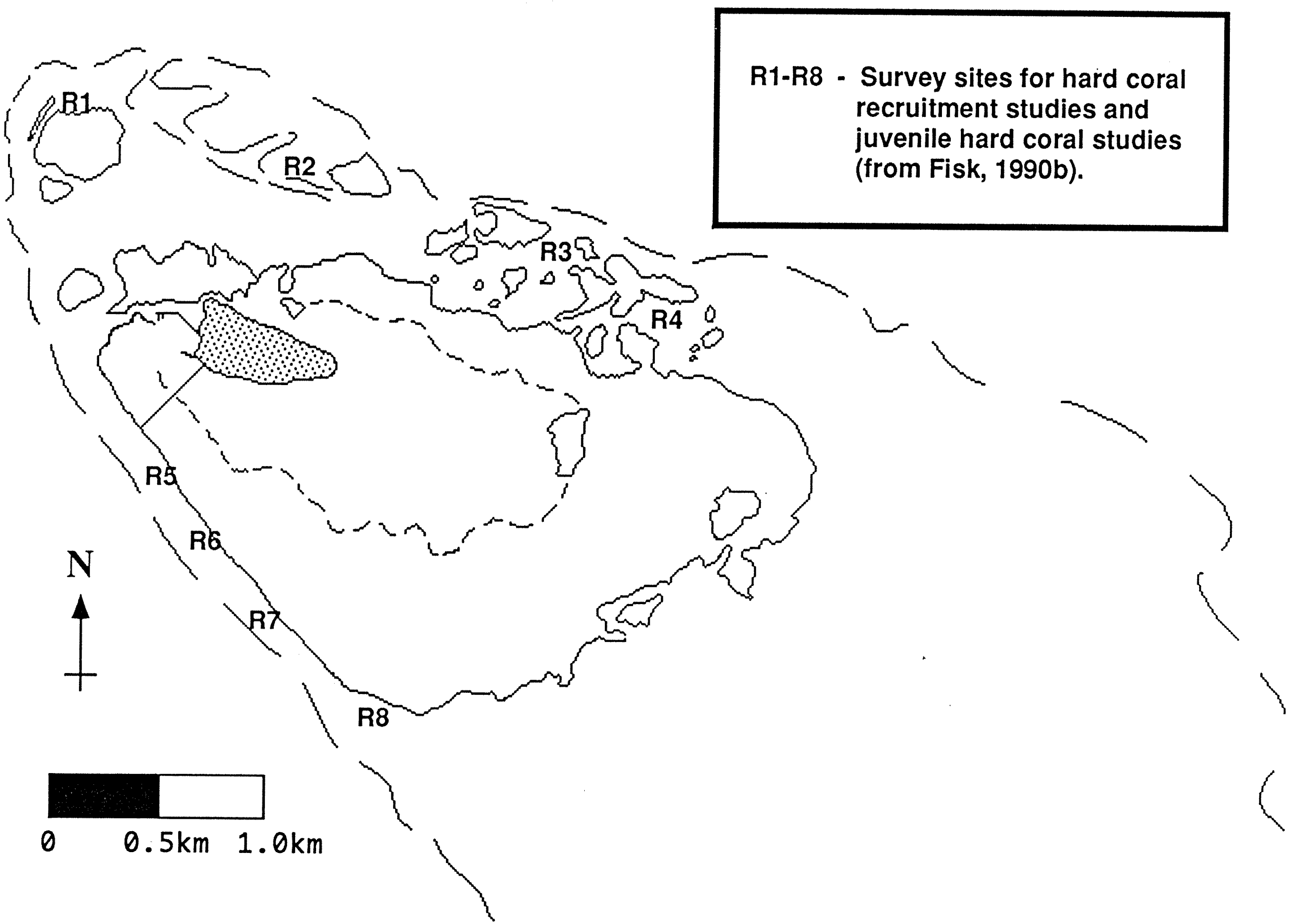


Figure 4.2 **Location of juvenile hard coral population dynamics study sites**

Chapter 5 FISH

A small boat survey conducted by the Queensland Fisheries Service in 1978 showed Green Island reef to be the most heavily visited reef in the Cairns region, being visited by 35% of the boats operating out of Cairns. Average catch/boat was 4 fish (Australian Littoral Society, 1990). The Green Island Management Committee (1980) refer to depletion of large demersal carnivore stocks due to fishing. Average catch/boat was 4 fish (Australian Littoral Society, 1990). Economic Associates Australia (1983) considered the depletion in stocks of large individuals of some species to be the only major human impact on Green Island and its reef.

I have been unable to locate a published species list for the fish of Green Island reef. Cannon and Goeden (1983) provide a species list of the bottom-dwelling fish netted during their 1980 benthic survey of stations around Green Island, although these were taken from depths between 30m and 50m at considerable distances from the reef itself. A list of the 90 species recorded on Green Island by McCorkick and Choat (1989) is available from Mark McCormick (James Cook University), although this was not received in time to be included in this review.

Ayling's trout survey, 1983

A coral trout survey was conducted by Ayling (1983) in February 1983 at sites positioned randomly along the south-western edge of the reef (specific site locations are not given). Two survey techniques were employed - hectare counts (5 replicates) in which 150m x 67m areas were intensively searched, and 50m x 20m belt transects (10 replicates). The water depths at which the counts were made are not given.

The hectare counts yielded mean trout densities of 13/ha for Plectropomus leopardus (common coral trout) and 0.2/ha for Plectropomus melanoleucas (footballer trout). The latter species has since been recorded by Ayling and Ayling (1986) as 'Plectropomus laevis, footballer form'. The belt transect counts yielded trout densities of 19/ha for P. leopardus and 1/ha for P. laevis. Pooling the hectare counts and belt transect counts, P. leopardus recruits were found at a density of 1.7/ha.

In an analysis of the effect of fishing pressure on P. leopardus numbers, based on the hectare count data, Green Island reef was classified as a high-fishing reef. Within this classification, P. leopardus numbers were highest on Green Island reef (13/ha) and were very similar to the mean numbers recorded within the low-fishing classification (12.5 ± 1.24/ha) (Ayling, 1983).

Goeden's trolling survey, 1984-85

While the Marine National Park 'B' Zone at Green Island reef is closed to recreational and commercial fishing under the Great Barrier Reef Marine Park Authority's Zoning Plan, mackerel fishing is conducted within the Marine National Park Buffer Zone around the perimeter of the reef. Trolling is generally undertaken along the 10 fathom (18m) contour (Goeden, pers. comm.).

A project to assess the impact of trolling in Marine National Park Buffer Zones was conducted in the Green Island - Arlington Reef area by Goeden (1986) over the 1984 and 1985 commercial mackerel fishing seasons (October - December). Scomberomorus commerson (narrow-barred spanish mackerel) accounted for 92% of the catch, with the remainder Caranx and Carangoides species (both trevally), Sphyraena barracuda (barracuda) and Grammatocynus bicarinatus (shark mackerel). Size distributions, depth at capture (troll catches occurred only between 8 and 20m) and stomach contents of the catches were analysed. Stomach contents of the S. commerson caught were 93% fish, 4% crustacean and 3% mollusc remains, while the other species had either empty guts or unidentifiable stomach contents (Goeden, 1986).

McCormick and Choat's survey, 1988-89

Estimates of juvenile and adult fish abundances within and outside the Green Island seagrass meadows were made by McCormick and Choat (1989) in May 1988 and April 1989. The fish populations on each of five bommies within two seagrass meadow sites and two sites outside the meadows [Fig.3.1] were estimated using a visual strip transect technique.

The numbers of fish species recorded within (88 species) and outside (81 species) the seagrass meadows were similar, although a significantly higher number of juveniles were associated with the seagrass meadows. The abundance of adult fishes was greater at the Green Island reef sites than at sites on neighbouring Arlington Reef. While McCormick and Choat (1989) considered this may have been a function of the greater protection afforded to Green Island reef through the Great Barrier Reef Marine Park zoning, they felt greater recruitment of juveniles to Green Island suggested an effect of the seagrass meadows. A reviewer of the draft Green Island Information Review disputed this opinion and suggested that the seagrass meadows were merely a preferred habitat for juveniles within Green Island reef, with protection from fishing the main factor responsible for the greater numbers of adults and therefore of juveniles.

McKenzie's study, 1989-90

Since May 1989, L. McKenzie of the Queensland Department of Primary Industries Northern Fisheries Research Centre, Cairns, has been examining the diversity and abundance of the juvenile fish fauna associated with the Halodule uninervis/Cymodocea serrulata seagrass meadow on the north-west corner of the reef. Sampling has been on a 3-monthly basis using a beam trawl 1.5m wide and 0.5m high with 2mm mesh towed over 50m transects at approximately $0.5ms^{-1}$. Sampling is expected to continue until March 1992 (McKenzie, pers. comm.).

Chapter 6 OTHER FAUNA

While Kenchington (1981) mentioned that the Great Barrier Reef Marine Park Authority would be conducting biological surveys of Green Island reef 'later in 1979', I have been unable to locate data from any such surveys. Similarly, the Green Island Management Committee (1980) refers to surveys by the Queensland Fisheries Service (now the Fisheries Branch of the Queensland Department of Primary Industries) of demersal reef fish and crown-of-thorns starfish, and mapping of the overall coral reef community zonation, the results of which do not appear to have been published.

TURTLES

Mr J. Miller (Queensland National Parks and Wildlife Service) considers knowledge of the turtles at Green Island to be scarce, with 'numerous opinions about them...(but)...no published synthesis'. From his work on the turtle population, along with interviews with long-term residents, he has determined the presence of two species of turtles at Green Island reef - green turtles (Chelonia mydas) and hawksbill turtles (Eretmochelys imbricata). Juvenile, subadult and adult hawksbill turtles have been recorded as living on the reef, although population size is undetermined. While juvenile and subadult green turtles have been recorded, there appears to be no adults - possibly an artefact from local hunting (Miller, pers. comm.).

The Green Island Management Committee (1980) noted that while immature green and hawksbill turtles used the reef surrounding Green Island as year-round feeding grounds, the cay was not considered to be a turtle nesting area. However, Miller (pers. comm.) determined from an interview with long-term resident G. Craig that green turtle nesting had occurred in 1974/75 (2 individuals) and 1984/85 (1 individual which nested 7 times). It was noted that these coincided with the 'big nesting seasons' when large numbers of green turtles nested at all the major rookeries, many of the cays and along the mainland of eastern Australia (Miller, pers. comm.).

ASCIDIANS

Kott (1980) lists six species of algal-bearing didemnid ascidians from Green Island reef:

- Trididemnium miniatum
- Lissoclinum voeltzkowi
- Lissoclinum bistratum
- Lissoclinum punctatum
- Diplosoma virens
- Diplosoma similis

CRUSTACEANS

Since May 1989, L. McKenzie of the Queensland Department of Primary Industries Northern Fisheries Research Centre, Cairns, has been examining the diversity and abundance of caridean shrimps and penaeid prawns associated with the Halodule uninervis/Cymodocea serrulata seagrass meadow on the north-west corner of the reef. Sampling has been on a 3-monthly basis using a beam trawl 1.5m wide and 0.5m high with 2mm mesh towed over 50m transects at approximately $0.5ms^{-1}$. Sampling is expected to continue until March 1992 (McKenzie, pers. comm.).

ECHINODERMS

Saville-Kent (1893) noted that Green Island was a central station for the collection and curing of all of the most valuable commercial species of beche-de-mer. A representative series of these holothurians was collected and contributed to the British (Natural History) Museum. The commercial species of beche-de-mer were listed as:

Actinopyga echinites	A. mauritania
A. lecanora	A. polymorpha
Holothuria argus	H. impatiens
H. atra	H. mammifera
H. botellus	H. marmorata
H. coluber	H. sanguinolenta
H. edulis	H. vagabunda
H. fusco-cinerea	H. vitiensis
Stichopus chloronotus	
S. lutea	
S. variegatus	

Endean (1957) listed Holothurida rigida as present at Green Island. One species of ophiuroid (Ophiocoma brevipes) and one species of echinoid (Cyrtechinus verruculatus) were also listed specifically for Green Island by Endean (1957).

Cornelius (1982) gave a species list for the echinoderms of Green Island reef, provided by either the Queensland Fisheries Service or the Queensland National Parks and Wildlife Service (source not specified), but warned that it was not for publication as 'much of the Service's survey information is unpublished by those people currently working on projects in the area'.

McCormick and Choat (1989) surveyed the abundance of certain genera of sea urchins (Diadema spp. and Echinothrix spp.) on bommies within and outside the Green Island seagrass beds [Fig.3.1] in May 1988 and April 1989. Three 10m x 4m strip transects were searched in detail on five bommies at each site. Highest densities of Diadema spp. were located on the westernmost bommies surveyed within the seagrass beds, bommies around which were the most clearly defined bare sand 'halos'.

MOLLUSCS

The prosobranch gastropod Trochus niloticus was studied at Green Island in 1984 by Nash (1985). Trochus shells formed the basis for a small export trade with European and Asian mother-of-pearl industries, but there has been no Trochus fishing at Green Island since the reef was declared a Marine National Park, under Queensland legislation, in 1974. Nash (1985) surveyed the distribution of Trochus around Green Island reef using both line transect and fixed-time swim methods [Fig.4.1]. The highest stocks were found at 1m - 3m depth along the south-western reef edge. Further studies were made of Trochus growth rates, spawning, morphometrics and predation, both in the field and under laboratory conditions at the Queensland Department of Primary Industries' Field Station.

The presence of the corallivorous gastropod Drupella was noted by Fisk (1990b) during a survey of juvenile crown-of-thorns starfish in November 1989. Drupella were found on live coral colonies and in the rubble at 12 of the 20 sites surveyed, with their abundance and wide distribution considered a 'significant finding'. It was noted that most feeding scars on the live corals were the result of Drupella feeding activity. While individuals were not counted, approximate numbers of groups of the gastropods or patches of feeding scars were recorded (Fisk, 1990b). These data are unpublished at present.

A list of some of the other molluscs of Green Island reef - from Blakey (1980) and Collins (1984, 1985a,b; 1986, 1987, 1988a,b,c; 1989) - are included in Appendix 4.

OTHER INVERTEBRATES

Records of many planktonic invertebrates, mainly cnidarians, observed by Dr J. Barnes in Green Island waters have been transcribed from his original notes by B. Kinsey (Sir George Fisher Centre, James Cook University of North Queensland).

Cannon *et al.* (1983) provide species lists of the benthic poriferans, cnidarians, molluscs, crustaceans and echinoderms netted during surveys of inter-reefal stations in the vicinity of Green Island reef in February 1987, October/November 1979 and October 1980. These surveys were made at water depths between 30m and 55m, and many of the stations were a considerable distance from the reef itself.

Chapter 7 SEAGRASSES

Seagrass meadows are prominent in aerial photographs of Green Island reef, particularly on the inshore flat to the north and north-west of the cay [Fig.1.2]. The dominant species within these dense meadows are Halodule uninervis and Cymodocea serrulata (Mellors, pers. comm.), with many species of blue-green and coralline algae associated with them (Kuchler, 1978). Though less apparent in photographs, low-density meadows (mainly Cymodocea rotundata and Thalassia hemprichii) are also widespread over much of the remainder of the reef flat (Mellors, pers. comm.). Table 7.1 lists the seagrass species recorded for Green Island reef.

Through photographic interpretation, Kuchler (1978) estimated the area of seagrass meadows to have increased markedly over the previous three decades [Table 7.2]. Hopley (1982) and Gourlay (1983) considered this increase to be a consequence of the discharge of sewerage effluent from the cay's resort, which has generally taken place at the south-western reef edge [Fig.2.1]. Following discussions with long-term residents of Green Island, which revealed that the sewerage outlet may once have been to the north of the cay, Kuchler (1978) unearthed effluent particles stored in the upper 20cm of sediment on the northern sand flat where seagrass was established.

Another possible contributing factor to the apparent expansion of the seagrass meadows may have been the redistribution of the fine sediments used in beach replenishment programs in 1973 and 1975. During winter, the prevailing south-easterly currents carried the sediment from the unprotected south-western beach to the north-west of the cay where it was deposited, providing an excellent substrate for seagrass colonisation (Kuchler, 1978).

The possibility also exists that, due to ecological succession within the seagrass community, the increase in seagrass meadow area may be only an apparent increase rather than a real increase. If they were present, the low-density Cymodocea rotundata/ Thalassia hemprichii meadows would have been difficult to detect in the early low-quality photographs from which Kuchler (1978) estimated seagrass meadow areas. These beds may then have been progressively replaced to the north-west of the cay by the more dense Cymodocea serrulata / Halodule uninervis meadows.

TABLE 7.1: Seagrass species recorded on Green Island reef.

SPECIES	LOCATION	SOURCE
Cymodocea rotundata	Southern flat	Mellors (pers. comm.)
Cymodocea serrulata	- North-western, northern and southern flat	Kuchler (1978) Mellors (pers. comm.)
Halodule uninervis	- North-western, northern and southern flat	Kuchler (1978) Mellors (pers. comm.)
Halophila ovata/ovalis	- North-western, northern and southern flat	Kuchler (1978) Mellors (pers. comm.)
Syringodium isoetifolium	Uncommon	Mellors (pers. comm.)
Thalassia hemprichii	- North-western, northern and southern flat	Kuchler (1978) Mellors (pers. comm.)

TABLE 7.2: Estimated areas of 'marine grass growth', 1945 - 1978 (from Kuchler, 1978).

YEAR	AREA (ha)
1945	0.09
1946	0.27
1959	1.48
1969	2.58
1972	3.89
1973	4.37
1978	13.56

SEAGRASS PRODUCTIVITY

Rates of productivity along transects through the seagrass meadows to the north-west of the cay were estimated in September 1988 by Baxter (1988, 1989). A floating data logger was utilised to determine productivity rates from changes in oxygen content, *p*H and temperature of water bodies traversing the meadows. The data are unpublished at present. Rates of calcification and calcium carbonate dissolution were also determined, and net dissolution was observed during both daytime and night-time traverses.

TIDES

The tides at Green Island are described by the Beach Protection Authority (1989) as mixed, semi-diurnal with a maximum range of 3.27m from Highest to Lowest Astronomical Tide.

Tidal planes for Green Island are given in Table 8.1. Heights relative to Local Low Water Datum (the mean of the Lower Low Waters, below which the tide seldom falls) are given by the Department of Harbours and Marine (1989); heights relative to the Australian Height Datum (Derived) are from the Beach Protection Authority (1989). The Australian Height Datum (Derived) was transferred by trigonometric heighting from Fitzroy Island and the mainland and was not determined by long term tidal measurements at Green Island (Beach Protection Authority, 1989).

Table 8.1: Tidal planes (in metres) for Green Island relative to Local Low Water Datum (L.L.W.D.) and Australian Height Datum (Derived) (A.H.D.(D)). Sources: Department of Harbours and Marine (1989), Beach Protection Authority (1989).

TIDAL PLANE	L.L.W.D.	A.H.D.(D)
Highest Astronomical Tide	3.18	1.46
Mean High Water Springs	2.20	0.48
Mean High Water Neaps	1.60	-0.12
A.H.D.(D)	1.72	0.00
Mean Sea Level	1.37	-0.35
Mean Low Water Neaps	1.10	-0.62
Mean Low Water Springs	0.50	-1.22
Lowest Astronomical Tide	-0.09	-1.81

Conversion of tidal predictions for Cairns (Green Island's standard port) is via the equation:
Height (Green Island) = [0.95 x Height (Cairns)] - 0.04m

(Department of Harbours and Marine, 1989)

On average, high and low waters occur 18 minutes earlier at Green Island than at Cairns (Department of Harbours and Marine, 1989).

WATER TEMPERATURE

Wolanski and Pickard (1985) measured water temperatures to the north-west of Green Island during their 1980/82 water current studies. Water temperature was generally 27 - 30°C during the summer months and 22 - 24°C during winter. However, they did note that water temperatures during the trade-wind season of 1982 were mostly 0.7 - 2.0°C lower than in 1980 or 1981, which they speculated may have been linked to the El Nino Southern Oscillation phenomenon apparent that year.

WATER CURRENTS

Wolanski and Pickard's study

From June 1980 to September 1982, Wolanski and Pickard (1985) measured water currents to the north-west of, and at an unspecified distance from, Green Island. Measurements were made at half-hourly intervals by a remote current meter situated 11m above the bottom in 35m water depth. They used this data to construct a simple model of the currents around Green Island to tentatively demonstrate that observed large seasonal and interannual fluctuations in current were due to a local on-shelf balance between winds and current in conjunction with fluctuations in Coral Sea circulation.

Beach Protection Authority study

Observations of wave and current conditions at four stations along the western end of the cay [Fig.1.3] were made by employees of the Green Island Reef Resort for the Beach Protection Authority from November 1982 until September 1987. The recording strategy was adapted from the Authority's Coastal Observation Program Engineering and parameters included average wave height, period and direction, and longshore current direction and velocity (from observation of a dye patch). Data from February 1983 to September 1987 are presented in Beach Protection Authority (1989).

Wave conditions around the western end of the cay were found to be quite complex. In general, waves came around the southern and northern sides of the cay and met at the north-western spit, indicating that the dominant wind and swell direction was from the south to south-east. Along with the measured current conditions, these observations were consistent with south-western erosion and north-western accretion at the cay (Beach Protection Authority, 1989).

Black and Gay's study

Black and Gay (1987) modelled the small scale hydrodynamics around and over Green Island reef using wind-current-tidal (WCT) simulations. The cay and large expanse of sub-tidal reef combined to produce complex patterns of flow on the reef in the lee of the cay. During flood tide, blockage due to the cay and high friction over the reef caused flow to travel around rather than over the reef, and the cay, leading to the formation of a strong eddy for some six hours during most of the ebb and the beginning of the flood tide.

Hillman's study

Mr. S. Hillman of the Great Barrier Reef Marine Park Authority utilised the data of Wolanski and Pickard (1985), with a computer model devised by Wolanski, to look at smaller-scale water movements around the cay itself. The model was run for several days during spring and neap tides occurring in November 1980, January 1982 and April 1982 - considered to be representative of conditions commonly experienced at Green Island. While Hillman acknowledged the limitations of the model, such as its depth-averaged nature, he drew some conclusions following discussion of the results with Wolanski. These include low flushing of the seagrass meadow area to the north-west of the cay during the summer months (when water flow is predominantly from the north-west) due to 'upstream blocking', but fairly good flushing of this area in the winter months (water flow from the south-east) (Hillman, pers. comm.).

Dight's study

Dight *et al.* (unpubl. ms.) modelled water movements within the Great Barrier Reef lagoon, including the Cairns region, to simulate the dispersal of larvae of the crown-of-thorns starfish, Acanthaster planci. Simulations under a variety of different hydrodynamic regimes showed strong connectivity between Green Island reef and the reefs off Innisfail - including Gibson, Howie, Feather and Peart reefs.

van Woesik's study

The small scale water flow around Green Island reef flat was studied by van Woesik (1990) as part of the Green Island Reef Multidisciplinary Study (Baxter, 1988). Measurements were made in April and September 1988 using tracer dye to determine current direction and current meters to determine current speeds at approximately 2m depth.

Survey site locations are shown in Fig.8.1. The preliminary data suggested that the predominant currents around Green Island were mainly wind driven, as currents did not reverse over various tidal cycles.

During south-east winds current flow was predominantly to the north-west during both flood and ebb tides. High retention areas were located in the lee of the cay [site 13: Fig.8.1], with double vortices recorded on the flooding tide. While these retention areas corresponded to the main seagrass meadow areas, van Woesik (1990) regarded these findings as 'speculative since no water quality information is available'.

During light north-east winds and a flooding tide, an anti-clockwise current flowed around the cay resulting in a poorly-flushed area over the southern reef flat. This area was considered to be continually exposed to the discharge plume from the sewer outfall.

SEWAGE DISPERSAL

Allan and Johns' study

One aspect of a study conducted by Allan and Johns (1989) in August 1987 and July 1988 was to determine the distribution in the water column and sediments of the biomarker coprostanol, which is unique to human sewage waste. Samples were collected from a number of sites [Fig.8.2] using horizontal particulate tows, benthic sediment sampling and sediment coring, with analysis utilising gas chromatography and gas chromatography-mass spectrometry.

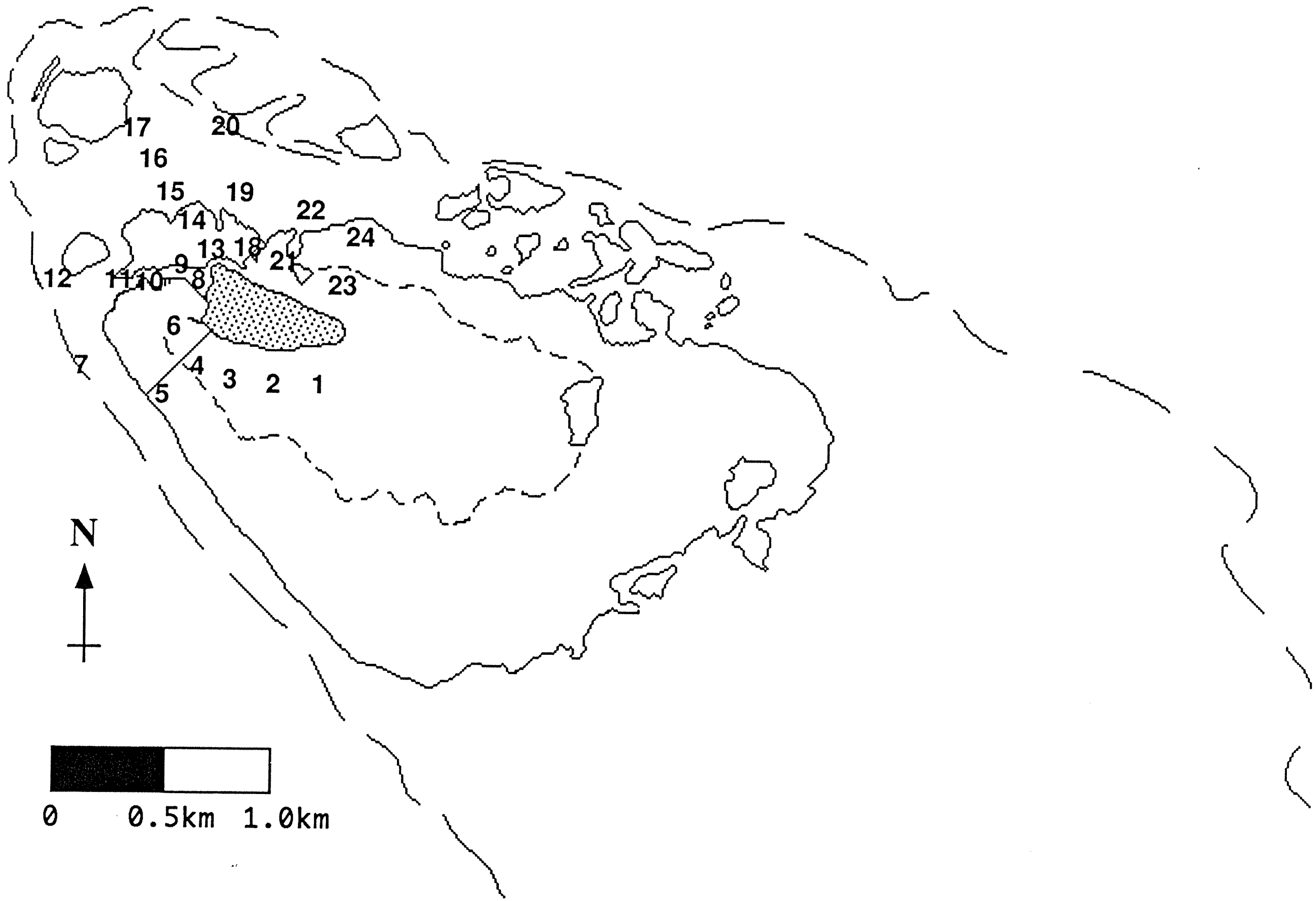
Coprostanol was detected at one site only - adjacent to the sewer outfall [site A15: Fig.8.2]. Allan and Johns (1989) concluded that sewage was probably dispersed (by tides and currents) and/or consumed fairly rapidly through oxidising conditions in the sediments.

van Woesik's study

Advection and dispersal of the sewer outfall plume was investigated by van Woesik (1990) and co-workers in April 1988. Dye was injected simultaneously at toilets within the resort and within the public toilet block, with bags containing activated charcoal positioned at several locations around the reef [Fig.8.2] to detect dye both qualitatively and quantitatively.

A dye plume was first visible about three hours after injection, indicating minimal treatment-response-discharge time for the sewage. Dye plumes were observed at approximately half hour intervals throughout the following two days, consistently passing 50m from the end of the jetty at a bearing of 330^{o}. The dye plumes appeared to be unstratified down to 6m depth.

Further investigations in September 1988, when dye was released at the sewer outlet, revealed significant retention of dye/effluent in the lee of the cay for a period of up to 18 hours (van Woesik, 1990).



<u>Figure 8.1</u> **Location of van Woesik (1990) hydrodynamic survey sites**

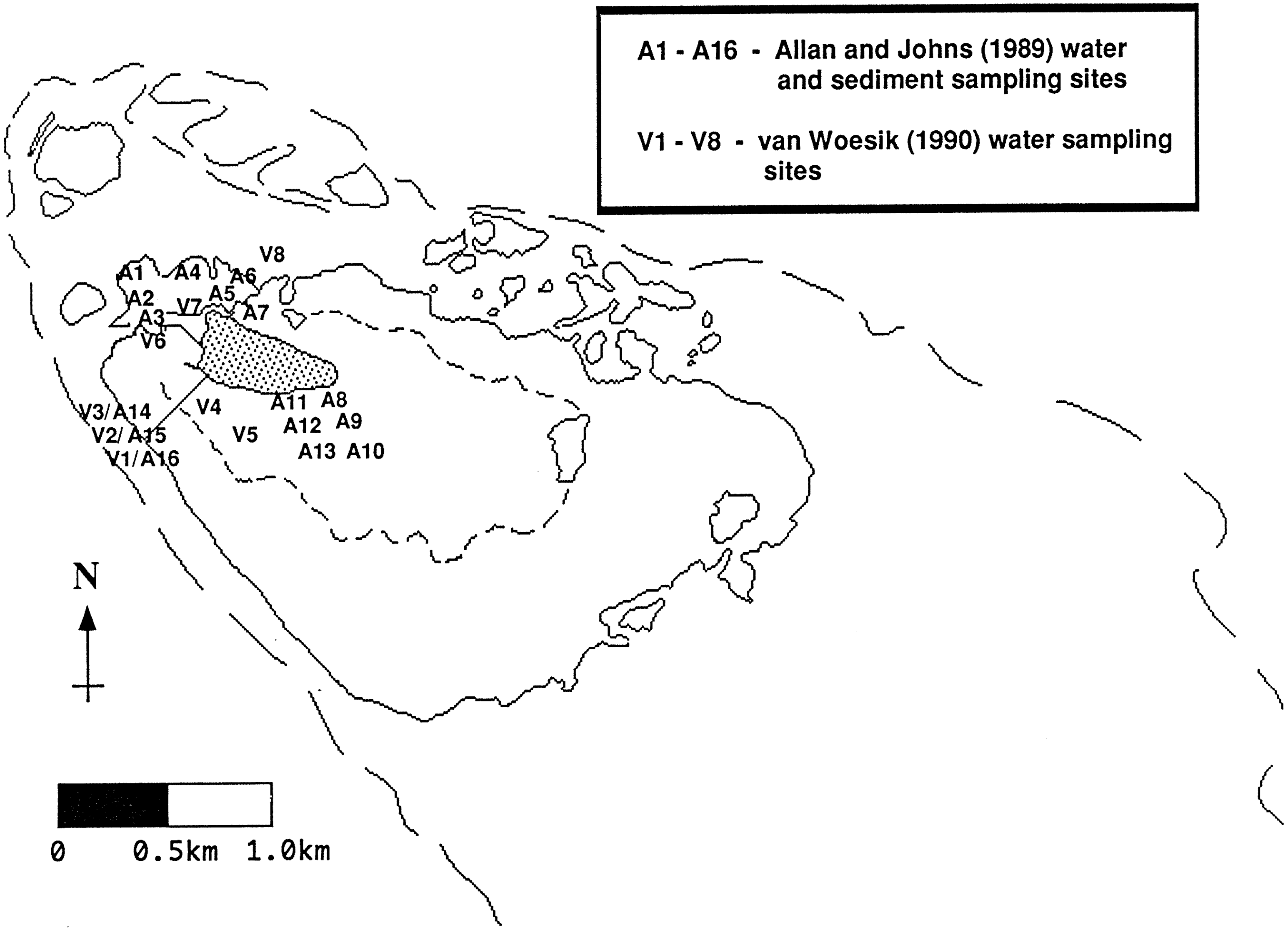


Figure 8.2 Location of sewage dispersal study sites

Chapter 9 WATER QUALITY

This section summarises research conducted at Green Island into both nutrients and hydrocarbons - two major determinants of water quality.

Within the past decade there has been increasing awareness about the possible deleterious effects on the Great Barrier Reef of elevated nutrient levels. A Great Barrier Reef Marine Park Authority workshop was held in 1987 in response to 'higher than average' levels of phosphorus and nitrogen in some localised areas of the Great Barrier Reef Marine Park (Kelleher, 1988). Green Island provided a focus for one discussion group as the reef environment was generally considered to be severely degraded, with circumstantial evidence linking this degradation to changes in nutrient levels (Zann and Day, 1988). Kinsey (1988) considered it likely that the progressive degradation of Green Island reef could reflect in part the influence of coastal water degradation, with the influence of localised nutrient enhancement from the sewer outfall 'generally accepted as being pronounced'.

An earlier workshop, also arranged by the Great Barrier Reef Marine Park Authority, focused on heavy metals, PCB's and hydrocarbons in the waters of the Great Barrier Reef Marine Park. It was concluded that levels of these contaminants were so low as to be barely measurable (Dutton, 1985). However, it is not surprising that measurable levels of hydrocarbons have been detected at locations frequented by power craft, such as the mooring areas of Green, Heron and Lizard Islands (Smith *et al.,* 1987).

NUTRIENTS

Rasmussen's studies

Water samples were collected from Green Island reef by the Queensland National Parks and Wildlife Service in April 1988 and March 1989 and analysed for phosphate, nitrate, nitrite, ammonia and dissolved silica (Rasmussen, 1988). In addition, sediment samples were collected in April 1988 and analysed for trace elements and nutrient desorption (Rasmussen, 1990). Phosphate levels in the water samples were found to be close to those regarded as capable of hampering calcification in hard corals, and it was suggested this may have been due to the agitation of the nutrient enriched sediments associated with the seagrass meadows (Rasmussen and Cuff, unpubl. ms).

To test the hypothesis that enhanced levels of nutrients in a marine environment may be recorded in coral skeletons as a change in skeletal chemical composition, coral cores were collected from Porites colonies at Green Island by Rasmussen (1990). These were analysed using Atomic Absorption Spectrometry for calcium, sodium, magnesium, potassium and iron content. Seasonal bands in the skeletons were studied using spectrofluorometric methods and X-radiography (Rasmussen and Cuff, unpubl. ms). It was noted that calcium carbonate precipitation had fluctuated considerably since the early 1940s,while magnesium precipitated into the skeletons had increased dramatically during the 1960s (Rasmussen and Cuff, unpubl. ms).

Allan and Johns' study

To gather information on nutrient levels and availability in the Green Island reef system, Allan and Johns (1989) performed protein and phosphorus analyses upon surface sediment samples collected from a number of sites [Fig.8.2] in August 1987 and July 1988. Details of the protein analysis technique employed are not given, while phosphorus analysis was conducted through the vanadium-molybdenum spectrometric method and the ascorbic acid method.

Protein levels were found to be very low, as were levels of free phosphorus, while virtually no acid hydrolyzable phosphorus was detected. A higher nutrient status of the seagrass meadow sediments was indicated by higher phosphate levels, although they did not consider the meadows to be acting as a sink for anthropogenic inputs through the trapping of particulates and sediment. The higher phosphate levels were attributed to the high primary production of macrophytes and possibly to the inlet/outlet pipes of the marineland. No reasons for the expansion of the seagrass meadows could be derived from the analytical data (Allan and Johns, 1989). Data from the study are unpublished at present.

Brady's study

Water samples were collected by Brady (1989) along a transect from the Barron River mouth to Green Island between September 1988 and December 1989. These were analysed for inorganic phosphate, total phosphorus, nitrate, nitrite, ammonia, dissolved oxygen, dissolved organic carbon and salinity. At the Green Island station, to the north-west of the cay [B: Fig.9.1], samples were collected at 10cm, 4m and 8m depths in September and November 1988, March 1989 and monthly between June and December 1989. For the samples collected between September 1988 and September 1989, mean phosphate and nitrate values were comparable to those reported by Steven *et al.* (1989). Mean total phosphorous was higher, and mean ammonia lower, than those values given by Steven *et al.* (1989). Data from Brady (1989) are unpublished at present.

Steven, Brodie and van Woesik's studies

In response to preliminary findings from the Green Island Multidisciplinary Study, which indicated a potential for sewerage effluent to be retained by eddies in proximity to areas of enhanced seagrass growth (van Woesik, 1989), Steven *et al.* (1989) conducted a pilot study of baseline levels of water quality around the reef. As a precursor to a comprehensive study of water quality at Green Island, the pilot study was undertaken to assess the spatial and temporal variation of a range of water quality parameters and to evaluate which parameters would be of most use in assessing water quality.

Field measurements were undertaken in June 1989 at a number of sites around the reef [Fig.9.1]. Nutrients (nitrate, nitrite, ammonium, orthophosphate (reactive phosphorus), total nitrogen, total phosphorus, particulate nitrogen), biological parameters (chlorophyll *a* , biological oxygen demand (5 days)) and physico-chemical parameters (suspended solids, clarity, dissolved oxygen, temperature) were measured (Steven *et al.*, 1989).

Higher concentrations of dissolved inorganic nitrogen (DIN) were recorded at the windward locations [S4, S6: Fig.9.1], with a significantly lower concentration on the north-eastern side of the reef in an area of patch reefs [S5: Fig.9.1]. Ammonium and DIN were found to vary significantly with respect to time of day and also between days. Particulate nitrogen and biological oxygen demand were considered unsuitable as parameters to be measured in the baseline study due to 'analytical problems and prohibitive costs' (Steven *et al.*, 1989).

While Steven *et al.* (1989) found no significant changes in ambient water quality which could be attributed to sewage discharge, phosphate levels were higher in the vicinity of the sewer outfall.

HYDROCARBONS

Hydrocarbons from petroleum products can be lethal to larval, juvenile and adult stages of some marine organisms, while sublethal levels may effect their behaviour and reproduction (Smith *et al.*, 1987).

Smith, Bagg and Sin's study

Smith *et al.* (1987) analysed samples of seawater, sediment and clams from Green Island reef for the presence of polycyclic aromatic hydrocarbons. The samples, taken during March 1983, showed only low levels of contamination which they attributed to fuel spillage and exhaust emission from power boats visiting the reef. Airborne and seaborne input of hydrocarbons from the adjacent mainland were considered to be insignificant.

Sediment samples were collected by divers from the top 2cm of the sediment layer at 21 sites [H1 - H21: Fig.9.1], while water samples were collected at seven of the sites [H1, H3, H4, H6, H7, H14, H16: Fig.9.1] and specimens of clams at six of the sites [H1, H5, H6, H11, H12, H14: Fig.9.1]. Significant hydrocarbon concentrations were detected, by high-performance liquid chromatography, in only four sediment samples [H15, H16, H17, H19: Fig.9.1], while only three water samples [H1, H6, H16: Fig.9.1] contained measurable concentrations. None of the clam samples contained detectable hydrocarbon concentrations. Concentration ranges of some of the hydrocarbons detected are given in Table 9.1.

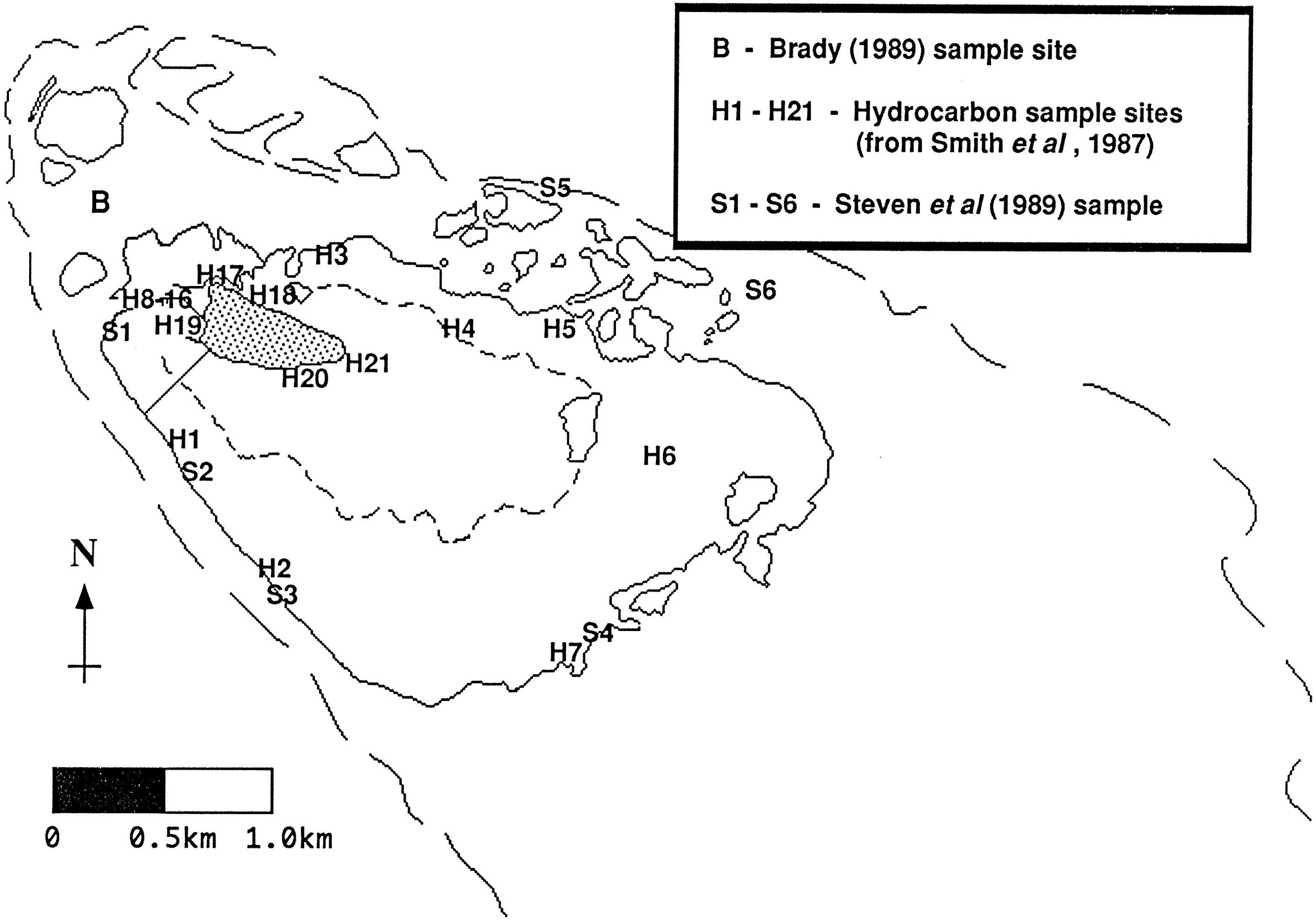


Figure 9.1 Location of water quality sample sites

Table 9.1: Concentration ranges of some polycyclic aromatic hydrocarbons at Green Island (from Smith *et al.*, 1987).

	WATER (ng l^{-1})	SEDIMENTS ($ug\ kg^{-1}$ dry wt)	CLAMS ($ug\ kg^{-1}$ wet wt)
Pyrene	53 - <1	15 - <1	<0.03
Anthracene	25 - <1	1.0 - <0.06	<0.05
Benzo(a)pyrene	6 - <0.2	4.3 - <0.004	<0.004

All four of the sediment samples and one of the water samples came from the main boat mooring area to the west of the cay, and fluorescence spectroscopy of the water sample indicated refined oil products as the most likely source of the hydrocarbons. Another of the 'positive' seawater samples was not from the mooring area but only 350m southeast of the sewerage outfall (polycyclic aromatic hydrocarbons have been reported in sewage effluent), although hydrocarbon levels in the corresponding sediment samples were not significant. The third 'positive' seawater sample was from the eastern reef flat, but no explanation is offered for the detection of hydrocarbons there (Smith *et al.*, 1987).

Johns' study

A benthic sediment survey was conducted by Johns (1988) in June 1987 along a transect from Cairns Harbour to Arlington Reef. The closest sampling site to Green Island was about 7km to the west. Benthic grab samples were analysed using gas chromatography-mass spectrometry for biomarkers for terrigenous and anthropogenic materials.

While the bulk of fluvially discharged terrigenous organic matter was confined to sediments within 10km of the mainland, traces were detected in the lagoon sediments of Arlington Reef. This was taken to indicate the potential for the transport to nearshore reefs of terrigenous pollutants adsorbed onto suspended particles. There was evidence for anthropogenically derived hydrocarbons, 'probably of petroliferous origin', near Cairns Harbour, although these appeared to extend no more than 20km from shore (Johns, 1988).

Allan and Johns' study

Biomarkers indicative of petroliferous hydrocarbon input were detected by Allan and Johns (1989) in samples from horizontal particulate tows and sediments from the jetty area [site 12: Fig.8.2] and from the main seagrass meadow area [site 15: Fig.8.2]. These samples were collected in August 1987 and July 1988, and analysed using gas chromatography-mass spectrometry

They considered the distribution of the biomarkers to be suggestive of movement of exhaust hydrocarbons from the jetty area and accumulation in a 'westerly-northerly arc' around the cay. Mainland derived terrestrial and anthropogenic inputs to Green Island sediments were considered possible but unlikely. Data from the study are unpublished at present.

Chapter 10 TOURISM

Pre-1900

The first recorded recreational use of Green Island, following its initial use by beche-de-mer fishermen, appears to have been in the late 1880s. By 1889 there were several grass huts to accommodate fishing and hunting parties, and organised pleasure cruises began in 1890 (Jones, 1976).

1900 - 1950

The first jetty on Green Island was constructed in 1906 by the Cairns Harbour Board following proclamation of the cay as a recreation reserve under the control of Cairns Town Council (Green Island Management Committee, 1980).

In 1924 the Hayles company commenced a fortnightly passenger ferry service from Cairns (Australian Littoral Society, 1982; Robinson, 1984). There are no published records of visitation rates in these early years.

The Cairns Town Council constructed a new jetty in 1931 and this was followed by the construction of huts and toilets for visitors (Jones, 1976). Another new jetty, also a kiosk and cottage were built in 1936 when the Queensland Government assumed control of Green Island (Green Island Management Committee, 1980).

In 1937 the Hayles company commenced reputedly the world's first glass-bottomed boat service and the following year they were granted a lease for a tourist development, with the first Coral Cay Hotel constructed in the early 1940s (Green Island Management Committee, 1980).

The jetty was destroyed by a cyclone in 1946 and rebuilt by the Cairns Harbour Board the same year (Green Island Management Committee, 1980).

1950 - 1980

An underwater observatory, the first in Australia, was installed at the end of the jetty in 1954 (Claringbould *et al.*, 1984).

The earliest published visitation rates for Green Island were for 1957/58 [Table 10.1], when the Coral Cay Hotel could accommodate 34 overnight guests (Green Island Management Committee, 1980).

In 1960/61 the Cairns Harbour Board constructed a new jetty and in 1961 both the marine zoological gardens and the theatre opened (Green Island Management Committee, 1980). An updated Coral Cay Hotel opened in 1963, camping on the cay was discontinued in 1964 and a further hotel building was constructed in 1965 (Green Island Management Committee, 1980).

The present public toilets and changerooms were constructed on the esplanade in 1972 (Green Island Management Committee, 1980). In 1975 a second ferry service - the Coral Seatel - began operating to Green Island (Economic Associates Australia, 1983). The 1976 visitation figure given by the Australian Littoral Society (1990) may have been an estimate of total visitation rather than visitation via the ferry services alone, and approximately 95% of these visitors were daytrippers.

Table 10.1:
Published yearly visitation rates for Green Island.
References are:
ALS = Australian Littoral Society (1990)
CM = Cameron McNamara (1986)
CO = Chenoweth and O'Hara (1980)
DCE = Department of Environment and Conservation (1989)
EAA = Economic Associates Australia (1983)
GIMC = Green Island Management Committee (1980)
H = Hopley (1989)

YEAR	VISITATION	SOURCE	REF
1957/58	28,000	Hayles	GIMC
1960	47,646	Hayles	GIMC
1966	82,000	Hayles	EAA
1970/71	98,000	Hayles	GIMC
1975	130,000	Hayles/Seatel	EAA
1976	135,000	Total?	ALS
1978	118,000	Hayles/Seatel	EAA
	130 - 135,000	Total	EAA
	150,000	Total?	GIMC
1979	119,000	Hayles/Seatel	GIMC
	127,000	Total	EAA
1979?	130,000	Total?	CO
1981	98,000	?	H
1985/86	300,000	?	CM
	250,000	?	DCE/ALS
!988/89?	400,000	?	H

Economic Associates Australia (1983) noted a decline in visitation via the ferry services after 1975. Their estimate of 1978 visitation took into account non-fare paying ferry passengers, visitors in private craft and visitors arriving by seaplane. They stressed the need for a standard definition of 'visitation', opting for 'the number of return trips made ... by persons of all ages whose length of stay ... exceeds three hours' (Economic Associates Australia, 1983). The 1978 visitation rate estimated by the Green Island Management Committee (1980) was probably their estimate of total visitation as elsewhere in their report they present the same 'visitation via ferries' data as Economic Associates Australia (1983). The Australian Littoral Society (1990) includes in their database the estimate given by the Green Island Management Committee (1980) rather than that given by Economic Associates Australia (1983).

A survey by the Queensland Fisheries Service (now the Fisheries Branch of the Queensland Department of Primary Industries) in 1978 revealed Green Island to have the most heavily used reef in the Cairns region, being visited by 35% of the small boats operating out of Cairns at that time (Green Island Management Committee, 1980).

The 1979 total visitation estimate given by Economic Associates Australia (1983) consisted of the estimated visitation via the two ferry services, given by the Green Island Management Committee (1980), and the number estimated to travel by seaplane or charter boats (3000) and by private craft (5000, based on statistics from the Cairns Coast Guard).

Peak daily visitation level in 1979 was estimated by Economic Associates Australia (1983) to be 1000 with the capacity of the ferry services the main limiting factor. The practical maximum capacity of the hotel was 65 overnight guests at that time, though beds were available for up to 80 people (Economic Associates Australia, 1983). The number of residents (all associated with the tourist facilities) on Green Island varied from about 40 in the off-season to 70 during the peak season (Green Island Management Committee,1980).

Chenoweth and O'Hara (1980) gave an undated estimate of visitation, probably relating to 1979, with up to 1,000 persons on a peak day. They also classified Green Island as the most intensively used part of the Great Barrier Reef proper.

Economic Associates Australia (1983) found a marked seasonal variation in visitation rates between 1964 and 1979. The peak season (about 60% of total annual visitation) was from May to September (winter), with the highest monthly visitation (about 16% of annual total) in August.

Driml (1987) reviewed visitor use and economic impacts of activities on the Great Barrier Reef, with Green Island considered not in isolation but as a part of the overall Cairns Section of the Great Barrier Reef Marine Park.

Cornelius (1982) surveyed visitor usage of the Green Island Marine Park between 1978 and 1980, encompassing the sociological, biological and exploitative fields. He personally conducted research into reef-walking activity, and interpreted data from visitor surveys conducted by the Queensland National Parks and Wildlife Service.

1980 - 1990

There have been few published figures for post-1980 visitation rates, although monthly visitor rates since 1960 and daily rates since 1979 are on record at the Cairns office of the Queensland National Parks and Wildlife Service (Hunnam, pers. comm.). The 1985-86 visitation estimate of Cameron McNamara (1986) was apparently based on a Queensland National Parks and Wildlife Service estimate. However, the visitation estimate for 1985/86 given by both the Department of Environment and Conservation (1989) and the Australian Littoral Society (1990) is also quoted as sourced from the Queensland National Parks and Wildlife Service.

Hopley (1989) gave unreferenced estimates of visitation for 1981 and for 'today' (presumably 1988-89) with up to 2000 people on the cay at midday 'today'. In 1989 the Dreamworld Corporation was placed in the hands of receivers and overnight accommodation at the Green Island Reef Resort was subsequently discontinued, although the resort continued to service day visitors. The resort is currently being refurbished and should be reopened, with a capacity of about 90 overnight guests, before the end of 1990 (De Campo, Queensland National Parks and Wildlife Service, pers. comm.).

A self-guiding snorkel trail inshore to the west of the cay was established in 1982 by the Queensland National Parks and Wildlife Service (Hicks and Cornelius, 1983). This was removed for maintenance in October/November 1987 and has not been replaced (Hicks, pers. comm.).

A survey of charter boats utilising Green Island was conducted by Hundloe *et al.* (1986) between July 1984 and the end of June 1985 as part of a broader survey encompassing the entire Great Barrier Reef region. The confidential report, held by the Great Barrier Reef Marine Park Authority, covered activity patterns, fish catch and economic characteristics of the operators.

Access to Green Island by seaplane has been possible since 1978. Craft are permitted to take-off and land in an area to the north-west of the cay and to moor off the north-western cusp. Brown (1986) conducted surveys in May 1986 to determine visitors' perceptions of seaplane activity and the ways in which it added to or detracted from their enjoyment. While 90% of visitors surveyed noticed seaplane activity, over half indicated that it made no difference to their enjoyment. Of the remainder, the majority considered their enjoyment increased rather than decreased as the seaplanes were a novelty and interesting to watch.

Students of Smithfield State High School (Cairns) conducted visitor and vessel surveys at irregular intervals in the period March 1987 to September 1988, in conjunction with the Cairns office of the Queensland National Parks and Wildlife Service (Smithfield State High School, 1988; Hicks, pers.comm.). Copies of the report are available through that office.

To cater for the education of visitors, organised reef walks have periodically been conducted by officers of the Queensland National Parks and Wildlife Service from Cairns. These have generally taken place within areas to the north-east and south-west of the cay (Hunnam, pers. comm.).

A prototype marker for a self-guiding SCUBA trail was devised by Hicks and Cornelius (1984), but this has not been installed. Materials have also been tested for potential use in elevated reef-walking trails (Hicks, pers. comm.).

Chapter 11 <u>HISTORY IN BRIEF</u>

This historical summary is compiled from information contained in Jones (1976), Kuchler (1978), Green Island Management Committee (1980), Australian Littoral Society (1982, 1990), Cairns Port Authority (1982), Department of Environment and Conservation (1989), Beach Protection Authority (1989) and Queensland National Parks and Wildlife Service (1990).

Prior to European discovery, Green Island is thought to have been visited periodically by aborigines from the mainland.

1770 - Charted and named by Captain Cook.

1857 - Settled by a beche-de-mer fisherman, J.V.S. Mein, who cleared the centre of the cay for planting but left a year later following near-inundation by storm surge during a cyclone.

Late 1860s to 1890s - Many beche-de-mer fishermen operating from Green Island, several massacres by Aboriginal and Islander workers during the early 1870s. George Lawson (known as 'Yorkey') established a fishing station in the late 1870s.

1889 - Vegetation removed from western end of cay and grass huts built for the accommodation of fishing and hunting parties. Coconuts planted around the perimeter by a botanist, E. Cowley.

1890 - Organised pleasure cruises conducted in the 'Zeus'.

1905 - Yarrabah Mission aborigines apply unsuccessfully for lease on Green Island to supplement their resources.

1906 - Green Island proclaimed a Recreation Reserve under Cairns Town Council control.
First jetty constructed by Cairns Harbour Board.

1924 - Hayles Ltd commenced fortnightly passenger service from Cairns.

1929 - Surveyed by the Geographical Section of the British Expedition to the Great Barrier Reefs.

1931 - Jetty constructed by Cairns Town Council.

1932 - Licence granted by Cairns Town Council to remove coral from an area within a one mile radius of low water mark. Coral was used as a source of lime for the mainland cane fields.

1935 - Green Island declared a fauna sanctuary.

1936 - Control assumed by the Queensland Government.
New jetty, a kiosk and cottage built.

1937 - Green Island declared a National Park. Hayles Ltd commenced glass-bottomed boat service (reputed to be a world first). Foreshore and reef within one mile of low water mark protected under the Fish and Oysters Act.
Permission granted to B. Cummings for the erection of a laboratory and living quarters for nature study purposes.

1938 - Lease granted to Hayles Ltd for tourist resort development.

1939 - First groynes built to protect foreshore - one major and four minor on western side, constructed mainly of timber.

Early 1940s - First Coral Cay Hotel constructed by Hayles Ltd.

1945 - Cairns Town Council revokes licence for removal of coral within one mile of low water mark.

1946 - Groynes damaged and jetty destroyed by cyclone, all reconstructed by Cairns Harbour Board within a year.

1954 - Underwater observatory installed.

1957 - Restoration of existing groynes.

1958 - Land Agent, Cairns ceased issuing camping permits for Green Island.

1960/61 - New jetty constructed by Cairns Harbour Board.

1961 - Marine zoological gardens and theatre constructed.

1962 - First outbreak of crown-of-thorns starfish on Green Island reef.

1963 - New Coral Cay Hotel opened.
Inshore half of major groyne reinstated.

1964 - Camping on cay discontinued by Hayles Ltd.

1965 - Main building of Coral Cay Hotel constructed.

1966 - Queensland Department of Harbours and Marine funded a study of the crown-of-thorns starfish.

1969 - Abundance of crown-of-thorns starfish declined markedly.

1972 - Groynes removed.
Public toilets constructed and sewerage system for hotel buildings and public toilets established by State Works Department.

1973 - Green Island surveyed during the Royal Society and Universities of Queensland Expedition to the northern Great Barrier Reef.
Sand replenishment program (2,300m^3) undertaken by Queensland Department of Harbours and Marine.

1974 - Surrounding reef declared a Marine National Park by the Queensland Government, covering 3000ha and extending from low water mark to 1.6km beyond the outer edge of the reef.

1975 - Incorporated into the Cairns Local Government Area.
Sand replenishment program (16,000m^3) undertaken by Queensland Department of Harbours and Marine, sand-bag groyne constructed.
Queensland Fisheries Service assumed control of Marine National Park.
Coral Seatel ferry service commenced.

1977 - State Cabinet decides no further funds to be made available for shore protection works.
Beach monitoring program commenced by the Beach Protection Authority.

1978 - Green Island Management Committee established by Queensland State Cabinet.
Seaplane access permitted.

1979 - Application by Hayles Ltd to install groyne on south-western side of cay approved by Marine Board of Queensland.
Large numbers of crown-of-thorns starfish reported at south-eastern end of reef, commencement of second infestation.
Green Island Economic Study conducted by Economic Associates Australia.
Former residence of Noel and Kitty Monkman acquired by Queensland Department of Primary Industries.

1980 - Hydroflite ferry service commenced, operated by Hayles Pty Ltd.
Steel pile and concrete panel groyne constructed on reef flat at south-west corner of cay by Hayles Pty Ltd..
Crown-of-thorns starfish in low abundance by end of year.
Green Island Management Plan adopted as policy by State Cabinet.

1981 - Green Island reef zoned as a Marine National Park `B', with a Marine National Park Buffer Zone extending 500m out from the reef edge, within the Cairns Section of the Great Barrier Reef Marine Park.
Cairns Port Authority limits extended to include part of Green Island foreshore.
Timber extension to jetty constructed by Hayles Pty Ltd following cay erosion.

1982 - Self-guiding snorkel trail established by Queensland National Parks and Wildlife Service.
Fast catamaran ferry service commenced, operated by Hayles Pty Ltd.
Resort redevelopment carried out, including regeneration of natural vegetation within lease area.
Seawall on western end of cay extended northwards by Hayles Pty Ltd..

1983 - Cairns Section of the Great Barrier Reef Marine Park gazetted.
Seawall extended further northwards.

1985 - Walking trail along southern shoreline of cay closed.
Jetty control and maintenance (including channel dredging) transferred from Hayles Pty Ltd to Cairns Port Authority.

1986 - Cyclone Winifred passes to south-east in February, foreshore vegetation on western side 50% defoliated or salt abraded, minor damage to resort.
Green Island Management Committee disbanded as a formal body.

1987 - Self-guiding snorkel trail removed.

1988 - Hayles Pty Ltd (including ferry service and Green Island Reef Resort) purchased by Dreamworld Corporation, operating as Great Adventures Pty Ltd.
Zoning of Green Island under review as part of the Great Barrier Reef Marine Park Authority's Cairns zoning plan review.

1989 - The Queensland marine park declared in 1974 amalgamated into the Cairns Marine Park gazetted by the Queensland Government.
Green Island Reef Resort closed.
Sunlover Cruises commence operation to Green Island.
Esplanade landscaping carried out by Queensland National Parks and Wildlife Service and Cairns City Council - including trackwork, mulching, beach access, windbreaks and tree planting.

1990 - Draft supplement to Green Island Management Plan released for public comment.
Green Island cay and reef declared a Recreation Area under Queensland Government legislation.

Chapter 12 MAPS AND PHOTOGRAPHS

MAPS

1943 - Cairns, Queensland. 1:253,440. Royal Australian Survey Corps. Topographic features.

1946 - Queensland: Cairns. 1:63,360. Royal Australian Survey Corps. Topographic features.

1975 - Parish of Trinity County of Nares: Cairns Land Agents District: Cook, Queensland. 1:320. Queensland Survey Office.

1978 - Great Barrier Reef, Green / Arlington transect. Green Reef. 1:5000. Australian Survey Office, 23/5/82. Orthophoto from aerial photograph, 18/10/78.

Kuchler (1978) contains maps of changes in nearshore sand accumulation, vegetation shoreline, nearshore patch reef development and seagrass distribution between 1936 and 1978.

1979 - Green Island: location of beach profiles and features, survey marks as at December 1979. 1:1250. Department of Harbours and Marine. 10/7/80.

1980 - Green Island Management Committee (1980) contains a map of changes in the western shoreline between 1958 and 1979.

1981 - Townsville SE 55, Nature Conservation Reserves. 1:1,000,000. Division of National Mapping.

1982 - Great Barrier Reef index series, Cape Melville to Clump Pt. 1:250,000. Great Barrier Reef Marine Park Authority. July 1982.

Great Barrier Reef Mapping, Cairns Section, Green Island. 1:2500. Dept. of Mapping and Surveying, Brisbane. Orthophoto from aerial photograph 6/9/82.

Hayles (1982). Contains a map of changes in the western shoreline between 1938 and 1982.

1983 - Australia - east coast, Queensland, Russell Island to Low Islets. AUS 830. 1:150,000. Hydrographic Service, R.A.N. 28/10/83.

PHOTOGRAPHY

General

Kuchler (1979, 1982). Horizontal photographs - 1925/30, 1937, 1940, 1953.

Hayles (1982). Obliques 1936 - 1982.

Dakin (1950). Undated horizontal.

Greetings from Green Island, a tropical coral island on the Great Barrier Reef. Bolton, Cairns. Undated. Various photographs.

Pannell Kerr Forster (1971). Undated aerial oblique.

Cornelius, N.J. (1982). Undated oblique.

Hopley, D. (1982). Undated aerial oblique.

Aerial

Aerial photographs denoted 'BPA' (Beach Protection Authority) are available for purchase through the Sunmap Aerial Photography Centre, Department of Geographic Information (Beach Protection Authority, 1989).

1936 - Oblique. In Kuchler (1979, 1982).

1938 - Oblique. 2588 - 2589, 8097, 29/8/38. Held by the National Library of Australia.

1945 - Vertical. In Kuchler (1979, 1982).

1946 - Oblique. In Kuchler (1979, 1982).

1950 - Oblique. In Kuchler (1979, 1982).

1956 - Oblique. In Kuchler (1979, 1982).

1959 - Vertical. In Kuchler (1979, 1982).

Vertical. Division of National Mapping: Cairns E55-2. Run 62, CAB 147, 5123-5124, 24/12/59, 25000ft.

Vertical. Division of National Mapping: Cairns E55-2. Run 61, CAB 148, 5007-5008, 31/12/59, 25000ft.

1960 - Vertical. Division of National Mapping: Cairns E55-2. Run 7, CAB 175, 5118, 16/9/60, 25000ft.

1963 - Oblique. In Kuchler (1979, 1982).

1964 - Oblique. In Kuchler (1979, 1982).

1969 - Oblique. In Kuchler (1979, 1982).

1972 - Oblique. In: Islands of Australia (Baglin, D. and B. Mullins authors). Ure Smith, Sydney.

Vertical. In Kuchler (1979, 1982).

Verticals. BPA: Green Island Project. Run 1, 9565 - 9574, 2/4/72. 912m (Sunmap QAS484c).

1973 - Oblique. In Kuchler (1979, 1982).

Oblique. In Wright (1973).

1974 - Oblique. In: Great Barrier Reef features above mean high water at November 1974. Division of National Mapping Technical Report 20, 1975.

1975 - Oblique. In Kuchler (1979, 1982).

1976 - Oblique. In Kuchler (1979, 1982).

1978 - Oblique. In Kuchler (1979, 1982). 25/1/78, 600m.

Oblique. In Kuchler (1979, 1982). 16/5/78, 600m.

Verticals. BPA: Green Island Project. Run 1, 4597 - 4601, 15/6/78. 1824m (Sunmap Q3507).

Verticals. BPA: Green Island Project. Run 2, 4603 - 4618, 15/6/78. 912m (Sunmap Q3507).

Oblique. In Kuchler (1979, 1982). 7/78. 150m.

Verticals. Australian Survey Office (ASO): Green / Arlington transect. Run 12, SOC147, 76 - 78, 18/10/78, 15000ft.

Vertical. In Kuchler (1979, 1982).

1979 - Verticals. BPA: Townsville - Cooktown. Run 63, 8648 - 8655, 16/11/79. 915m ASL. (Sunmap QP3707c).

Verticals. BPA: Townsville - Cooktown. Run 64, 8639 - 8644, 16/11/79. 1830m ASL. (Sunmap QP3707c).

1980 - Verticals. ASO: Green / Arlington transect. Run 38, SOC309, 23 - 30, 9/5/80, 5000ft.

Verticals. ASO: Green / Arlington transect. Run 39, SOC309, 32 - 41, 9/5/80, 5000ft.

Verticals. ASO: Green / Arlington transect. Run 40, SOC309, 42 - 50, 9/5/80, 5000ft.

Verticals. BPA: Green Island. Run 1, 01 - 09, 12/9/80. 915m ASL. (Sunmap Q3736).

Verticals. BPA: Green Island. Run 2, 09 - 24, 21/10/80. 455m ASL (Sunmap Q3737).

1981 - Verticals. BPA: Green Island. Run 1, 01 - 11, 21/9/81. 915m ASL (Sunmap QP3964).

Verticals. BPA: Green Island. Run 2, 23 - 33, 21/9/81. 455m ASL (Sunmap QP3964).

Obliques. ASO: Green / Arlington transect. SOC 427, 9139 - 9140, 21/8/81.

1982 - Verticals. Sunmap: Cairns. Run 8, 6455, 18/7/82. 5720m AMGL, 900m datum. (Sunmap Q4089).

Verticals. BPA: Green Island Project. Run 1, 147 - 179, 6/9/82. 915m ASL. (Sunmap QP4076c).

Verticals. BPA: Green Island Project. Run 2, 180 - 190, 6/9/82. 455m ASL. (Sunmap QP4076c).

1983 - Verticals. BPA: Townsville - Cooktown. Run 63, 09 - 15, 26/6/83. 1830m ASL (Sunmap QPc4231).

Verticals. BPA: Townsville - Cooktown. Run 64, 01 - 08, 26/6/83. 915m ASL. (Sunmap QPc4231)

Vertical BPA: Townsville to Cooktown. Run H10, 05, 6/7/83. 7600m ASL (Sunmap QPc4262).

Obliques. Sunmap: Cairns and surrounding areas. 13- 14/9/83. (Sunmap QPc4271)

Verticals. BPA: Green Island. Run 2, 01 - 09, 18/10/83. 450m ASL. (Sunmap QP4196c).

Verticals. BPA: Green Island. Run 1, 31 - 58, 9/11/83. 900m ASL (Sunmap QP4196c).

Vertical by Qasco Pty Ltd., Sydney. In: Reader's Digest Guide to the Australian Coast. Reader's Digest, Sydney.

1985 - Verticals. BPA: Green Island. Run 1, 182 - 196, 7/8/85. 910m ASL (Sunmap QP4512).

Verticals. BPA: Green Island. Run 2, 197 - 202, 7/8/85. 450m ASL (Sunmap QP4512).

1986 - Verticals. BPA: Green Island. Run 1, 01 - 23, 13/12/86. 915m ASL (Sunmap Q4137).

Verticals. BPA: Green Island. Run 2, 24 - 36, 13/12/86. 455m ASL (Sunmap Q4137).

1987 - Verticals. BPA: Townsville - Cooktown. Run 1, 01- 27, 14/7/87. 915m ASL (Sunmap QPc4673).

Verticals. BPA: Townsville - Cooktown. Run 2, 28 - 35, 14/7/87. 450m ASL (Sunmap QPc4673).

DIGITAL IMAGERY

1984 - Image of Green Island obtained by the Great Barrier Reef Marine Park Authority using the National Safety Council of Australia airborne multi-spectral scanner, 10/5/84.

Cairns Reef Shuttlemap. 1:370,000. Dept. of Mapping and Surveying. Photography by experimental large format camera on Shuttle Mission 41-G, October 1984. Available from Sunmap.

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Appendix 1 VEGETATION

This species list is derived from lists in Kuchler (1978), Green Island Management Committee (1980) and Cornelius (1982). The list in Kuchler (1978) is compiled from lists of Mr. L. Smith (1957), Professors Specht and Clapham (1970) and Mr. A.W. Gardner (1973). The other two lists are identical, from surveys by the C.S.I.R.O. Division of Forest Research in July 1978 and February 1979. Those species occurring only in the list of Kuchler (1978) are denoted *, those occurring only in the other two lists are denoted ^.

Trees

Aglaia elaegnoidea
Alstonia scholaris^
Calophyllum inophyllum
*Canarium australianum**
Canarium vitiense^
Casuarina equisetifolia
Claoxylon tenerifolium
Cordia subcordata
Cryptocarya cunninghamii
Cryptocarya hyposodia^
Diospyros compacta^
Diospyros ferrea var *reticulata**
Diospyros maritima
Drypetes australasica
Elaeodendron melanocarpum
*Erythrina phlebocarpa**
Erythrina variegata
Ficus benjamina^
Ficus drupacea^
Ficus microcarpa
Ficus obliqua var *petiolaris**
*Ficus opposita**
*Ficus retusa**
Ficus virens var *sublanceolata*^
Ganophyllum falcatum
Glycosmis pentaphylla
Gomphandra australiana^
Guettarda speciosa^
Hibiscus tiliaceus^
Ixora klanderana^
*Ixora planderi**
Linociera ramiflora
Mallotus nesophilus^
*Mallotus paniculatis**
Micromelum minutum^
Mimusops elengi
Morinda citrifolia
Myristica insipida
Pandanus spp.
*Pandanus tectorius**
Pithecellobium grandiflorum
Planchonella obovata
Polyalthia nitidissima
Pongamia pinnata
Premna obtusifolia^
*Premna corymbosa**
Sophora tomentosa
Terminalia arenicola^
*Terminalia catappa**
*Terminalia melanocarpa**
*Terminalia seriocarpa**
Thespesia populnea
Vavaea amicorum^
Vitex negundo

Palms

Arenga australasica
*Cocos nucifera** (intro)

Herbs

Euphorbia tannensis^
Tacca leontopetaloides

Vines

Caesalpinia bonduc
*Caesalpinia pulcherrima** (intro)
*Canavalia maritima**
Canavalia obtusifolia vel. aff.^
Cansjera leptostachya^
Cassytha filiforme
Columbrina asiatica
Flagellaria indica
Grewia orientalis^
Ipomoea pes-caprae
*Ipomoea tuba**
Jasminium aemulum^
*Jasminium didymum**
Maclura cochinchinensis^
Pachygone ovata^
Pycnarrhena sp.^
Rhamnaceae ? ventilago^

Grasses

Cymbopogon refractus^
Eleusine indica^
Imperata cylindrica^
*Spinifex hirsutum**
Thuarea involuta

Herbaceous creepers

*Commelina ensifolia**
Commelina undulata
Triumfetta repens

Scrambler

Clerodendron inerme

Shrubs

Eugenia carissoides^
*Euphorbia atoto**
Euphorbia cyathophora
*Euphorbia eremophica**
*Euphorbia heterophylla** (intro)
*Euphorbia pulcherrima**
Messerschmidia argentia
Morinda citrifolia
Rivina humilis
Scaevola sericea^
*Scaevola taccada**

Ungrouped

*Abrus precatorius**
Abutilon sp.*
*Boerhavia diffusa**
*Carallia brachiata**
Cassia sp. (intro.)*
*Cayratia clemitidae**
*Cerbera manghas**
Clerodendron sp near *inerme**
Crotalaria sp cf *lanceolatum**
*Cudrania jovanensis**
*Cupaniopsis anacardioides**
*Derris trifoliata**
*Dodonaea viscosa**
*Euroschinus falcatus**
*Leucodena glauca**
*Macaranga tanarius**
Melia azedarach var *australasica**
Modiola sp.*
Podocarpus sp.*
*Schelhammera multiflora**
Schistocarpaea sp.*
*Sesuvium portulocastrum**
*Stentaphrum micranthum**
*Syzygium rubiginosum**
Tridax procumbens (intro)*
*Vigna marina**
*Wedelia biflora**

Appendix 2 BIRDS

This list is compiled from information in Wright (1973), Kikkawa (1976) and Green Island Management Committee (1980).

Seabirds

Black-naped Tern
Brown Gannet
Caspian Tern
Common Noddy
Crested Tern
Eastern Common Tern
Greater Frigate-bird
Lesser-crested Tern
Lesser Frigate-bird
Little Tern
Silver Gull
Sooty Tern
White-capped Noddy

Land and shore birds

Australian (Brown) Goshawk
Bar-tailed Godwit
Beach Stonecurlew
Black-faced Cuckoo-shrike
Black-faced Flycatcher
Channel-billed Cuckoo
Common Sandpiper
Curlew Sandpiper
Dollarbird
Eastern Golden Plover
Forest Kingfisher
Green-winged Pigeon
Grey-breasted Silvereye
Grey-tailed Tattler
House Sparrow
Leaden Flycatcher
Magpie Lark
Mangrove Honeyeater
Osprey
Pied Butcherbird
Red-crowned Pigeon
Reef Heron
Sacred Kingfisher
Scrub Fowl
Sooty Oyster Catcher
Spangled Drongo
Spectacled Flycatcher
Torres Strait Pigeon
Turnstone
Varied Honeyeater
Wandering Tattler
Whimbrel
White-breasted Sea Eagle
White-breasted Wood-swallow
White Egret
Wompoo Pigeon
Yellow-breasted Sunbird
Yellow Figbird

Appendix 3 CORALS

The coral genera and species recorded for Green Island are grouped here as scleractinia, non-scleractinia and alcyonarians (soft corals). Species names have been standardised to Veron (1986). Sources are:

B1: Bradbury *et al.* (1986); B2: Bradbury *et al.* (1987);
GIMC: Green Island Management Committee (1980);
H: Harriott (1984); HF: Harriott and Fisk (1987, 1989);
N: Nash (1985); PE: Pearson and Endean (1969);
W: Woodhead (1971).

SCLERACTINIA

Acroporidae			
Acropora cuneata	W	*Acropora grandis*	HF
Acropora cytherea	HF	*Acropora hyacinthus*	PE,HF
Acropora echinata	PE,W	*Acropora nobilis*	W
Acropora elseyi	W	*Acropora valida*	W
Acropora florida	W,F	*Montipora digitata*	HF
Acropora formosa	W,HF	*Montipora* spp.	PE,H,HF
Caryophylliidae		**Dendrophylliidae**	
Euphyllia sp.	H	*Turbinaria sp.*	H
Faviidae			
Cyphastrea sp.	H,HF	*Goniastrea* spp.	H, HF
Diploastrea heliopora	B1,HF	*Leptastrea* spp.	H,HF
Favia spp.	W,H,HF	*Platygyra* spp.	W,H,HF
Favites spp.	H,HF		
Fungiidae	HF	**Musiidae**	
Fungia sp.	H	*Lobophyllia* sp.	H,HF
Oculinidae		**Siderastreidae**	
Galaxea sp.	H	*Psammocora* sp.	H
Pocilloporidae		**Poritidae**	
Pocillopora damicornis	PE,W,H,N,HF	*Goniopora* spp.	W,H
Seriatopora hystrix	PE,HF	*Porites cylindrica*	HF
Stylophora pistillata	PE,HF	*Porites* spp.	PE,W,H, B1,B2,HF

NON-SCLERACTINIA

Heliopora coerula	PE,W,HF
Millepora spp.	PE

ALCYONARIA

Clavularia sp.	N
Sinularia sp.	GIMC

Appendix 4 MOLLUSCS

Molluscs recorded from Green Island and detailed in Cairns Shell Club Newsletters (Blakey, 1980; Collins, 1984, 1985a,b, 1986, 1987, 1988a,b,c, 1989), Dalton and Reynolds (1984), Nash (1984) and Fisk (1990b).

Cone shells
Conidae
Conus artoptus
Conus boeticus
Conus mitratus
Conus tenuistriatus

Drupe
Thaidinae
Drupella sp.

Murex shells
Muricidae
Favartia confusa
Muricopsis noduliferus
Phyllonotus venustulus

Strombs
Strombidae
Strombus (Canarium) dentatus
Strombus (C.) erythrinum
Strombus (C.) fragilis
Strombus (C.) terebellatus
Strombus (Dolomena) dilatatus
Strombus (D) plicatus pulchellus
Strombus (Tricornis) sinuatus

Triton shell
Cymatiidae
Charonia tritonis

Trochus shell
Trochidae
Trochus niloticus

Cowries
Cypraedae
Cypraea becki
Cypraea subteres
Cypraea teres
Ovulidae
Ovula ovum

Helmet shell
Cassidae
Cassis cornuta

Olive shell
Olividae
Oliva carneola

Terebrids
Terebridae
Terebra alveolata
Terebra amanda
Terebra amoena
Terebra cinctella
Terebra collumelaris
Terebra laevigata
Terebra paucistriata
Terebra quoygaimardi
Terebra textilis
Terebra triseriata
Terebra undulata

Volute
Volutidae
Amoria volva