COLLECTED TECHNICAL REPORTS ON THE MARMION MARINE PARK, PERTH, WESTERN AUSTRALIA

Environmental Protection Authority
Perth, Western Australia
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FOREWORD

Most of the reports presented in this volume were written prior to the formal proclamation of the Marmion Marine Park, in May 1987. Hence, in these reports the study area is sometimes referred to as the proposed Marmion Marine Park. Furthermore, the boundaries of the proclaimed park now extend beyond those proposed in Recommendation M10 of the 1983 System 6 Report (page 175) by the Environmental Protection Authority. Hence, the boundaries indicated in some papers in this volume are now superseded. The actual boundaries are similar to those shown on page 87 of Woods, Kerr, Ottaway & Mills (1985); however, the WA Government Gazette of March 1987 should be consulted for the precise details of the boundaries as proclaimed.

This volume, together with the two already published on the Marmion Marine Park area (Woods, Kerr, Ottaway & Mills 1985; Ottaway & Humphries 1986; see bibliography pp 226 and 236 for details), completes the terms of reference given to the Department of Conservation and Environment in February 1985:

(i) to characterise and describe the marine environments and marine communities of the area, and produce a report on the findings of the study;

(ii) to identify and evaluate present and future impacts on the proposed M10 marine reserve; and

(iii) after consideration of (i) and (ii) above, and in consultation with representatives of the user-groups with interests in the proposed M10 marine reserve area, to frame a management plan for the proposed reserve, with respect to scientific research, education conservation and recreation.

HISTORY AND DEVELOPMENTS LEADING TO PROCLAMATION OF THE MARMION MARINE PARK

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Abstract

A summary is given of the developments, from 1972 to May 1987, which led to proclamation of the Marmion Marine Park. In 1972, a proposal was first made by the Western Australian Branch of the Australian Marine Sciences Association for a marine reserve to protect the Sorrento-Mullaloo reefs. This proposal formed the basis for Recommendation M10 in the System 6 Reports (Department of Conservation and Environment, 1981; Environmental Protection Authority, 1983), and for a draft management plan released for public comment in September 1985 (Woods *et al*. 1985). The marine park is now being managed by the Department of Conservation and Land Management, and a management plan should be available next year (1988).

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1. INTRODUCTION

The original proposal for a marine reserve, in the area now designated as the Marmion Marine Park, came from the Western Australian Branch of the Australian Marine Sciences Association (AMSA), in 1972.

In a general sense, any type of marine protected area may be considered a marine reserve. For example, Ivanovici (1984) lists about 200 marine and estuarine protected areas in Australia, all of which may be regarded as various forms of marine reserve. The actual designation of these reserves varies according to the legislation under which they were declared, and in some instances reserves for similar purposes have different designations from State to State. At present, there are at least 23 designations for marine reserves in Australia, including Aquatic Reserve, Coastal Park, Conservation Area, Fish Habitat Reserve, Fish Sanctuary, Historic Shipwreck Protected Zone, Marine Park Section, Marine Reserve, National Park, Nature Reserve, and Restricted Use Area (Ivanovici 1984). In practice many marine reserves are zoned to allow separation of conflicting activities, which can include recreational activities. In Western Australia, however the term 'Marine Reserve' generally implies that the primary purpose of the area is to protect species or habitats, or to protect the reserve area for scientific research, while the term 'Marine Park' implies that an intended primary purpose is to manage the area for public recreation.

2. DEVELOPMENTS LEADING TO THE DECLARATION OF THE MARMION MARINE PARK

Porter (1986) discussed the background leading to the draft management plan produced by the former Department of Conservation and Environment (DCE) in 1985. This review summarises the main events and developments to the present time, including those covered by Porter (1986).

In 1972, the Western Australian Environmental Protection Authority established the Conservation through Reserves Committee (CTRC) to review and make recommendations on national parks and nature reserves in Western Australia. The Committee divided Western Australia into 12 systems, of which System 6 included the Darling Range and the entire Perth metropolitan area (Figure 1). One of the first submissions to the CTRC was the 1972 AMSA report, which discussed general concepts for marine reserves in the State and listed specific localities suitable for reserve status. The "Sorrento-Mullaloo reefs" were one of the localities listed:

> "An 'underwater park', with National Park status, should be created to take in the reefs of the coast between Sorrento and Mullaloo to a distance of 1 mile offshore. Angling should be banned from part if not all of this area. Commercial fishing, spear fishing and the taking of invertebrate specimens should be totally banned."

The motive behind this suggestion was, clearly, to give high protection to the marine communities of the reefs which occur in the area to a distance of about 1 km offshore.

Detailed work on System 6 started in 1976, and in 1981 the 'System 6 Green Book' was produced. This listed 209 areas proposed for parks or reserves, including three marine reserve areas: the Sorrento-Mullaloo reefs, Point Peron - Shoalwater Bay, and Carnac Island.

Recommendation M10, in the 1981 System 6 Green Book, was derived from the 1972 AMSA report:

M10.1 The Environmental Protection Authority (EPA) should commission a study of the Sorrento-Mullaloo reefs with the aim of recommending the establishment of an Aquatic Reserve.

M10.2 Marine life should be conserved through revision of regulations to prevent any fishing except by line.

After consideration of about 1 500 submissions on the System 6 Green Book, officers from the Department of Conservation and Environment produced a revised volume of recommendations, which was reviewed by the Environmental Protection Authority and then published as the 1983 System 6 Red Book. In that, Recommendation M10 was then given as:

M10.1 That our general recommendations on planning and management of Regional Parks be applied to this area.

M10.2 That a study of the area be commissioned by the Environmental Protection Authority with the aim of establishing a marine reserve to be managed for the purposes of scientific research, education, conservation and recreation.

M10.3 That, subject to the implementation of M10.2, a management plan be prepared for the Reserve.

In addition, the 1983 report acknowledged existing uses of the area for commercial fishing, education, boating, diving, swimming, and recreational fishing. It also noted a "MWA sewage outfall and a boat ramp at Whitfords."

Little more was done on the proposed marine reserve until February 1985, when State Government directed the Department of Conservation to implement recommendation M10 and produce a draft management plan. Details are given in Woods *et al* (1985, pp 1-3). While it was known that the proposed legislation for the new Department of Conservation and Land Management (CALM), which was proclaimed in March 1985, gave control of marine parks and reserves to CALM (Woods *et al*. 1985, pp 69-70), CALM at that time did not have the resources or expertise to undertake the work.

After extensive consultation with interested organisations, local marine scientists, and members of the general public, DCE produced a draft management plan which was released in September 1985. Public submissions were received and analysed, and a revised draft management plan was submitted to the Environmental Protection Authority, together with an analysis of the public submissions, in December 1985. EPA made its report to Government, the report was accepted, and in that month the Premier of Western Australia, Brian Burke, announced Government's intention to proceed with declaration of the proposed park, designated the Marmion Marine Park.

Further work on park management and development of the park's management plan was taken over by CALM. A marine park manager, Gregory Pobar, was appointed by CALM in May 1986. Fisheries Department assigned an inspector, John Marek, to assist with park management from January 1987.

Details of the park were published in the Western Australian Government Gazette on 13 March 1987, and the Marmion Marine Park was proclaimed on 20 May 1987. The detailed management plan is scheduled for release by the end of 1987.

A chronology of these developments is given below:

YEAR/MONTH	DEVELOPMENT
1972	Environmental Protection Authority establishes the Conservation Through Reserves Committee.
1972 August	AMSA submission to CTRC proposes marine reserves for Western Australia, and an "underwater park" for the Sorrento - Mullaloo reefs area.
1976	Department of Conservation and Environment special project team starts work on the System 6 area.
1981 April	System 6 Study Report produced, with Recommendation M10 for an "Aquatic Reserve". (This recommendation was based substantially on the 1972 AMSA submission, although the designated Reserve area was markedly increased).
1981-1983	Public comments received and assessed by DCE.
1983 October	The Darling System - System 6 report produced. Contains a modified M10 proposal (as one of 209 localities proposed for management).
1984 March	State Government directs DCE to implement the System 6 (1983) M10 recommendations. Requests production of a draft management plan to be completed by December 1985.
1985 February	Terms of reference received by DCE special project team coordinator. Temporary staff contracted.
1985 March	M10 project team consults EPA. Field work commenced. Consultations with key organisations.
1985 March	CALM Act (1984) proclaimed, giving CALM authority to reserve any part of Western Australian waters as a marine nature reserve or a marine park.
1985 June	M10 seminar and workshop. Work started on detailed draft management plan (DMP).
1985 August	First draft of DMP circulated to 98 people, representing special interest organisations or groups, for comments and criticisms.
1985 September	Comments assessed. Revised DMP released.

YEAR/MONTH	DEVELOPMENT
1985 November	Public submissions assessed. DCE reports to EPA. EPA makes preliminary report to Government.
1985 December	DCE makes final report to EPA. EPA makes report to Government. Premier announced intention to proceed with declaration of the Marmion Marine Park. CALM takes over park management.
1986 May	Marmion Marine Park Manager appointed by CALM.
1987 January	Fisheries Department assigns fisheries inspector to management of the park.
1987 March	Details of Marmion Marine Park published in WA Government Gazette.
1987 May	Marmion Marine Park proclaimed.

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A REVIEW OF THE METEOROLOGY, OCEANOGRAPHY AND COASTAL PROCESSES IN THE VICINITY OF THE PROPOSED MARMION MARINE PARK

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Abstract

This report reviews existing knowledge of the meteorology, oceanography and coastal processes in the area identified by Recommendation M10 of the System 6 Report (Environmental Protection Authority 1983), as being suitable for the establishment of a marine park. The report also discusses issues, related to these physical characteristics, and to man's present and projected uses of the area, which should be considered by managers of the proposed marine park.

The study area is characterised by a series of shore-parallel Pleistocene limestone ridges separated by linear depressions. The largest of these ridges forms the mainland coast. The remainder form broken chains of islands and reefs about 1 km and 4 km offshore.

During the last 6 000 years, ocean swell has impinged on the complex limestone ridge and depression bathymetry. The resultant wave interference patterns have driven sediment movements, which have led to the formation of the transverse submarine Lal Bank and the triangular beach ridge plain at Whitford, and caused exposure of the main limestone ridge further to the north and south. Swell waves and locally generated wind waves together drive longshore seasonal pulses of sand, to the north in summer, and to the south in winter. These gross seasonal sand movements dominate any nett longshore drift of sand. There is also evidence of much longer term changes to the sandy coast, including intermittent periods of beach ridge building, and the gradual translocation of sand from the south to the north face of the Whitford Plain. The contrasting stability and exposure to wave energy of sandy and rocky coastal stretches needs to be taken into account when determining long term management strategies for the area, and when making land-use decisions.

Water currents in the study area are predominantly wind-driven, and are strongly influenced by the local bathymetry. On average, the inshore waters are flushed every few days. Major anthropogenic loads of nutrients to the waters of the study area are from wastewater outfalls and submarine groundwater discharge. Though nutrient concentrations in the local seawater are presently low, by temperate water standards, some phytoplankton blooms have been observed in the study area. Nutrient loads to the area will inevitably increase with increasing urbanisation of adjacent lands.

CONTENTS

FIGURES

1. INTRODUCTION

This report is one of the technical documents supporting the Draft Management Plan for the proposed M10 Marine Park (Woods *et al* 1985). It:

- reviews existing knowledge of the meteorology, oceanography and coastal processes in the nearshore zone adjacent to Perth's metropolitan area, and in particular within the study area;
- discusses how these processes influence the natural environment of the study area; and
- identifies related issues which should be considered by future managers of the proposed marine park.

The 'study area', shown in Figure 1, is defined as the waters and islands described in Recommendation M10 (pp 174 and 175) of the System 6 Report (Environmental Protection Authority 1983), adjacent State waters between Trigg and Ocean Reef, and all land west of West Coast Highway/Merrifield Place/Ocean Reef Road and its proposed extension, and the sea.

2. CLIMATE AND METEOROLOGY

The study area is centred on Whitford Beach, about 22 km northwest of Perth. It experiences hot, dry summers and mild, wet winters. Air temperatures are similar to those of Perth, where mean daily maximum temperatures vary from 30.3^{o}C in summer to 17.6^{o}C in winter, and mean daily minimum temperatures vary from 9.1^{o}C in winter to 18.6^{o}C in summer. Rainfall is moderate (about 880 mm/y) and falls mainly in the months May to October. Evaporation is high (about 1 980 mm/y).

Winds are fairly uniform over the coastal and nearshore region off Perth. There is a marked seasonal variation in winds, related to the latitudinal migration of eastward travelling pressure systems (Gentilli 1972). Winter is characterised by storms with intervening calmer periods. Major storms, involving 20 m/s winds for periods of 6-24 hours, occur 2-10 times/y (Steedman and Craig 1979). The directions of storm winds are generally northwest to southwest. The daily land breeze and sea breeze variation intensifies in summer, and is superimposed on a persistent southerly airstream, so that the resultant wind blows from the southeast at night and in the morning, and from the southwest in the afternoon.

Tropical cyclones, with associated strong winds and pressure gradients, occasionally travel far southward in summer-autumn, and may influence this part of the coast, bringing strong winds from any direction. A notable example was tropical cyclone 'Alby' which, in April 1978, brought gale force winds to the Perth area for four hours, with a maximum wind gust of 36 m/s (Bureau of Meteorology 1978).

Calm periods (hourly average winds less than 1.5 m/s) last from 4 hours to 2 days and may occur at any time of the year (Steedman and Craig 1979).

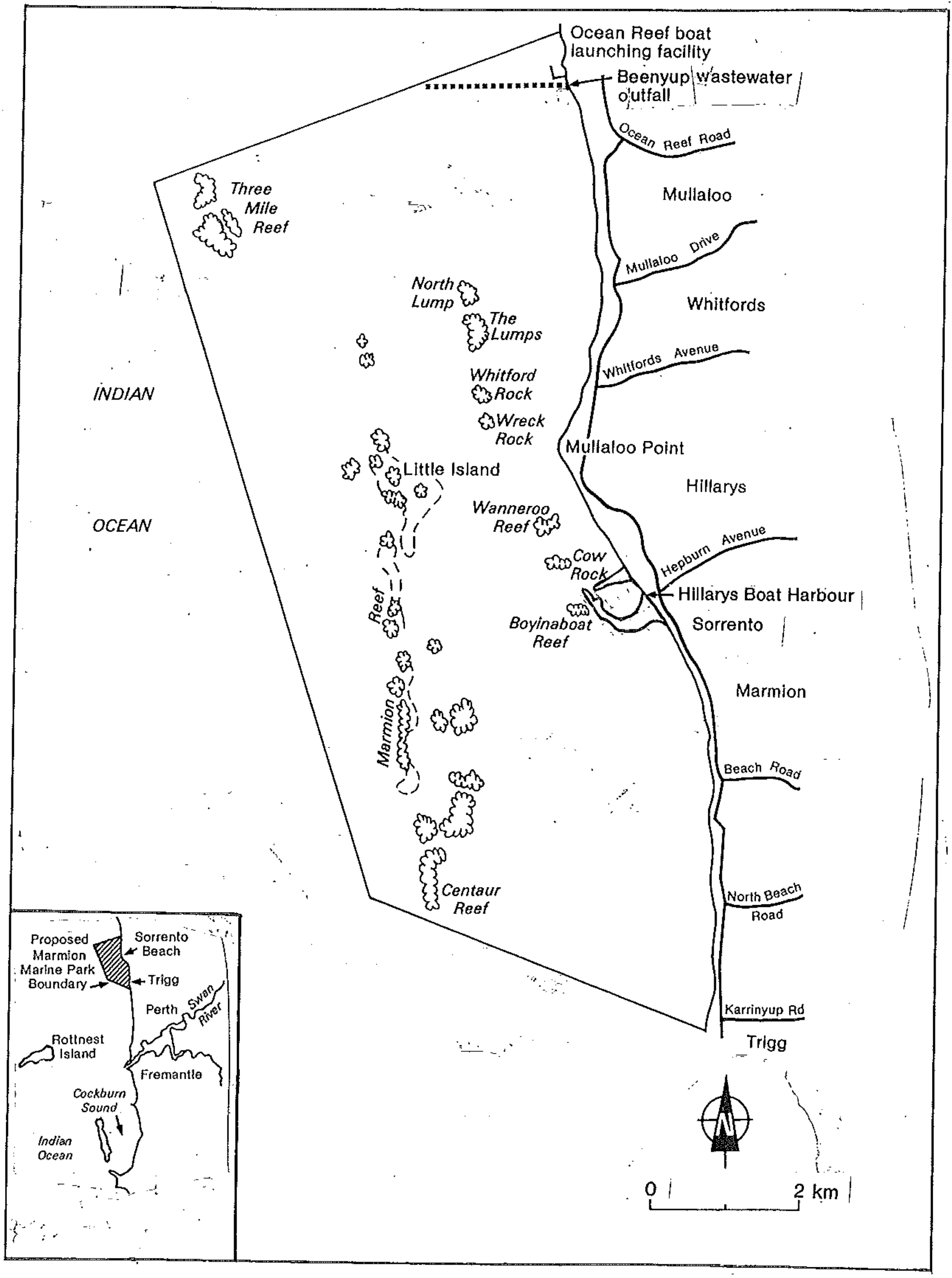

Figure 1. Map showing location of the study area for the proposed M10 marine reserve (boundaries of reserve as in DCE 1981, EPA 1983).

3. OCEANOGRAPHY

3.1 BATHYMETRY

3.1.1 PERTH METROPOLITAN REGION

The Perth metropolitan coast is fronted by a moderately sloping inner continental shelf which is covered with quartz and feldspathic sands (Searle 1984). In places the shelf is separated from the mainland shore by a complex carbonate ridge and depression topography; in other places it grades into a shallow submarine plain immediately off the beach.

3.1.2 STUDY AREA

The general bathymetry of the study area is shown in Figure 2. A major limestone ridge determines the general alignment and position of the coast. Offshore, a series of lower broken limestone ridges form chains of reefs and islets that are parallel to the shore. The most continuous of these reef chains, the offshore Marmion Reef, rises in places to about 15 m above the sea-floor. The study area is unusual in that it also contains a chain of nearshore reefs within the water basin protected by the offshore reefs. Water depths in linear depressions between the reefs may reach 15 m. The nearshore depression between Marmion and Mullaloo has water depths of about 7-10 m. This depression is divided into two basins by a transverse sand bank, Lal Bank, over which water depths are 3-4 m. The southern basin, 'Marmion Lagoon', is open to the south,and the northern basin, 'Mullaloo Lagoon', is open to the north. The sea-floor is a complex mosaic of bare sand, seagrass meadows on sand, rock outcrops mostly covered with algae and invertebrates, and various reef structures with typical reef communities (Ottaway and Simpson 1986). West of the outer reef chain, the water quickly deepens to 20 m and more.

3.2 WATER LEVELS

The southwest coast of Western Australia experiences the smallest astronomic tides found on the Australian coastline. At Fremantle, the tide is predominantly diurnal, and has a mean range of about 0.4 m (Hodgkin and Di Lollo 1958; Easton 1970). Non-tidal water level changes, of comparable magnitude, are common. These occur in response to long period (5-15 day) barometric pressure variations (Hodgkin and Di Lollo 1958), long period wave disturbances propagated along the continental shelf (Provis and Radok 1979), and shorter period high energy events such as storms and cyclones. Water levels are also influenced by wave set-up inside the surf zone.

3.3 CIRCULATION

3.3.1 PERTH METROPOLITAN REGION

The main features of water circulation in the open, nearshore (inner 10 km) region off the Perth metropolitan area have been outlined by Steedman and Craig (1979), and Steedman and Associates (1981).

The dominant influence on circulation is wind stress. Nearshore waters respond to changes in the wind within a few hours. Wind-driven currents are, therefore, extremely variable with time, and transient in nature. Current speeds in the range of 0.05-0.2 m/s are typical, and may increase to 0.4 m/s under very strong wind conditions. These currents are constrained by the nearshore bathymetry, and generally flow parallel to the coast, with a

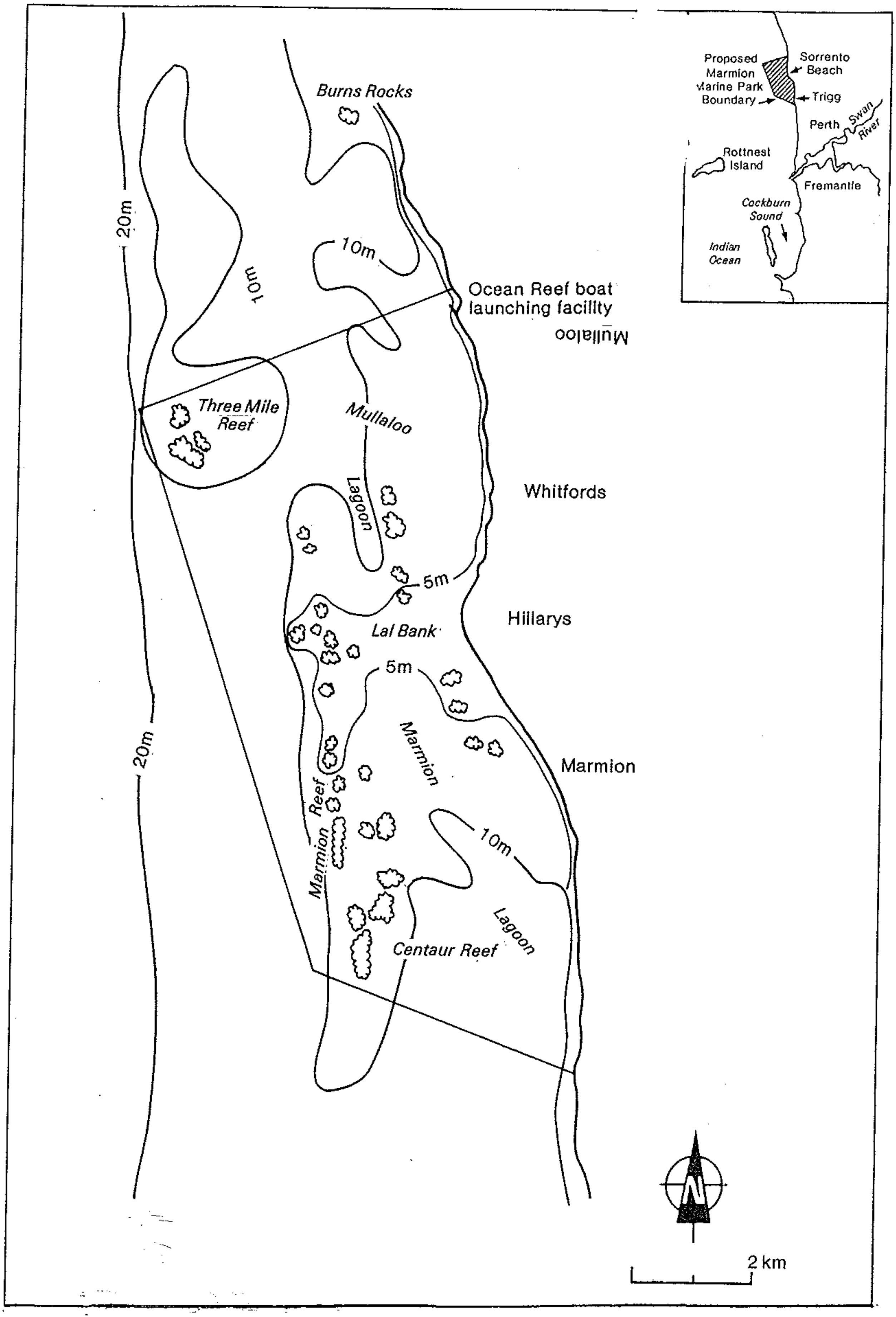

Figure 2. Map showing the general bathymetry of the study area.

velocity component downwind. Predominant seasonal flow directions are northward in summer, and southward in winter, with summer flow being more consistent than winter flow. Currents also respond markedly to the passage of synoptic weather patterns, which occur over periods of 2-4 days (Gentilli 1972), and to the daily sea breeze/land breeze cycle in summer. Water currents are generally weakest in April-May and September-October, the periods of change over in the seasonal wind patterns.

Tropical cyclones migrating southward may generate strong currents, in the nearshore waters off Perth, for periods less than a day. These currents are influenced both by wind stress and strong atmospheric pressure gradients. The direction of water flow depends on the path followed by the cyclone.

Underlying the local wind-driven water flow, there is a longshore current which persists even during periods of no wind. This current has typical speeds of about 0.05 m/s in the nearshore area, and undergoes a seasonal reversal of direction, from northward in summer, to southward in winter. This reversal is thought to be associated with the onset of the Leeuwin Current which, in autumn and winter, brings an intrusion of tropical water southward along the continental shelf and slope (Cresswell and Golding 1980).

Tidal currents are insignificant in unconfined waters off the Perth metropolitan coast.

3.3.2 STUDY AREA

Knowledge of water circulation in the study area comes from current meter measurements (Steedman and Associates 1976), extensive drogue tracking (Petrusevics 1980; Hearn 1983) and from mathematical modelling studies (Hearn 1983). Flow is predominantly to the north in summer, and to the south in winter. Wind is the dominant force driving water movement in the study area, for wind speeds in excess of about 4 m/s. Flow is modified to some extent by the ridges (particularly the Marmion Reef) and the transverse submarine bank, Lal Bank, off Mullaloo Point. The effect of the ridges is to encourage longshore and ridge-parallel flow, and to reduce current speed (Steedman and Associates 1976). The transverse bank tends to limit longshore flow, and to divert water in a direction perpendicular to the shore. Hearn (1983) has shown that, under prolonged easterly winds, water over the Lal Bank is driven westward, inducing circulation and exchange between inshore and offshore waters. Measurements by Steedman and Associates (1976) and Petrusevics (1980) also suggest the presence of local circulation patterns during sustained easterly winds. Superimposed on these general trends is a considerable variability in the water currents, caused by fluctuations in the wind forcing.

For relatively calm periods (wind speeds less than about 4 m/s), the presence of the underlying regional shelf current becomes apparent, although this influence is attenuated by the discontinuous reef line and by frictional resistance in the shallow inshore waters.

In general, mean current speeds are small, of the order of 0.05 m/s. Hearn (1983) has estimated a typical water replacement time for the 'Marmion lagoon' of 1-2 days, although this may reach 4-5 days under infrequent periods of prolonged calm (Hearn, personal communication 1985).

3.4 SEAWATER HYDROLOGY

3.4.1 PERTH METROPOLITAN REGION

Seawater temperatures differ between inshore and offshore sites. Hodgkin & Phillips (1969) compared surface water temperatures of Cockburn Sound eastern shore and the CSIRO 50 m station, 11 km northwest of Rottnest Island. At the Cockburn Sound site, water temperature generally follows air temperature and ranges from approximately 15°C in July-August to 23°C in January-February. At the 50 m offshore station, water temperature ranges from 18-22°C. The offshore temperature maximum occurs typically 3 months later than the Cockburn Sound maximum. This suggests that offshore water temperature may be regulated by north-south current flow along the continental shelf.

Seawater salinity (parts per thousand - ppt) at the CSIRO 50 m station varies from 35.4 to 35.8 (CSIRO, unpublished data). Low salinity levels in winter are partly related to the arrival of tropical water brought south by the Leeuwin Current (Rochford 1969). In summer more saline subtropical water intrudes from the south. Evaporation is an important factor increasing summer salinity levels in the nearshore zone.

In winter, marked east-west temperature and salinity gradients, extending longshore, have been encountered in waters immediately west of Garden Island and further south, consistent with a predominantly southward flowing coastal current at that time of the year. During high winter outflows from the Swan River, well-defined plumes of low salinity water deflected to the south have been observed (Steedman and Associates 1981).

3.4.2 STUDY AREA

Monthly hydrological survey data (seawater salinity, temperature and dissolved nutrient concentrations) were gathered by CSIRO for three years, between June 1979 - June 1982, at about 20 stations within the study area (Pearce *et al* 1985).

These data show that monthly mean seawater temperatures peak at about 22°C between January and April, and fall to a minimum of about 17°C between July and September. This temperature range is about 3°C less than that encountered in the semi-enclosed waters of Cockburn Sound (Hodgkin and Phillips 1969). The limited scatter in the data for each survey suggests some degree of uniformity in temperature throughout the study area, although, in early winter, significant cooling was recorded in waters adjacent to the coast.

The CSIRO survey indicates annual salinity ranges of about 1 ppt. The salinity variations are approximately in phase with the temperature cycle. Evaporation of coastal water in the summer appears to be the main reason for the greater salinity range experienced by the study area, compared with that of the CSIRO 50 m station off Rottnest Island. Pearce *et al* (1985) have not detected any influence on the study area attributable to freshwater outflow from the Swan River, situated some 25 km to the south. Most of the annual Swan River flow occurs for a few months each winter when the predominant longshore current is directed southward.

Pearce *et al* (1985) also noted that dissolved nutrient concentrations in the study area are generally low, and within the range of concentrations reported for other temperate coastal waters; however, concentrations of nitrate and phosphate are higher than off Rottnest Island, particularly in winter. Heavy phytoplankton blooms have not been observed commonly in the Marmion lagoon (Johannes and Hearn 1985), though blooms of the blue-green alga, *Trichodesmium* (Creagh 1985) have been noted in the study area. In March 1987 *Trichodesmium* accumulations were observed at numerous points along the west coast of WA, including Fremantle, Rottnest Island, the study area, Jurien Bay, and as far north as Coral Bay, indicating that the factors causing these blooms can operate on a regional scale.

Johannes and Hearn (1985) reported relatively low-salinity, nutrient-rich water within a few hundred metres of the shore, formed by the mixing of seawater with groundwater discharged at the coast. Their data indicate that groundwater discharging to the study area has nitrate and silicate concentrations two orders of magnitude higher than those of the receiving seawaters; the nitrate concentrations in local groundwaters are two to five times higher than those measured in groundwater discharge further to the north, where urbanisation is minimal (Johannes 1980). Based on the work of Allen (1981), and Johannes and Hearn (1985), total groundwater discharge to the study area is estimated to be 82 000 m^3/d, and the rate of nitrogen input (as nitrate) via groundwater is estimated as 107 kg/d. Other nutrients (nitrite, ammonia, dissolved organic phosphorus and reactive phosphorus) are present in the groundwater at concentrations no higher, or only slightly higher than the local ambient seawater concentrations. As the degree of urbanisation inland from the study area intensifies, the loads of nitrates and silicates discharging at the coast are expected to increase, though this will occur with a considerable time lag, because of the rate (90 m/y) of groundwater movement to the sea (Allen 1981).

Two wastewater outfalls provide nutrient loads to the ocean waters off the Perth metropolitan coast north of Fremantle. The Beenyup outfall, situated 1.6 km offshore of the Ocean Reef boat launching facility, had an average daily flowrate during 1983/4 of 35 000 m^3/d (Metropolitan Water Authority 1984). Secondary treated wastewater effluent at Beenyup contained average concentrations of about 45-50 mg/L nitrogen, mainly as ammonia, and 11-12 mg/L phosphorus, mainly as phosphate (Water Authority of Western Australia, personal communication 1985). Average loads of nitrogen were estimated at about 1 750 kg/d and average loads of phosphorus at about 440 kg/d. By 1987 the Beenyup outfall had an average daily flowrate of 42 000 m^3/d and contained average loads of nitrogen and phosphorus of 2 100 kg/d and 504 kg/d respectively. The Subiaco outfall is located about 10 km south of the study area and 1.6 km offshore. During 1983/4 it had an average daily flowrate of 55 000 m^3/d (Metropolitan Water Authority 1984). Assuming effluent concentrations similar to those at Beenyup, average loads of nitrogen were 2 800 kg/d, and of phosphorus, 704 kg/d. The Subiaco wastewater outfall should have a minimal influence on water quality in the study area, because of its distant location.

Regular water quality surveys conducted about the Beenyup wastewater outfall, by the Water Authority of Western Australia, trace the form and extent of the effluent plume, and associated levels of nutrients, bacteria and other contaminants. Phytoplankton blooms attributable to nutrient enrichment from the Beenyup outfall have not been reported. Seagrass beds in the study area mainly occur in the protected, shallow (2-5 m) areas of Marmion and Mullaloo lagoons to the south of the outfall. These meadows generally comprise dense communities with high standing biomass and high species diversity, and appear to be essentially free of nuisance levels of epiphytic algae. Bacterial monitoring of water at beaches along the local shoreline has been conducted by the Public Health Department.

Results have shown that bacterial levels along these beaches are generally very low and well within the safe limits for primary contact recreation. One area, however, requires special consideration; the rocks and adjacent waters located approximately 530 m south-east of the Beenyup outfall diffuser. This area is used by divers and for the harvesting of rock lobsters, and at times may be exposed to elevated levels of bacteria from the existing outfall.

Local surface runoff is considered insignificant as a nutrient source compared with the sources mentioned above (Johannes and Hearn 1985).

3.5 WAVE CLIMATE

3.5.1 PERTH METROPOLITAN REGION

R K Steedman and Associates have summarised available data and knowledge concerning the wave climate of this region (Metropolitan Water Supply, Sewerage & Drainage Board 1981).

Swell waves, generated by remote Southern Ocean storms, continually reach the continental shelf. During their passage across the shelf, they undergo refraction and approach the coast from south-southwest to west directions (more westerly in winter). Predominant swell periods are 8-12 s.

Shorter waves, mainly of 4-6 s period, are generated by local winds and travel in a downwind direction. They predominate from the southwest and west quadrants in summer, and from the north to west during winter storms. These waves are minimally refracted, since they are influenced by the sea bed in limited areas of shallow water only. Their crests, therefore, are frequently able to approach the shore at an angle.

3.5.2 STUDY AREA

Offshore reefs of the study area dissipate much of the incident ocean wave energy (Steedman and Associates 1976). The amount of energy actually transmitted inshore of these reefs varies spatially, and depends on the local prominence of the ridges.

Swell waves are subjected to diffraction and refraction as they penetrate the broken reef chains of the study area, and form complex interference patterns. These swell patterns determine areas of sand transport (both onshore and longshore) and accumulation; they control the general alignment and extent of the sandy coast. Swell approaches the coast predominantly from the south-southwest in summer, and from the west in winter. This direction change contributes to a seasonal variation in longshore sand transport.

Short period waves generated outside the study area may reach the outer reef chains and be partially transmitted through them. Short period waves may also be generated inshore of the reefs. Wave directions vary seasonally, and on shorter time scales, in response to the varying winds that generate them. The incidence of short period waves at an angle to the coastline produces longshore currents and sediment drift, particularly within the breaker zone. During summer, sediment movement is predominantly to the north. Winter storms generate significant local waves and important southward sediment pulses. The short period waves therefore force a seasonal oscillation of longshore sand transport which in turn leads to seasonal fluctuations in beach width and shore alignment.

4. COASTAL PROCESSES

4.1 GENERAL

Over the last 5 000 years, sea level has remained approximately constant, and fluctuations in meteorological and oceanographic conditions have been minor (Woods and Searle 1983, Semeniuk and Searle 1986). The main sources of sediment to the study area during this period have been erosion products derived from existing landforms, reefs and seabed as a result of wave action, and contemporary calcareous materials formed by marine organisms (Searle and Semeniuk 1985).

The longshore distribution of shore types has been largely determined by the variable shelter afforded by local chains of reefs and islets (see Figure 3). Less sheltered portions of the coast have been subjected to continuous divergent patterns of swell and to high energy storm waves generated over long fetches. These parts of the coast are areas of erosion, and typically comprise rocky, limestone shores. The area inshore of Little Island, sheltered by the most prominent part of the Marmion Reef chain, has been continually subjected to convergent patterns of swell waves which have induced sediment transport onshore, over Lal Bank, and longshore, toward the site of the triangular beach ridge plain at Whitford. The Whitford Plain is the main sediment store of the study area and its general form is determined by the the swell regime, the local bathymetry and the rate of sediment supply (Searle and Semeniuk 1985).

It is important to recognise that the sandy parts of the coast have formed in the last 6 000 - 7 000 years (Semeniuk and Searle 1986), and are still adjusting to changing conditions of sediment supply, and shelter provided by the degrading offshore reefs. Superimposed on this evolution are shorter term fluctuations in sand movement, beach width and shore alignment, possibly owing to changes in climate. These fluctuations also need to be recognised and taken into account in any planning for human use of the coast.

4.2 SEASONAL CHANGES

In summer, under the influence of swells and wind waves from the southwest, the predominant direction of sediment movement is north. Some sediments pass around Mullaloo Point and are moved to the northern face of the Whitford Plain, and for a limited distance further north. This leads to seasonal erosion of the southern beaches and exposure of rocky substrate, indicating that there is very little influx of sand from south of the study area.

In winter, moderate to severe storms generate waves from the north to northwest. Swells are more westerly during this part of the year. These forces induce movement of sediment to the south. Sand is, again, transported around the apex of the Whitford Plain. Beaches to the south are replenished, at the expense of the northern beaches.

The magnitude of these seasonal pulses at Sorrento Beach has been estimated as typically 70 000 - 90 000 m^3 and up to 120 000 m^3 (Public Works Department 1984), ie up to 120 000 m^3 of sediment passes, and returns past a given point in one year. There is also evidence of a nett sediment movement to the north of about 5 000 m^3/y to 10 000 m^3/y.

The longshore seasonal pulsing of sediment is coupled with an onshore and offshore seasonal movement. Sustained moderate summer swell moves sand

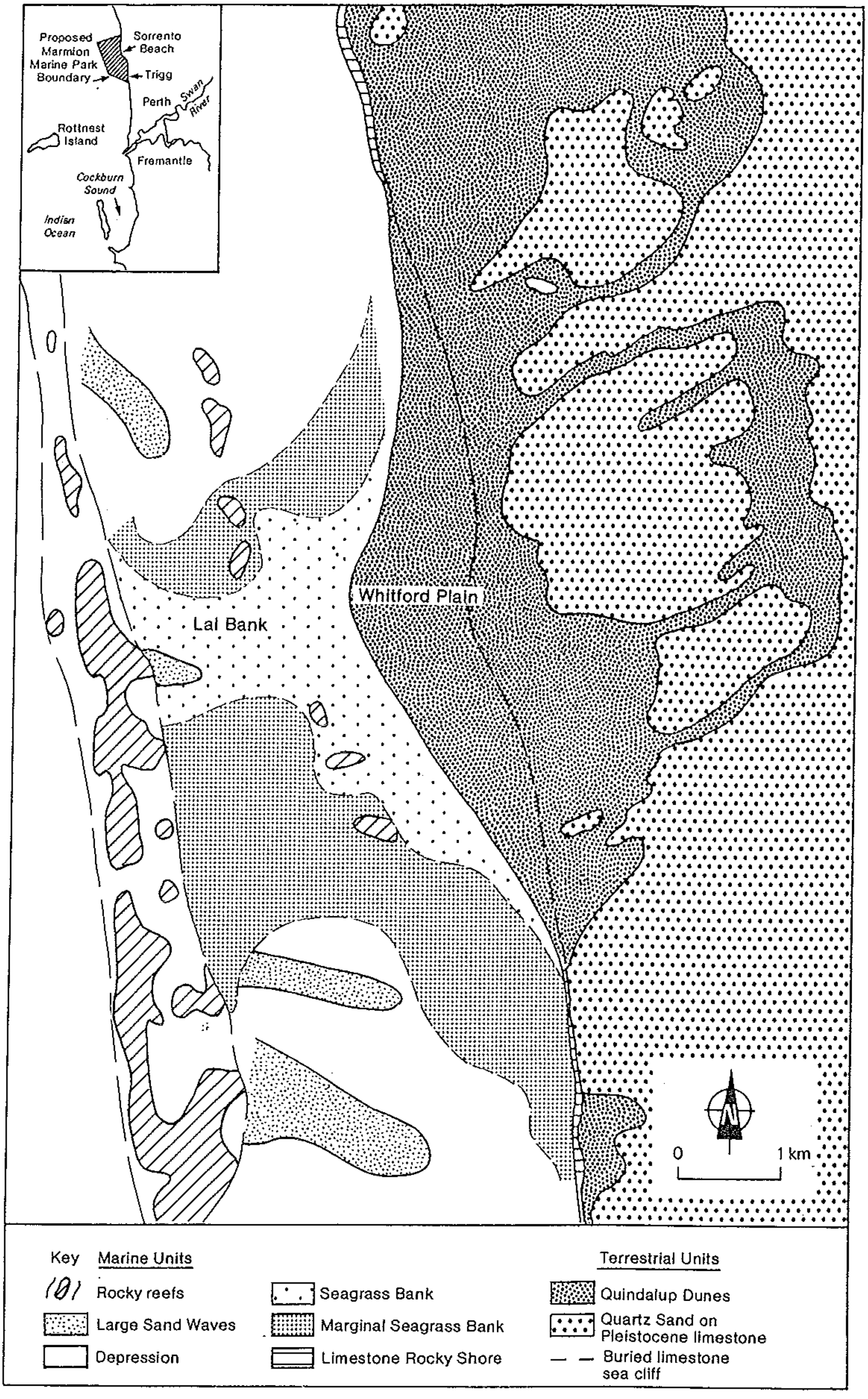

Figure 3. Map showing the discontinuous reefs, the transverse seagrass bank (Lal Bank) and the distribution of rocky and sandy shores in the study area.

onshore in a beach-building process, whereas the episodic, energetic storm waves in winter lead to beach erosion, offshore transport and the formation of an offshore bar.

Thus, on the basis of present knowledge, the study area can be considered a nearly-closed littoral system, in that the seasonally - reversing components of sand transport are much greater than the nett gains and losses of sand. The latter are difficult to measure, and can be considered meaningful only on time scales of hundreds of years.

4.3 LONG TERM CHANGES

Nett gains and losses of sediment include:

- a small onshore supply from reef erosion products. Present reef erosion product supply rates appear to have decreased over time (Woods 1983);
- a small onshore supply from biological materials (including skeletal fragments) derived from marine organisms;
- a nett loss of sand offshore into deeper water owing to intense storm wave attack;
- a nett loss of sand inland owing to wind transport; and
- a small nett longshore sediment flux, estimated as 5 000 - 10 000 m^3/y (Public Works Department 1984), part of which may represent a gradual, local reshaping of the Whitford Plain, as sand is stripped from its southern face and is accumulated on its northern face.

The coast between Mullaloo and Mullaloo Point shows geomorphological evidence of a period of static shoreline position and dune building, followed by a period of shoreline advance and building of low beach ridges over the last few hundred years (Woods 1984; Semeniuk and Searle 1986). Such medium-long term events may have occurred in response to changes in climate or to sediment supply.

Semeniuk and Searle (1986) used radiocarbon dating analyses of shell and peat materials, collected from a number of stratigraphic columns on the Whitford Plain, to infer shoreline changes in this area during the last 8 000 years. As illustrated on Figure 4, these results show that the most recent postglacial marine transgression reached the shore of the Whitford area some 8 000 years before present (BP). About 5 000 years ago, sea level had risen to approximately its present position, and a significant volume of sediment had accumulated in the form of a seagrass bank, capped by beach and beach ridge sediments. The accumulation developed behind a cluster of islets and reefs, centred on Little Island. By 1 300 years BP the accumulation had reached the present position of Mullaloo Point. Subsequently the building phase continued for a time, and then ceased. More recently, the Whitford Plain has undergone shoreline readjustment, with the southern shoreline retreating across older dunes. If present trends prevail the future of the Whitford Plain appears to be one of continuing erosion, with some transfer of material from south to north of Mullaloo Point. It has not yet been established what proportion of the eroded material has been lost through longshore, as opposed to on/offshore movement.

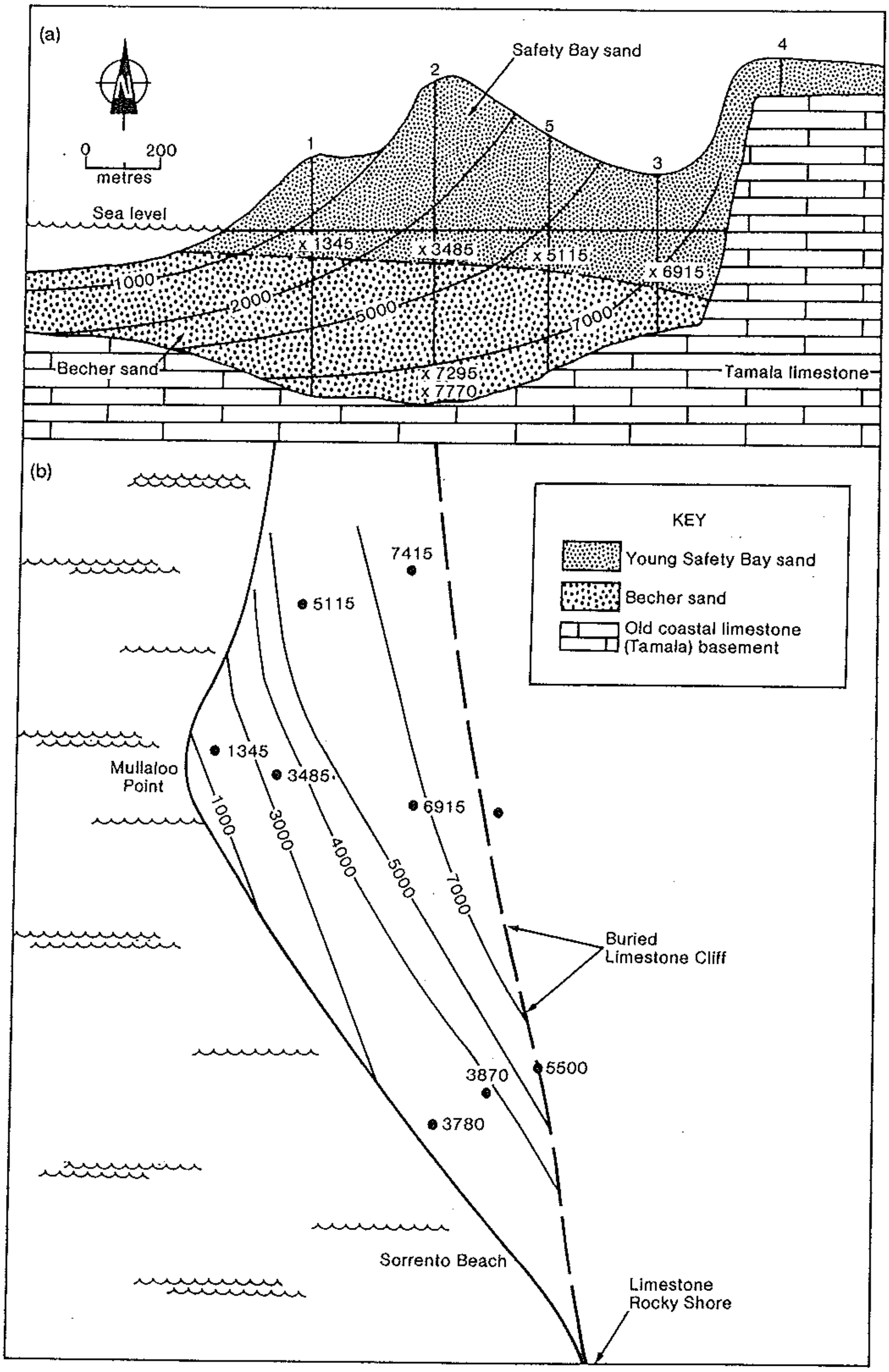

Figure 4. Shoreline changes of the Whitford Plain (redrawn from Semeniuk and Searle, 1986). a: composite cross-section through the Whitford Plain, showing the young Becher and Safety Bay sands overlying older Tamala limestone. Growth lines (in thousands of years) are based on radiocarbon dates (x). b: plan view of the plain showing the position of the shoreline through time. The plain started growing about 7 000 years ago, but the shoreline north of Sorrento now appears to be eroded.

5. DISCUSSION

From the foregoing review, a number of issues emerge, which should be recognised clearly in any management plan for the study area.

The main, sandy portion of the study area coastline exists because of the protection afforded by the Marmion Reef/Little Island complex, and the convergent patterns of swell waves established behind it. Destruction or degradation of portions of the reefs will cause permanent changes to the inshore swell patterns, greater exposure to storm waves, and hence modification of the existing dynamic sediment regime. This in turn may lead to the disruption of seagrass banks, and to rapid (in geological and possibly planning terms) and permanent changes in the alignment of sand beaches along this coast.

The sandy beaches undergo natural fluctuations of width. These fluctuations occur seasonally and on longer time scales. Prevailing onshore winds transport sand inland, away from the active coastal sand system. Medium term (100 year) cycles of accretion and erosion also occur naturally. Superimposed on all these fluctuations is the evolution of coastal landforms over periods of 1 000 years or more. Man's use of the coast and nearshore waters should allow for these natural changes.

Major construction works along the sandy foreshore and nearshore may lead to changes in the sediment transport regime, and particularly to the sediment movements which occur on a seasonal basis. There may be disruption of long-shore littoral drift, destabilisation of seagrass beds leading in turn to increased sand mobility, offshore loss owing to wave reflection from rock breakwaters, or trapping of sand in wave shadow areas created by structures.

Coastal engineering projects and coastal land-use plans are generally formulated on the assumption that climatic and sea level data from the immediate past, without modification, are a reliable guide to the future. This may no longer be a good assumption, since increasing concentrations of "greenhouse gases" in the atmosphere are predicted to cause a significant warming of the global climate and a subsequent rise in sea-level of 0.2-1.4 m within decades (World Meteorological Organisation 1986). Such a sea-level rise could significantly affect the evolution of sandy coasts whose extent and forms depend on the degree and nature of the wave shelter provided by offshore reef chains. Future planning in relation to the study area should therefore take into account the results of continuing research on imminent changes of climate and mean sea level. Planners should consider the implications of such changes, in particular their potential effects on the coastal form, and the increased costs and risks that would be associated with continuing present trends in coastal development.

Between December 1982 and December 1983, the former Public Works Department constructed three groynes near Sorrento townsite to alleviate local erosion problems in the vicinity of the lifesaving club and the beaches to the south. These 'problems' arose as a result of poor siting of buildings, and a failure to take into account natural variations in beach width. As a result of placing these three groynes, beach alignment between the groynes was stabilised. The buildings they were designed to protect are no longer under threat. The northern groyne has become the new limit for the southward moving winter pulse of sand, and the coast immediately north has become the site of seasonal beach width variations.

In June 1985, the State Government announced that the Hillarys Boat Harbour would be constructed on the southern face of the Whitford Plain, just to the north of the Sorrento townsite. Construction of the breakwaters commenced in September 1985. The boat harbour covers a total area of about 55 ha and is enclosed by two rock breakwaters extending up to 600 m offshore (Public Works Department 1984). The southern breakwater is approximately 350 m north of the northern groyne at Sorrento Beach.

While preparing the draft management plan for the proposed Marine Park (Woods *et al* 1985), an assessment was made of changes to sand movements and shoreline stability that might occur as a result of the construction and presence of Hillarys Boat Harbour. It was considered that:

- between the northern groyne at Sorrento and the southern breakwater of the boat harbour, the sandy shore, formerly subjected to seasonal fluctuations, would be stabilised, although some minor periodic renourishment of the beach could still be necessary to replace sand lost offshore during periods of winter storms waves, or blown inland by wind;

- the northern breakwater would become the new barrier to the southward longshore pulse of sand in winter, and there would most likely be a winter building of the beach immediately north of the boat harbour.

There was uncertainty concerning the extent to which sand, accumulated during winter in an area immediately to the north of the boat harbour, would be naturally moved north by the ensuing summer wave regime. It was felt that the projecting breakwaters of the boat harbour could possibly provide an area of partial shelter from the prevailing summer southwest swell and wind waves. Furthermore, there was concern that, if accumulated sand were to remain adjacent to the northern breakwater through summer until the subsequent winter, then it would be exposed to storm waves from the northwest, and could be moved offshore into deeper water. The result of this would be a permanent loss of sand from the active beach system. Such a sand loss, unless artificially replenished, could result over a number of years in progressive shoreline erosion between the boat harbour and Mullaloo Point. Siltation of the entrance to the boat harbour could also occur should sand creep along the northern breakwater.

The Department of Marine and Harbours made available diagrams of shoreline positions in the area for March 1985, and on a monthly basis from September 1985 (when breakwater construction commenced) to December 1986. These charts were derived from aerial photographs, taken at selected times and tidal states, and have been used to assess the initial effects of the Hillarys Boat Harbour on sediment and shoreline movements in the area.

The timing of the breakwater construction was such as to trap sand which had been driven south of the site during the preceding winter months. The shoreline charts indicate that the total amount of sand trapped by the breakwaters and in storage to the south of the harbour has not changed appreciably since construction commenced. This sand now appears to be part of a virtually closed sediment system, with very little nett sediment input from the south, even during summer. This result strengthens the prediction (Public Works Department 1984) that only occasional bypassing of sand from south to north of the harbour will be necessary.

In December 1985 some placement of sand was in progress on the beach immediately to the north of the northern breakwater. The February 1986 chart indicated shoreline recession (relative to December) by about 10 m over a distance of 800 m north of the breakwater. The eroded sand may be involved as part of the northward moving pulse of sand generally experienced in summer.

About 60 000 m^3 of sand were placed north of the northern breakwater in February-March 1986, resulting in a widening and reshaping of the beach in the immediate vicinity of the harbour. This sand did not appear to move during the subsequent winter. From March to June 1986 there was a general beach widening (about 7 m) along the first 450 m north of the northern breakwater, and beach erosion occurred for at least the next 500 m further north. From June to September 1986 there was only slight further beach widening in the first 450 m, but substantial (15 m) building of the beach segment eroded from March to June. These shoreline movements during winter 1986 were consistent with the occurrence of a southerly winter pulse of sand. A volume of sand of the order of 50 000 - 100 000 m^3 has apparently moved in from the north during winter.

In November - December 1986 a further 40 000 m^3 of sand were placed on the beach to the north of the boat harbour. This nourishment of the beach masked the shoreline response to the early 1986 summer swell and wave pattern. At distances of greater than 500 m north of the breakwater, the beach showed minor erosion from September to December 1986.

In summary, from September 1985 to December 1986, approximately 100 000 m^3 of sand were placed to the north of the Hillarys Boat Harbour. The net change in shoreline position over this period consisted of a marked beach widening and realignment extending up to 400 m north of the boat harbour, and a minor erosion (about 5 m) for a further 350 m, which is within the limits of seasonal change expected for this shoreline. It is too early to identify and evaluate the significance of annual sand losses from the system. The size of these losses will be one of the main factors determining the need for and extent of ongoing beach nourishment.

Rocky coasts are associated with areas of divergent swell patterns, and have little shelter from storm generated waves. Land-based developments constructed on stable, rocky coasts are exposed to lower risks of structural damage compared with developments on sandy coasts.

A summary of the management implications of using the sandy and rocky coasts in the study area is given in Woods (1986).

Blasting of reefs, or dredging of Lal Bank, is likely to affect the hydrodynamics as well as the sediment dynamics of the study area. Removal of parts of the protective reefs or the sand bank will affect patterns of water circulation, and may lead to changes in water residence times, the regimes of water temperature, salinity and nutrient concentrations in the study area. Thus, blasting and dredging activities are likely to have both a local impact and secondary, wider impacts, especially on the biological systems of the area.

The Hillarys Boat Harbour, because of its size (55 ha) when compared with that of the waters of the study area (10 700 ha), or that of the 'Marmion lagoon' (2 500 ha), is not likely to affect the main patterns of water circulation, or the residence times of these water bodies. Generally, the local nearshore currents will be deflected around the boat harbour. Some local, transient circulation patterns may be induced by the projection of the breakwaters. Drift material, such as seagrass wrack, may accumulate adjacent to the harbour, and this may be of nuisance value to beach users and swimmers. Wave energy immediately seaward of the breakwaters may be increased by about 20% with some possibility of seagrass loss and changed sea bed sediment movement (Public Works Department 1984), though this is expected to be quite localised on what is already a moderate wave energy coastline.

Twice-yearly monitoring of water quality and sediment contamination levels inside and outside the Hillarys Boat Harbour has been performed by the Department of Marine and Harbours, as part of the Environmental Monitoring and Management Programme for the harbour (Department of Conservation and Environment 1985). This monitoring was initiated in August 1985, just prior to construction. Insufficient measurements are available at present to make predictions about the long-term quality of the waters and sediments within and around the harbour. However the results indicate:

- that widespread, fine, suspended sediment plumes resulting from rock dumping operations occurred commonly during construction of the breakwaters;

- that pollutant loads from within the harbour do not at present appear to be causing problems; and

- that the harbour can trap and accumulate widespread, naturally occurring organic debris, such as seagrass drift and algae from blooms.

Johannes and Hearn (1985) have estimated that the present annual nitrate load to the 'Marmion lagoon' from submarine groundwater discharge is equivalent to about one half of the nitrogen requirements of lagoon macrophytes. Nitrate concentrations in Perth groundwater have been increasing significantly in the last decade (Martin 1980) because of accelerating urbanisation. These concentrations will inevitably continue to increase. Furthermore, because of the movement of the groundwater at the rate of 90 m/y, existing concentrations in groundwater now situated 1 km inland may be anticipated at the coast in about a decade. It may therefore be many years before the full impact of urbanisation on groundwater discharge to the coast is realised; once it is, reversal of this trend to one of decreased nutrient input will be very difficult.

The Beenyup and Subiaco wastewater outfalls currently provide large loadings of nitrogen and phosphorus to the coastal waters of the study area and surrounds. The Water Authority projects that, by about the year 2 000, flow rates from the Beenyup outfall will triple (Water Authority of Western Australia, personal communication 1985), and is currently proposing to duplicate the Beenyup ocean outfall pipe. The Environmental Protection Authority has asked for a study of the environmental implications and potential impacts of this proposal. This work has been commissioned by the Water Authority and is now being performed by its consultants.

The cities of Perth, Stirling and Wanneroo intend to develop a long-term organic refuse disposal facility at Mindarie, about 6 km north of the study area and 2 km north of Burns Beach (Kinhill Stearns 1983). Disposal of solid waste to a 22 ha site is scheduled to start in 1989. Groundwater beneath the proposed site flows toward the coast, and some nutrient enrichment of coastal waters from leachate may occur. This development may therefore have an eventual impact on the proposed marine park, particularly if the park is extended north to Burns Beach. The Environmental Protection Authority has requested that the developers formulate and implement an acceptable

Environmental Management and Monitoring Plan (Department of Conservation and Environment 1985). This would include contingency plans for implementation of alternative waste disposal practices should the contaminated groundwater plume from this site pose environmental problems. It is important that any signs of impending problems be detected as early as possible, because it would take a considerable time to reverse these trends. The CSIRO Division of Groundwater Research is presently conducting research at Mindarie to develop better methods for the monitoring and prediction of contaminated groundwater plumes.

Future cumulative loadings from these and other sources will lead to increased nitrogen and phosphorus concentrations in seawater, stimulating growth of planktonic and epiphytic algae, and possibly causing loss of seagrasses and large attached algae by shading. Loss of seagrass meadows and the attached algae on reefs would have major ecological consequences because fish and other marine organisms in the area require these plants as habitats, and as direct and indirect food sources. The loss of these large plants would result in changes to the structure of the marine communities and changes in sediment movement patterns, as seagrasses are the major agents stabilising sandy sediments of the lagoons.

6. CONCLUSIONS

From the review of information presented in this paper, the following conclusions may be drawn:

- In view of the key role of the offshore reefs and the transverse Lal Bank in maintaining existing sediment movement, water circulation and flushing patterns, the integrity of these natural structures should be guarded.

- Seasonal and longer term natural fluctuations of the sand beaches within the study area need further study. Oscillations of the coastline at these places should be given due consideration in the long-term management strategy for the study area.

- Allocation of land uses should also take into consideration the stability and wave exposure of rocky coasts, compared with the mobility and wave shelter of sandy coasts.

- The Hillarys Boat Harbour is likely to affect the movement of sand along the coast, and adjacent shoreline positions may be altered as a consequence.

- Anthropogenic sources of nutrients (originating from wastewater outfalls, submarine groundwater discharge, and other sources), and nutrient dispersal in the coastal waters of the study area need further investigation. Monitoring of nutrient levels in the coastal waters, from submarine groundwater discharges, and in inland aquifers, should form part of the basis for a management strategy for the proposed marine park, and for the general Perth metropolitan coastal waters.

- The implications for the study area of a projected rise in mean sea-level in the order of 1 m within decades, predicted as a consequence of the "greenhouse effect", should be studied. Future planning directions for the study area should reflect an awareness of these implications.

7. ACKNOWLEDGEMENTS

Dr J Hunter, School of Physics and Geosciences, Western Australian Institute of Technology, provided comment on the meteorology and wave climate sections. Officers of the Water Authority of Western Australia furnished information on present and projected secondary treated effluent discharges, and provided data on nutrient concentrations in groundwater. E Moore and Dr J R Ottaway (EPA) provided valuable editorial assistance, and B Stewart (EPA) assisted with the publication of this report.

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A PILOT STUDY OF SOCIAL AND BIOPHYSICAL ATTRIBUTES OF THE PERTH METROPOLITAN COAST BETWEEN TRIGG ISLAND AND SORRENTO BEACH

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Abstract

The results from a pilot study to assess recreational pressure on the coast between Trigg Island and Sorrento Beach are presented and discussed. Recreational use of the coastal complex, its geomorphology and water circulation patterns and, the identification and distribution of its biota are the main aspects covered.

Photogrammetric aerial surveys of the coastal reserves in the proposed Marmion Marine Park were undertaken at 0800, 1200 and 1600 hours on Sunday 3 March 1985 to assess spatial variability of reserve use. The aerial surveys were complemented by ground surveys undertaken between Trigg Island and Mullaloo Point at half-hourly intervals between 0600 and 1800 hours on Wednesday 6 March and Sunday 10 March 1985.

Data from the aerial surveys suggested marked temporal and spatial variation in numbers of people using the coastal reserve and nearshore environment. This was confirmed by the ground surveys. Beach usage, in terms of numbers and types of activities, varied markedly between midweek and the weekend, and from embayment to embayment. An informal zoning of activities existed, with recreational focus points at Trigg Island, Mettams Pool, Mettams Beach, Watermans Beach and Sorrento Beach. These embayments were suitable for passive recreation activities, which need to be kept apart from activities such as fishing. The informal zoning could be supported by careful provision of appropriate onshore amenities.

Recreational pressures have had impacts on the study area and have exacerbated natural processes already at work. Firstly, there is a purported decrease in abundance of biota and change in species composition. On the rock platform adjacent to Mettams Pool, where recreational use was greatest, species diversity was low and trends in distribution differed from other platforms. Secondly, there may be a decline in water cleanliness in some rock pools in late summer. Thirdly, erosion of limestone intertidal platforms has been hastened by recreational users who have inadvertently or intentionally broken pieces of limestone or excavated soft aeolianite. Fourthly, although much has been done to control unrestricted tracking through sand dunes, there are still areas where tracking is uncontrolled and blowouts could begin. Recreational pressures have also influenced beach cleanliness, so that both residents and retailers perceive a decline in the cleanliness of beaches in the coastal reserves.

CONTENTS

FIGURES

FIGURES (cont'd)

TABLES

1. INTRODUCTION

In February 1985, arrangements were made to enable Honours students from the Department of Geography to undertake studies of the coastal reserve bounded by Trigg Island and Sorrento Beach, Perth, Western Australia, together with the nearshore waters. The City of Stirling Coastal Report (City of Stirling 1984) recommended, amongst other things, that a more detailed examination be undertaken of the biological status of the nearshore reefs and rock platforms, together with a more detailed examination of nearshore morphology, water circulation and sediment movements (City of Stirling 1984). The City of Stirling and the Department of Conservation and Environment also wished to acquire more information on current beach use, to provide a basis for the assessment of future use of the coastal complex for recreational, educational, scientific and conservation purposes.

The project that evolved from these requirements focused on recreational activity in the coastal reserve and its environmental implications. A range of information was gathered and assessed for the study. This included:

- field surveys of recreational use of the coastal reserves, circulation patterns and biota of rock platforms adjacent to rock pools;
- a reappraisal of questionnaire surveys of residents and local retailers conducted by Keating in 1983;
- aerial surveys of beach user activity;
- mapping of geomorphology from aerial photographs and ground checking the resultant maps.

1.1 DEFINITION OF THE STUDY AREA

The study area (Figure 1) included the coastal reserves of the Stirling and Wanneroo municipalities from the northern side of Trigg Island to Sorrento Beach. Its eastern boundary was West Coast Highway, while the western boundary extended approximately 100 metres offshore to the edge of a series of rock platforms characteristic of this section of coastline. Hence, the coastal reserves included the nearshore environment of the beach system and land immediately adjacent to it, which was the shore boundary of the proposed Marmion Marine Park, formerly referred to as M10 Marine Park, (Environmental Protection Authority 1983). This coastal strip includes about 1.5% of the area of the proposed M10 marine park; however, that 1.5% supports about 80-90% of the activities of the beach going population using the park area, and is therefore especially important.

1.2 CONTEXT OF THE STUDY

Coastal management in Western Australia has been, until recently, the responsibility of local government authorities acting under advice, or working cooperatively, with the State government authorities responsible for public works and town planning. As a result of this informality, coastal management has occurred on an ad hoc basis with adjacent local government authorities adopting, in some instances, conflicting shore protection policies (City of Stirling 1984). Declaration of the Environmental Protection Act (1971), formation of the Department of Conservation and

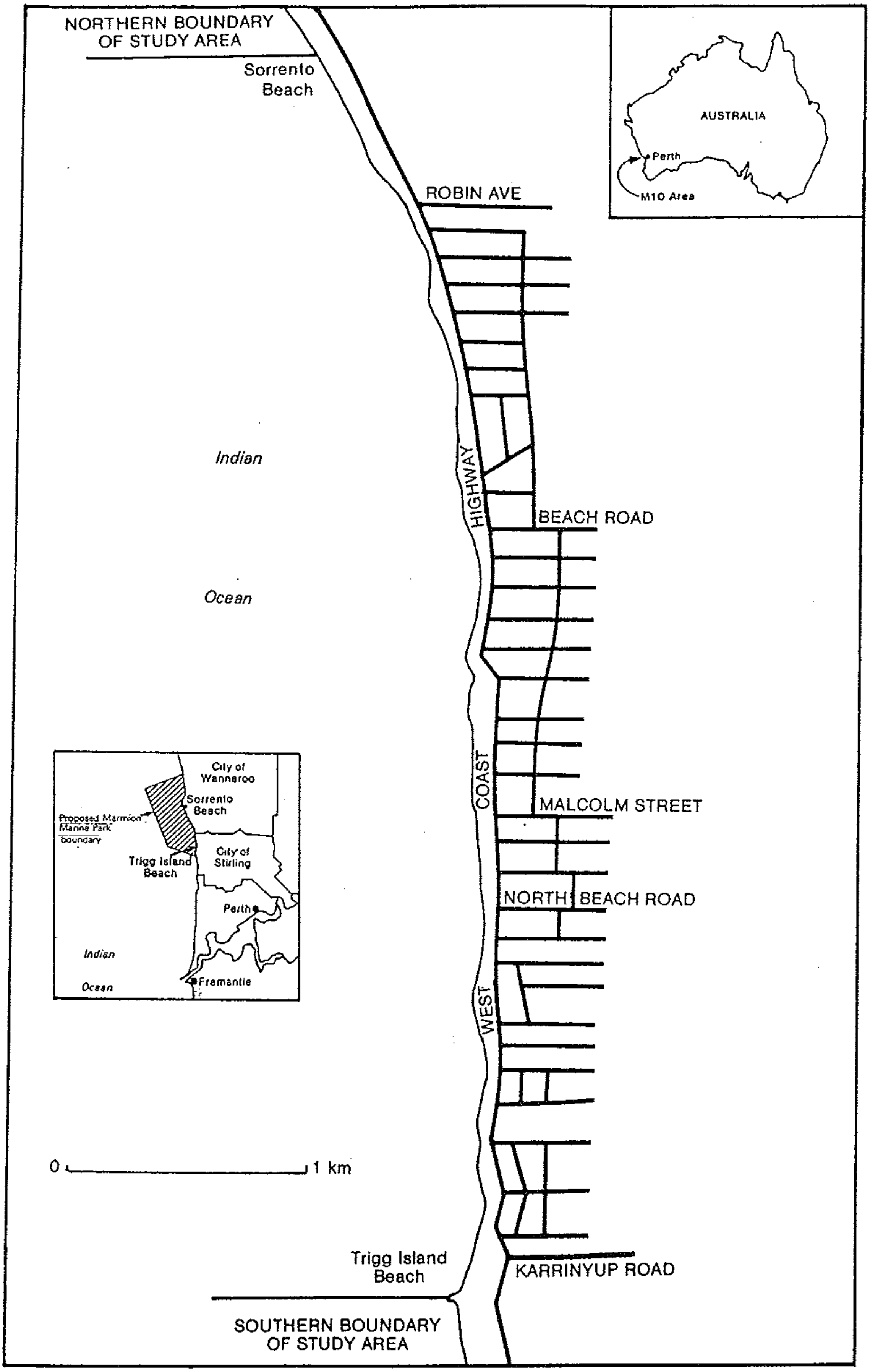


Figure 1. Location of study area. Inset: location of the proposed M10 marine reserve, with boundaries as shown in DCE (1981) and EPA (1983).

Environment, and increased public interest in the coastal zone, has led to a more coordinated approach to coastal planning and management (Sansom and Hamilton 1981), increased pressure for the declaration of an environmental protection policy for the coastal zone (Environmental Protection Authority 1977), generated compilation of non-statutory coastal management plans as working plans for local government authorities (for example, Chape and Sansom 1983; Chalmers and Davies 1984, City of Stirling 1984; Woods 1984 a,b), and has led to State government declaration of its position regarding coastal planning and management (Western Australian Government 1983).

Despite the burgeoning interest in coastal management and planning in Western Australia, there have been few systematic studies of recreational use of coastal reserves in the metropolitan area of Perth so that the value of the coastal reserve as a recreational resource is not fully appreciated. Prior to the mid-1970's, planning proceeded in an ad hoc manner, largely in response to government perceived pressures exerted by small interest groups with political influence. Government now plays a wider role, but coastal management continues to be organised on a piecemeal, project by project basis. Decision-making presently rests with governmental agencies which have little interest in the recreational use of marine resources (for example, see the arguments of the Main Roads Department in MRPA Technical Working Group, 1985). There does not appear to have been any general questioning of the nature and variety of recreational activities within the coastal reserves, of the space those activities demand, of the type of impact they might have on the coastal reserves, or of the economics underlying coastal recreation. This is particularly true of the M10 area, where the aims of establishing a marine reserve must necessarily be integrated with recreational and commercial usage of that reserve, if the viability of the reserve is to be maintained. There is now an urgent need to establish the resource potential of the coastal zone and its particular assemblage of coastal communities before we inadvertently commit it to landuse having a limited economic return.

1.3 AIMS OF THE STUDY

The major aims of this study were threefold: first, to assess the recreational pressure on the coastal reserve and its associated nearshore environment; second, to identify the coastal resources in the study area; third, to examine the impact of recreation on the environment and assess its potential use. This study was essentially a pilot survey for three main areas of research; recreational use of the coastal complex, its geomorphology and water circulation patterns and, the identification and distribution of its biota. These subjects are covered in Chapters 2, 3 and 4 respectively where specific aims are defined. Chapter 5 draws together the results and conclusions of each of these chapters in a discussion. Aspects that require further research are pinpointed and some recommendations (Chapter 6) are made as to how the study area could be maintained for multipurpose use.

2. RECREATIONAL USE OF COASTAL COMPLEX

2.1 INTRODUCTION

Two surveys of beach recreation have been reported from studies of the rocky coast between Trigg and Sorrento within the proposed park area. These have concentrated on the sociological attributes of the local residential population. One study was conducted by Keating (1983) for beaches between Trigg Island and Sorrento, where data were collected from local residents on a variety of characteristics including their use of the beach. It is likely that there is a discrepancy between what people say they do and how they actually behave. Hence, a survey of the resident population, such as that of Keating (1983) may define the potential use of the beach, rather than the actual use of it. The second survey reported by the City of Stirling (1984) endeavoured to establish characteristics of beach users by interviewing people using the beach. A survey of this nature has some problems, not the least being determining whom to interview, and when to interview, to obtain a representative sample of the population of actual beach users.

The present study adopted a different approach to examining the use of beaches between Trigg Island and Sorrento. By observing the people using this stretch of coastline, it was hoped to establish what activities were being undertaken, at what times, and by how many people. Coupled with the data collected on the geomorphology, water circulation patterns and biota, it was hoped that some conclusions could be drawn on the factors that govern use of rocky coastlines. The specific aims of this work were to:

(i) establish the temporal and spatial patterns of beach usage for the study area during daylight hours;

(ii) identify areas of intense recreational use and areas that were not frequently used;

(iii) report data collected by Keating (1983) to ascertain the attitudes of local residents to the development and use of the coastal reserve;

(iv) extract relevant data from an unpublished shopping centre survey conducted by Keating, in 1982, to establish the attitudes of local retailers to use and development of the coastal reserve;

(v) report the results of an aerial-photographic survey of beach use between Trigg and Ocean Reef conducted by the Department of Conservation and Environment on 3 March 1985;

(vi) identify coastal resources of the Study Area.

2.2 METHODS

BEACH USE BETWEEN TRIGG ISLAND AND OCEAN REEF: 3 MARCH 1985

An aerial survey to examine the pattern of coastal use from Trigg Island to Ocean Reef was conducted by the Department of Conservation and Environment as part of the Marmion Marine Park study. The survey was undertaken on Sunday, 3 March 1985 (the middle day of a long weekend), which was chosen as a day indicative of summer use. Aerial photographs were taken in three survey runs, 0800, 1200 and 1600 hours (Department of Lands and Surveys, photographic job 850018, WA2284(C), scale 1:3000, runs 1, 2 and 3, photographs 5001-5074; 5096-5168; 5009-5077) to enable estimation of both spatial and temporal beach use characteristics.

The coastline from Trigg Island to the northern side of Ocean Reef Boat Harbour was divided into sections of 250 m to facilitate interpretation from the aerial photographs. Each 250 m section included the coastal reserve, any adjacent carparks and public open space. The numbers of people, boat trailers and vehicles located in each 250 m section were counted from the aerial photographs. Data from each survey was compiled in tables. Histograms were drawn to show the spatial variations in the total number of people in each section for 0800, 1200 and 1600 hours. A composite histogram showing the total number of people using each section over the three periods was also compiled (Figure 3).

BEACH USE BETWEEN TRIGG ISLAND AND SORRENTO BEACH: 6 AND 10 MARCH 1985

Observations were made to examine spatial and temporal variations in beach use, and to establish areas of intensive use, on two days: Wednesday, 6 March and Sunday, 10 March. The surveys were conducted on these two days to examine variation between midweek and weekend beach use patterns. The study area was divided into eleven embayments (Figure 2), defined as areas of beach enclosed between two headlands. Each embayment was surveyed from vantage points along the cycle way adjacent to West Coast Highway.

Data collected from the ground surveys were compiled in tables to show the number of people undertaking the activities in each section of coastline over the study period. To simplify further analysis, activities were grouped into five categories relating to reef, water, beach, headland and the reserve (Table 1).

Table 1. Types of recreational activities observed between Trigg Island and Sorrento during surveys on 6 and 10 March 1985.

WATER RELATED ACTIVITIES	REEF RELATED ACTIVITIES	BEACH RELATED ACTIVITIES	HEADLAND RELATED ACTIVITIES	RESERVE RELATED ACTIVITIES
launching boats	snorkelling	line fishing	line fishing	picnicking
yachting	reef harvesting	walking	walking on rocks	using playground
surf skiing	education	jogging	education	walking
windsurfing	scuba diving	exercising dogs		jogging
wading		sunbathing		cycling
swimming		beachcombing		viewing scenery
board surfing		sporting activities		

Weather conditions, which can effect beach use considerably, were assessed for the beach survey days. Three hourly temperature readings for periods of fieldwork, and percentages of cloud cover for morning and afternoon were obtained from the Bureau of Meteorology. Fremantle Port Authority wind and tide anemographs were used to establish times and heights of low and high tide, wind direction and average speed as well as maximum wind gust.

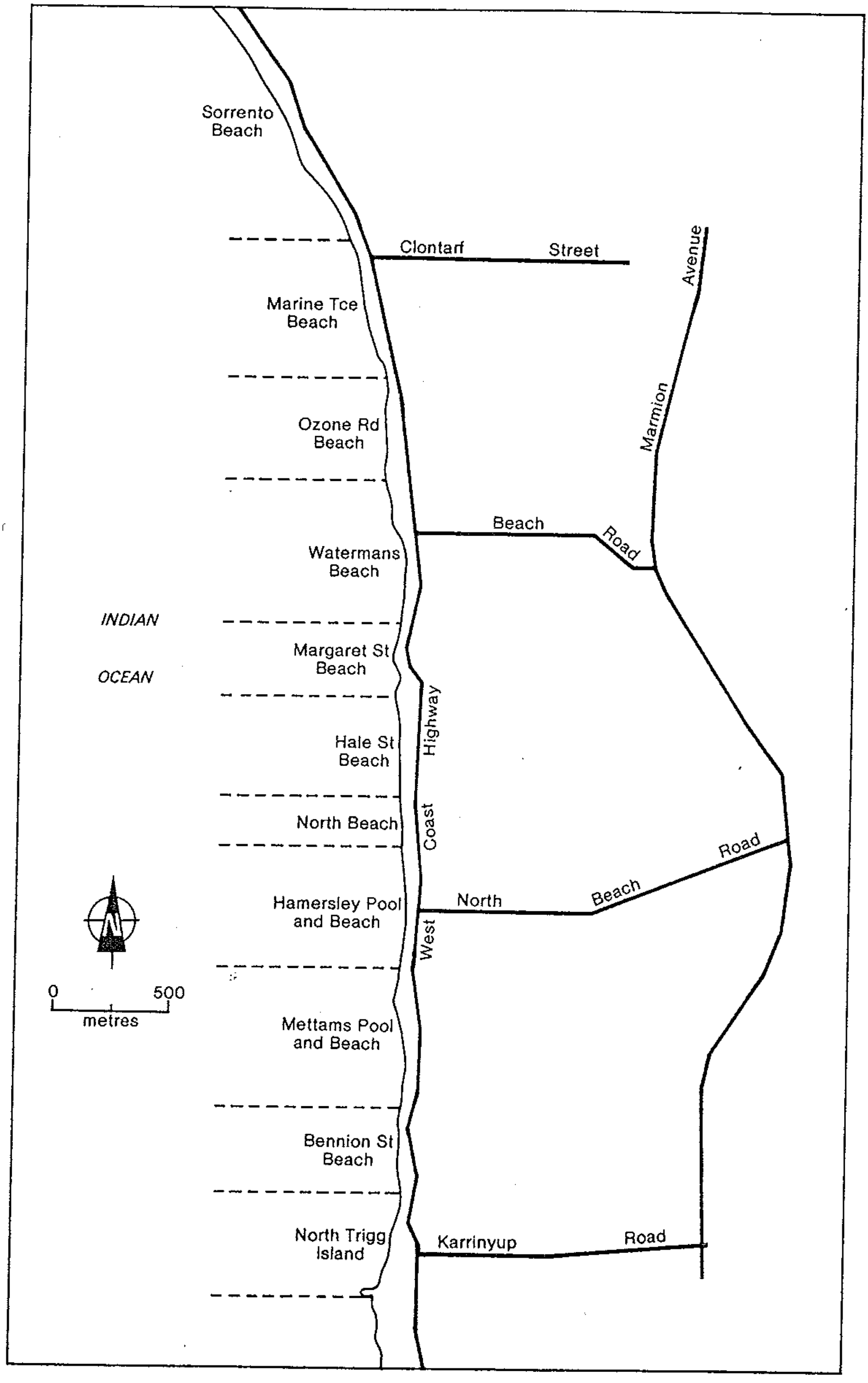


Figure 2. Division of the coast into nominated embayments, for the purpose of the recreational surveys on 6 and 10 March 1985.

ATTITUDES OF LOCAL RESIDENTS AND RETAILERS

Data collected by Keating in 1982 and 1983 were used to establish attitudes of local residents to the coastal reserve (Keating, 1983) and of retailers adjacent to the study area (unpublished data). Responses to selected questions were used as indicators of the attitudes of both groups and to establish patterns of beach use by local residents.

2.3 RESULTS

SURVEY RESULTS

Data on weather conditions prevailing during the beach surveys are given in Table 2.

Table 2. Weather conditions during beach surveys.

DATE 1985	WIND (FREMANTLE)			TIDE (FREMANTLE) *		φ TEMP PERTH °C	% CLOUD COVER PERTH
	TIME	DIRECTION	AVGE (MAX) VELOCITY KM/HR	HIGH TIME (HRS) HT (M)	LOW TIME (HRS) HT (M)		
3.3	0600				0600 (0.34)	18	
	0800	E	16 (30)				
	0900					21	13
	1200	ESE	16 (34)			27	
	1500					29	13
	1600	SSE	39 (50)	18.30 (1.04)			
	1800					27	
6.3	0600	SSE	10 (22)		0645 (0.43)	20	
	0800	S	22 (31)				
	0900					24	38
	1000	SSE	24 (30)				
	1200	S	25 (38)			25	
	1400	S	33 (46)				
	1500					25	50
	1600	S	33 (42)	19.30 (1.04)			
	1800	S	31 (42)			23	
10.3	0600	E	10 (15)		0700 (0.52)	14	
	0800	ENE	3 (6)				
	0900					19	13
	1000	SE	3 (8)	12.30 (0.85)			
	1200	S	11 (27)			23	
	1400	S	28 (37)				
	1500					23	13
	1600	S	30 (38)				
	1800	SSE	30 (40)			21	

Source of data: * Fremantle Port Authority Wind Anemographs and Tide Records
φ Bureau of Meteorology

Results from the aerial survey of the 3rd March are shown in Figure 3. These indicate population dimensions of discrete clusters of people using beaches between Trigg Island and Ocean Reef. Several important recreational focus points can be identified from this survey. Primary focus points were located at Mettams Pool, Mettams Beach, Sorrento Beach and Mullaloo Beach. Secondary focus points were located at Watermans Beach and Mullaloo Point. These findings were supported by the ground survey data collected on 6 and 10 March 1985. Spatial variation of beach use along the coastline is illustrated by a series of pie charts for three time periods: 0800 hrs, 1200 hrs and 1600 hrs (Figures 5-10).

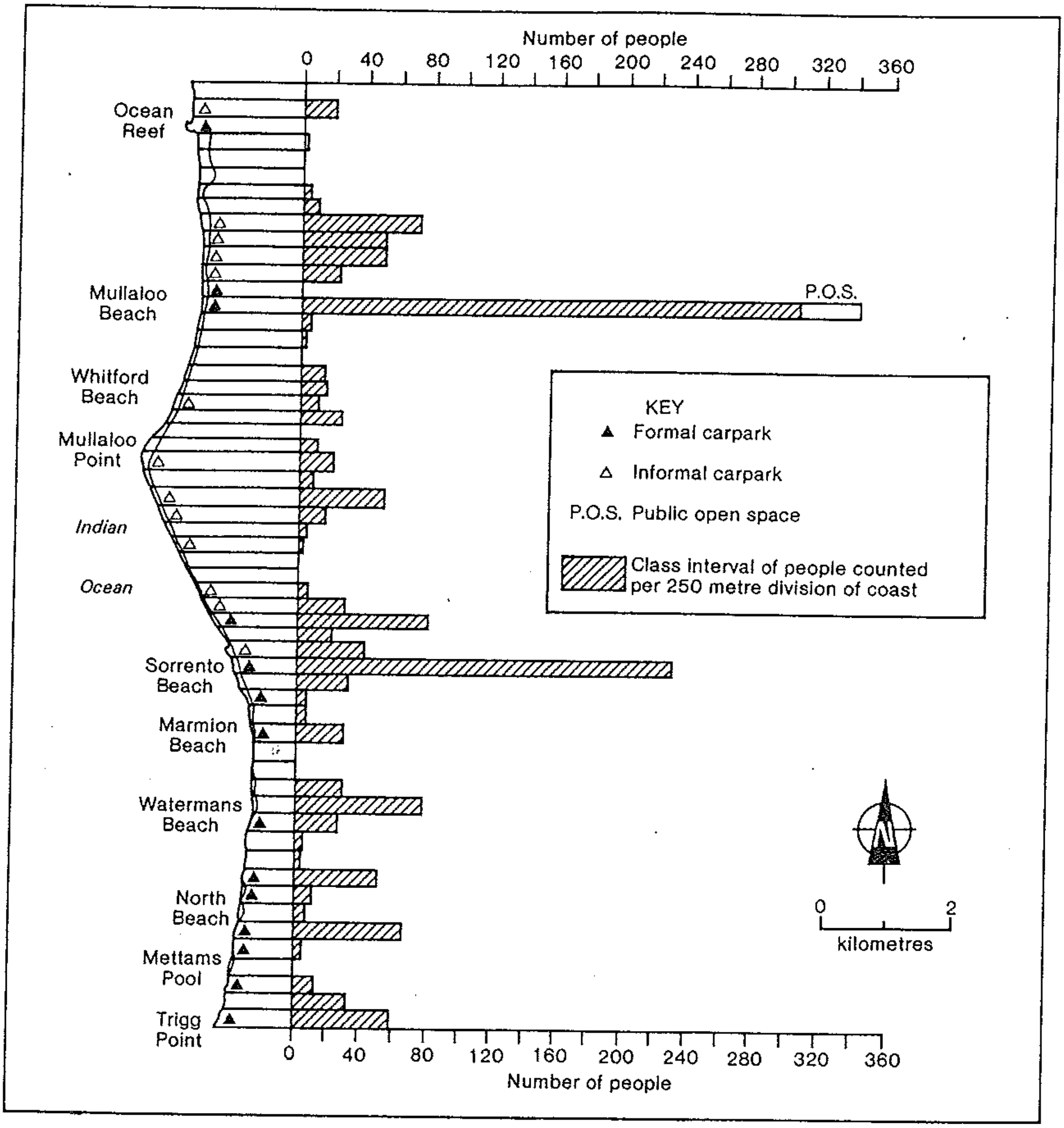


Figure 3. Distribution of people using the coast reserve. Numbers were counted from photographic prints taken during aerial surveys flown at 0800, 1200 and 1600 hours on 3 March, 1985.

The size of each pie chart varies depending upon the number of people at each embayment. The five categories listed in Table 1 are the five categories of the pie charts.

During the ground surveys four recreational focus points were identified between Trigg Island and Sorrento Beach. These were immediately north of Trigg Island, Mettams Pool and Mettams Beach, Watermans Beach and Sorrento Beach. The range of activities found at these four beaches was wide. Areas that showed consistently low levels of recreational use were also identified. They included the beaches opposite Hale Street, Margaret Street and Ozone Road.

The observed variations in numbers of people and range of activities occurring in the study area can be explained partly by the availability of facilities (including access and parking) and partly by the physical characteristics of each embayment (including water quality and beach cleanliness, as well as safety factors). The availability of amenities was determined by historical precedent, through development of the coastal communities as small, holiday settlements (Newell and Weller 1980). Environmental factors and supporting facilities which influence people to select a particular area for recreation are listed (Table 3).

All three surveys indicated that, although zoning was not formalised, there was potential for the encouragement of informal zoning through the provision of appropriate facilities, which should enhance as well as support existing recreational use of the major recreational focus points.

The Range of Recreational Activities occurring between Trigg Island and Sorrento Beach

There was great diversity in activities undertaken in the study area (Table 1). On Wednesday 6, the largest range of activities occurred at Watermans Beach, where twelve different activities were recorded. Eleven different activities were recorded at Sorrento Beach. Hale Street Beach showed the least diverse range of activities with only four different activities. On Sunday 10, the greatest range of activities was again recorded at Watermans Beach. The embayment north of Trigg Island, Mettams Pool and Beach, and Marine Terrace all recorded thirteen different activities, while the beach at Margaret Street had the least varied beach use pattern, with only seven different activities recorded. Overall, the embayment north of Trigg Island, Mettams Pool and Beach, and Watermans Beach showed the greatest range of activities over the study period. The beach at Margaret Street showed the lowest diversity of beach use (Table 4).

Temporal Variation in Beach Use between Trigg Island and Sorrento Beach

The variation in the total number of beach users over the two study days between 0600 hours and 1800 hours is illustrated (Figure 4). There were four discernible peaks in beach use on Wednesday 6 March 1985 at 0630, 1000, 1230 hours and 1630 hours. The peak at 0630 hours resulted primarily from early morning exercisers and fishermen. Peaks at 1000 hours and 1230 hours were caused by school children using the beach and nearshore areas for educational purposes. At 1630 hours, numbers along the coast were increased by people board surfing, wind surfing, and by school children using the coastal area for recreation after school had finished. The maximum number of people recorded in the study area was 337, at 1000 hours.

Table 3. Requirements for various types of water-based use of the coastal reserve.

(P): primary requirements and industries considered necessary for the particular recreational practice.
(S): secondary requirements support the recreational activity, and are needed in the general area.

ACTIVITY	SEA REQUIREMENTS	ONSHORE SUPPORT REQUIREMENTS/INDUSTRIES
Swimming	Clean water, sufficient water circulation and flushing; no dogs or sewage	Car and cycle parking reasonably close by (P) Access (P)
	Calm protected water of reasonable depths. (Open water can be experienced at South Trigg or Sorrento)	Changerooms, toilets, showers (P) Areas of sandy beaches (P) Surf life-saving clubs (S)
	Presence of sandy-bottom and absence of sharp, dangerous rocks	Suitable retail support in nearby shopping centres (S)
	Absence of strong or permanent rips	
	Infrequent accumulation of seaweed	
	Freedom from boats, boards, windsurfers, surf-skis and line fishing	
Wading	Water cleanliness for swimming (above)	
	Calm shallow water	
Board surfing/ surf skiing	Waves of suitable height, type and frequency	Parking facilities for cars or for bicycles with board trailers (P)
	Moderately deep water	
	Rips useful for 'lift' past breaker line	Suitable retail support in nearby shopping centres (S)
	Water for surfing should be free from rocks, although shoreline doesn't necessarily need to be rock free	
Windsurfing	Freedom from shallow water over rock platforms	Car park facilities in immediate vicinity (P)
	Uninterrupted wind, viz, not in immediate lee of headland	Suitable retail support in nearby shopping centres (S)

Table 3. Requirements for various types of water-based use of coastal reserve (cont'd).

ACTIVITY	SEA REQUIREMENTS	ONSHORE SUPPORT REQUIREMENTS/INDUSTRIES
Snorkelling (recreational)	Scenic underwater areas, such as those provided by rock platforms and even submerged reef Freedom from power boats, and skis Clear water for visibility Absence of strong wave activity	Car and cycle parking reasonably close by (P) Suitable retail support in nearby shopping centres (S)
Spearfishing	Supply of diverse fish (sustained) Absence of strong wave activity and underwater currents Freedom from power boats Absence of other recreation users	Car park facilities (P) Fish cleaning facilities (S) Spearfishing equipment shop (S) Medical back up (S)
Scuba diving	All of above snorkelling requirements Deeper water	Car park requirements (P) Scuba equipment and tank filling shops (S) Medical back-up (S)
Reef harvesting	Intertidal rock platforms No rips or strong flow over the reef platform Adequate and sustained supply of biota	
Line fishing	Supply of fish (sustained) Freedom from swimmers and boats No floating or submerged litter Place from which to cast-off	Car and cycle parking (P) Bait and tackle shop (S) Fish cleaning facilities (S)

Table 3. Requirements for various types of water-based use of coastal reserve (cont'd).

ACTIVITY	SEA REQUIREMENTS	ONSHORE SUPPORT REQUIREMENTS/INDUSTRIES
Boat launching	Access not too steep, either onshore or in water	Parking facilities for cars and trailers (P)
	Freedom from shallow submerged reefs	Waiting facilities near the boat ramp (P)
	Away from areas of turbulence and/or strong rips	Boat fuel supply (S)
	Preferably in lee of headland	
	Preferably away from areas of frequent seaweed accumulation and sand drift	Suitable retail support in nearby shopping centres (S)
	Away from other recreational activities	

Table 4. The number of different activities recorded at each beach over two study periods, Wednesday, 6 March and Sunday, 10 March.

BEACH	NUMBER OF DIFFERENT ACTIVITIES RECORDED		TOTAL NUMBER OF DIFFERENT ACTIVITIES
	WEDNESDAY	SUNDAY	
Trigg Island	10	13	15
Bennion Street	10	11	14
Mettams	10	13	15
Hamersley	7	8	10
North Beach	7	9	11
Hale Street	4	10	10
Margaret Street	5	7	8
Watermans	12	14	15
Ozone Road	6	9	10
Sorrento	11	12	13

The data for Sunday, 10 March 1985 were substantially different from those recorded during the midweek survey. The weekend observations indicated only two peaks, at 1030 hours and 1530 hours. On both occasions people involved in family and water based activities, such as swimming and surfing, made up significant portions of the total number of people using the rocky coastline. At 1030 hours, surf club activities at Sorrento also contributed to the large number of people using the study area.

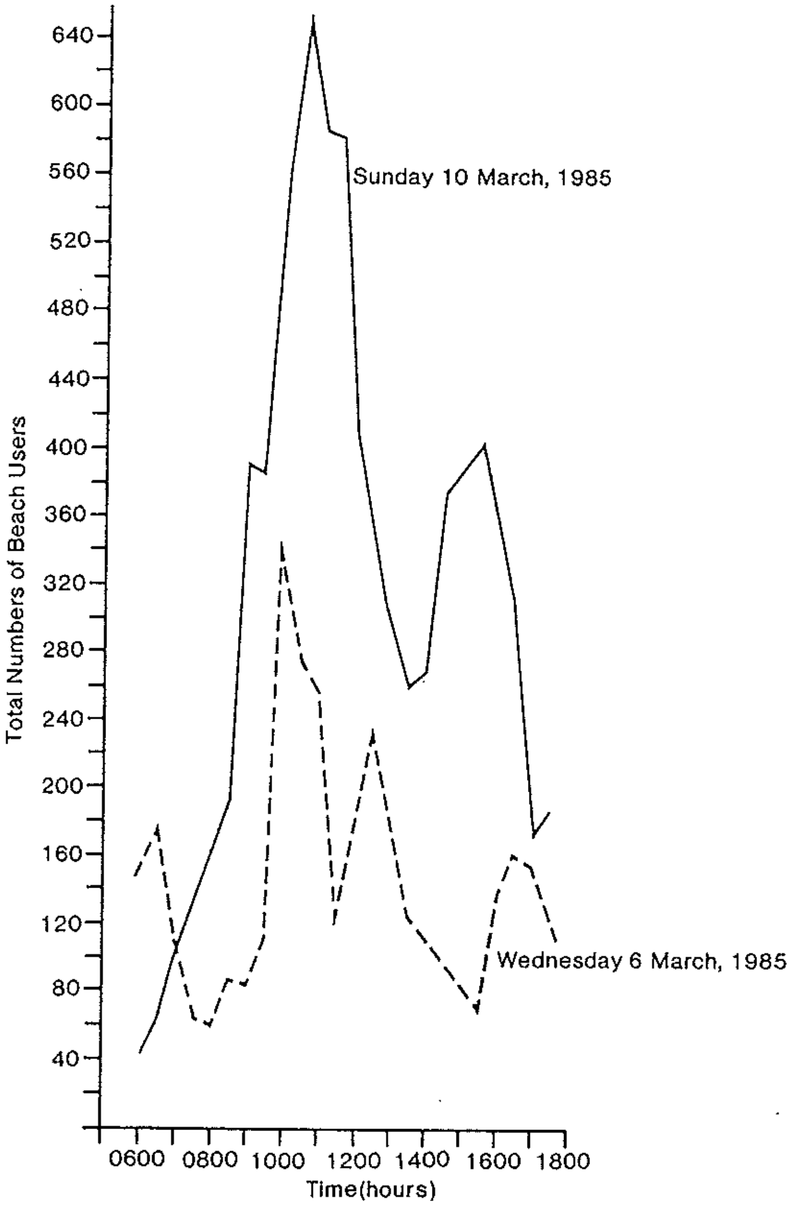


Figure 4. Variations in the total number of people using beaches in the study area on 6 and 10 March, 1985.

Broad-scale variations in total numbers of people using the coastline did not reflect the temporal patterns of beach use in individual embayments. The number of people using beaches and the types of activity varied considerably between embayments and over time. Eliot *et al.* (1986) details these variations with reference to the data from Trigg Island north, Mettams Pool, Watermans Beach and Sorrento Beach.

Spatial Variation in Beach Use between Trigg Island and Sorrento Beach

The proportion of people undertaking activities on the beach, in the water, on headlands, on reefs and in the reserve have been determined for 0800, 1200 and 1600 hours on both days (Figures 5-10).

Patterns of beach use are spatially complex. Generally however, numbers of people were fairly evenly distributed along the coastline at 0800 hours on both days (Figures 5 and 6). By 1200 hours on both days the range of activities increased and the distribution of people became more concentrated at several beaches. On Wednesday the largest crowd was at Bennion Street. This concentration was due to school children using the rock platform for biological studies. On Sunday, people were concentrated at Trigg Island north, Mettams Beach, Watermans Beach and Sorrento Beach. The concentration of people at Sorrento Beach, at this time, was due primarily to surf club activities. Surfing and windsurfing were the dominant activities at Watermans Beach at 1200 hours on Sunday, whereas Mettams Pool was dominated by swimmers and Trigg Island north by family groups with young children (Figures 7 and 8). By 1600 hours people were again distributed evenly along the coastline (Figures 9 and 10).

Attitudes of Local Residents and Retailers to the Study Area

Keating (1983) found that local residents used local beaches in preference to non-local beaches. The accessibility of a beach appeared to be the most significant factor in beach selection, but safety factors in reaching and using the beach were also considered important. Distance from the beach was important in determining, firstly whether a resident would use a beach and, secondly, what mode of transport would be used to travel there. Keating (1983) found that most local residents chose to walk. The critical distance for walking versus driving was 0.75 km along this part of the metropolitan coast (Figure 11). Many residents perceived traffic safety as a problem and through traffic on West Coast Highway as being an impediment to beach use.

Generally, local residents considered facilities adequate on the coast between Trigg Island and Sorrento (Keating 1983). They believed, however, that more changerooms would be beneficial and that access to the beach should be improved. They also considered that beach activities should be controlled by zoning, to reduce conflict; for example, specific beaches were needed for exercising dogs, and separately, for surfing. Cleanliness of beaches was also seen as requiring improvement, to enhance the amenity value of this part of the coast.

Most retailers interviewed by Keating (1983) believed that there were traffic problems on West Coast Highway which included parking, poor visibility and large volumes of through traffic. Suggestions made for solving these problems included reducing the speed limit on the highway, diverting all through traffic to a freeway, and making West Coast Highway a dual carriage-way with better access to the highway. Most respondents, however, did not believe that diverting traffic to other streets or slowing traffic would alleviate perceived problems in this area. Some 70% of the interviewed retailers believed that facilities along the rocky coastline were adequate and 30% believed that they were inadequate. Overall, 65% of retailers believed that improvements could be made to the facilities provided, including improvements to the cleanliness of facilities and the beach, safety controls on West Coast Highway, more parking, and better access to the beach.

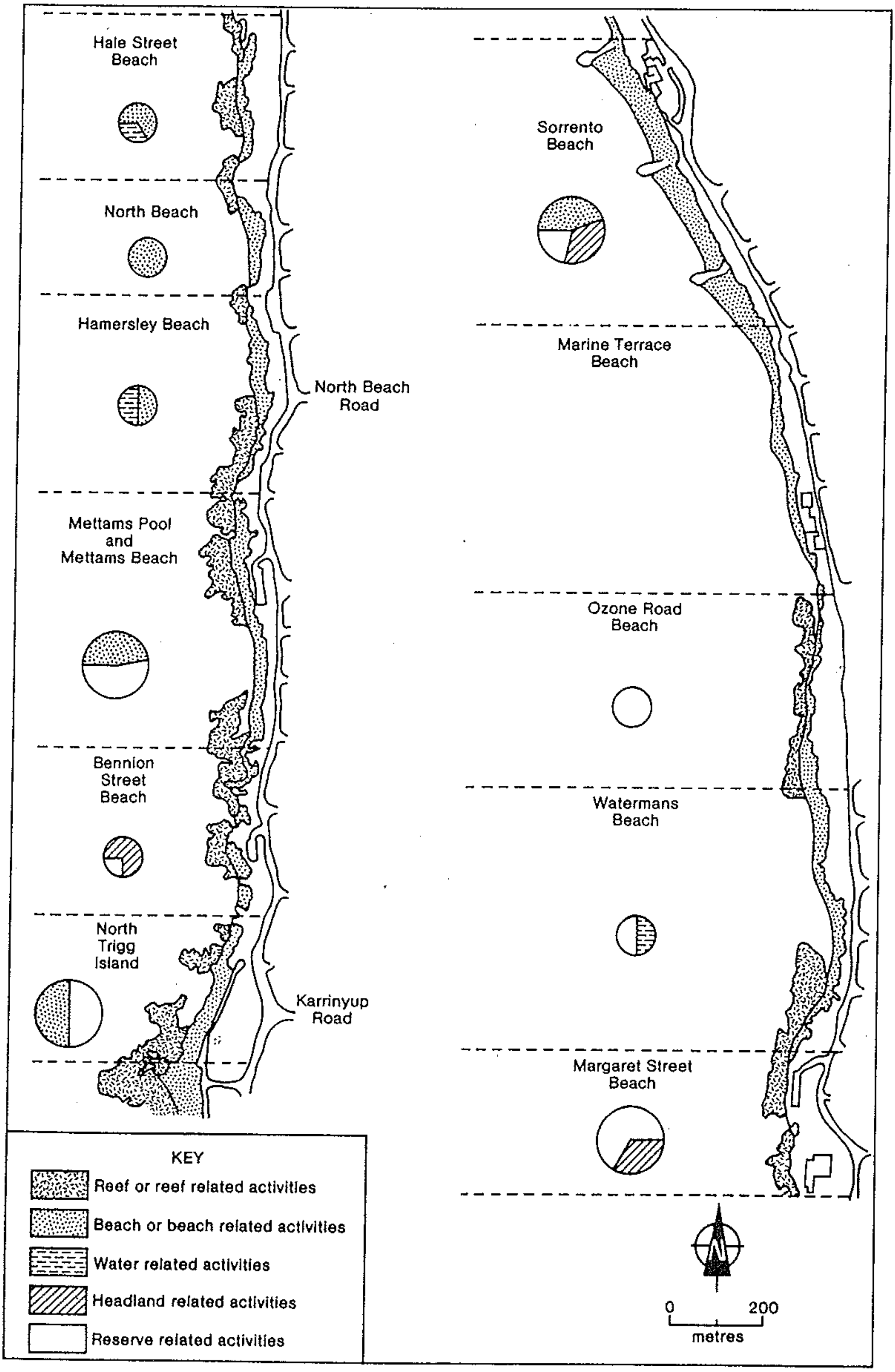


Figure 5. Variations in beach user activities at 0800 hours on Wednesday, 6 March, 1985.

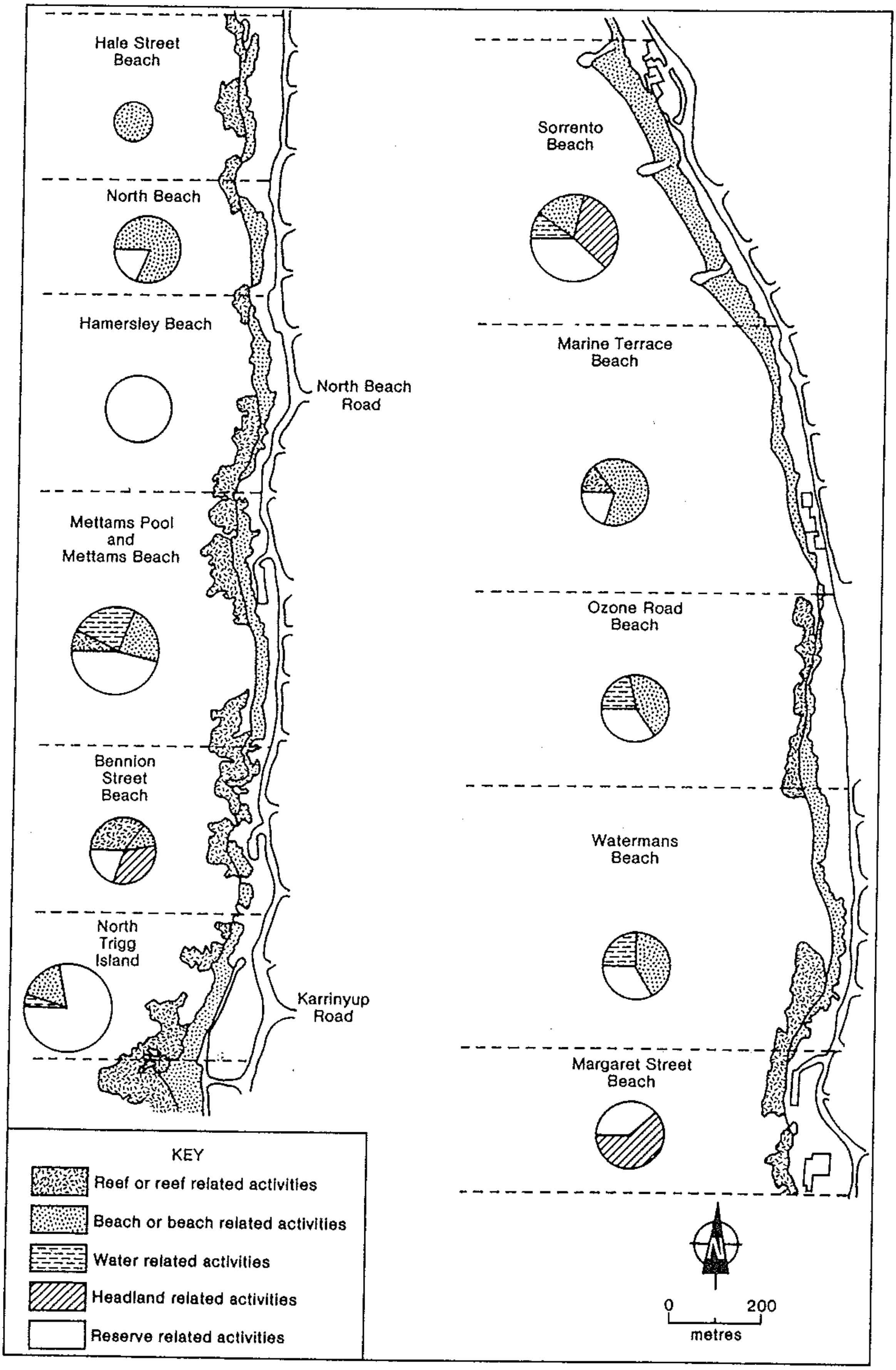


Figure 6. Variations in beach user activities at 0800 hours on Sunday, 10 March, 1985.

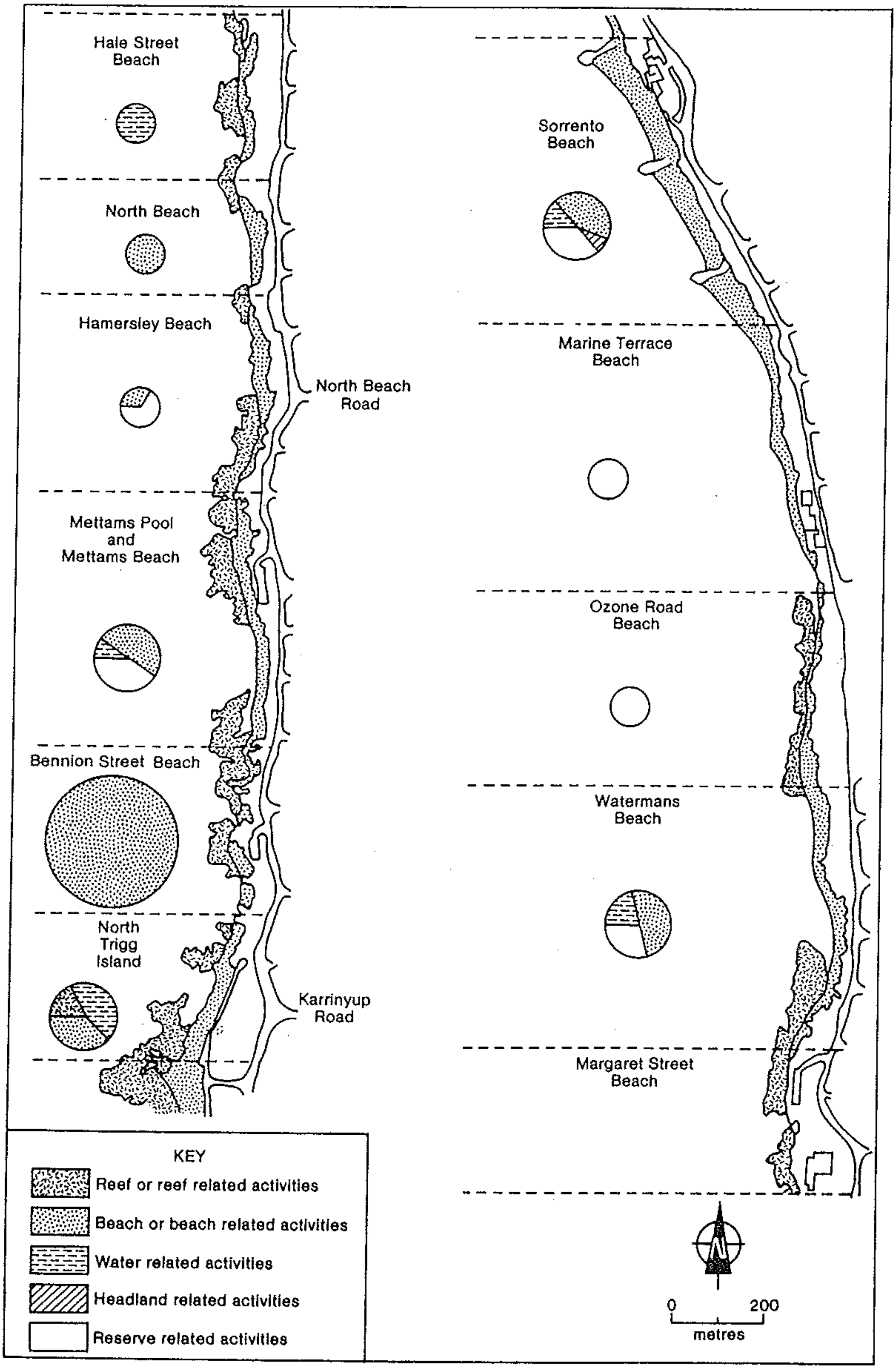


Figure 7. Variations in beach user activities at 1200 hours on Wednesday, 6 March, 1985.

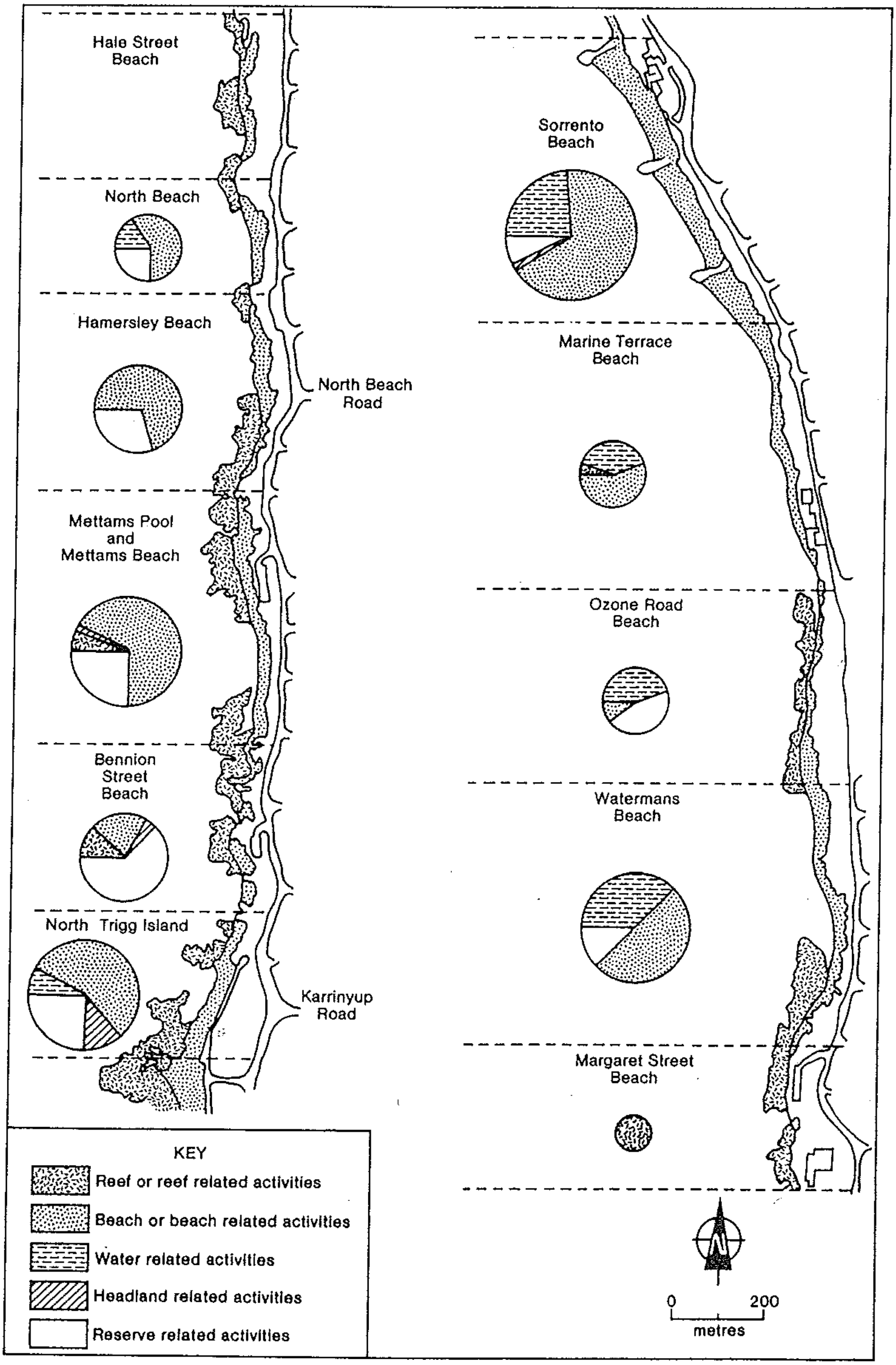


Figure 8. Variations in beach user activities at 1200 hours on Sunday 10 March, 1985.

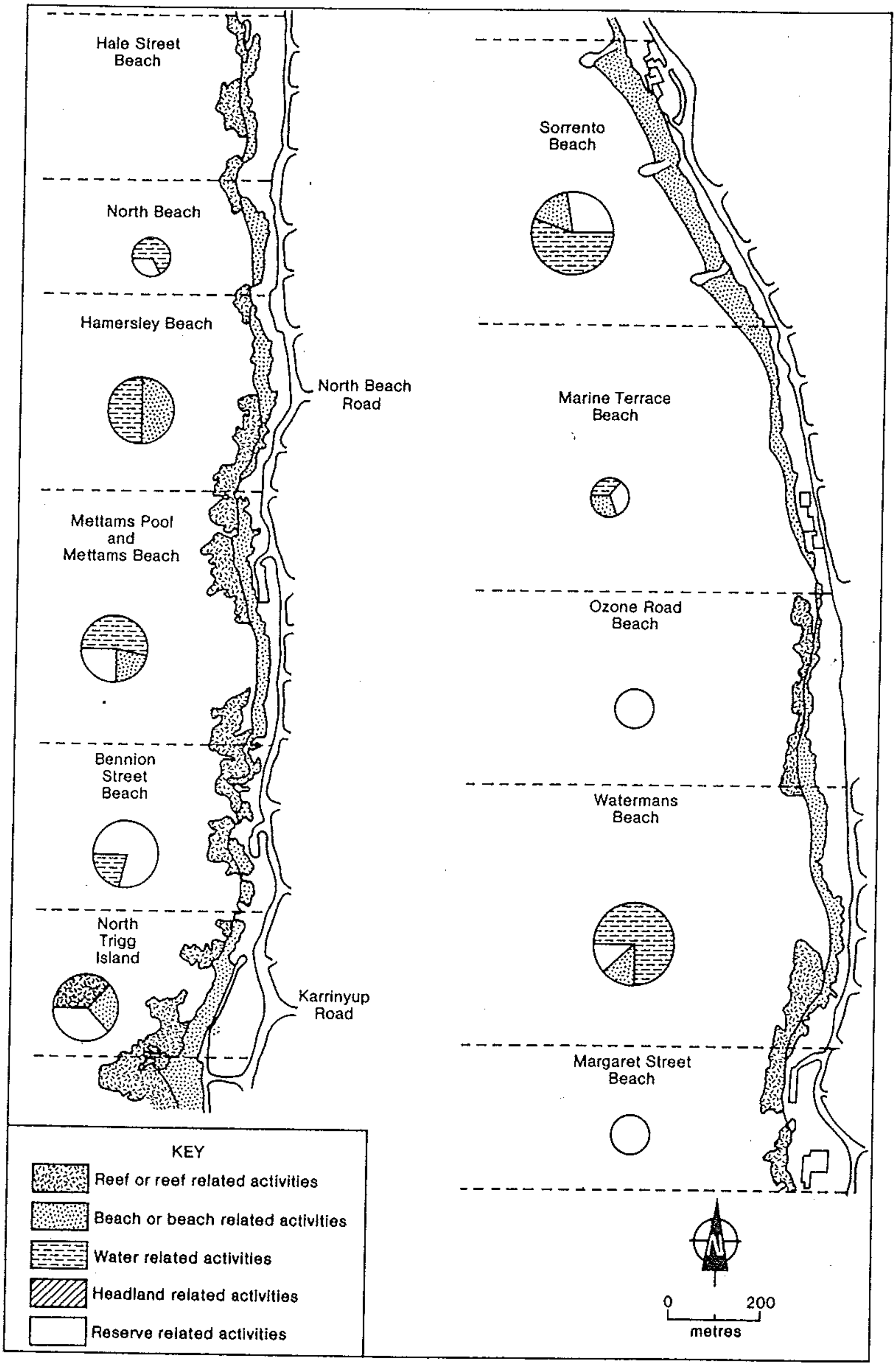


Figure 9. Variations in beach user activities at 1600 hours on Wednesday, 6 March, 1985.

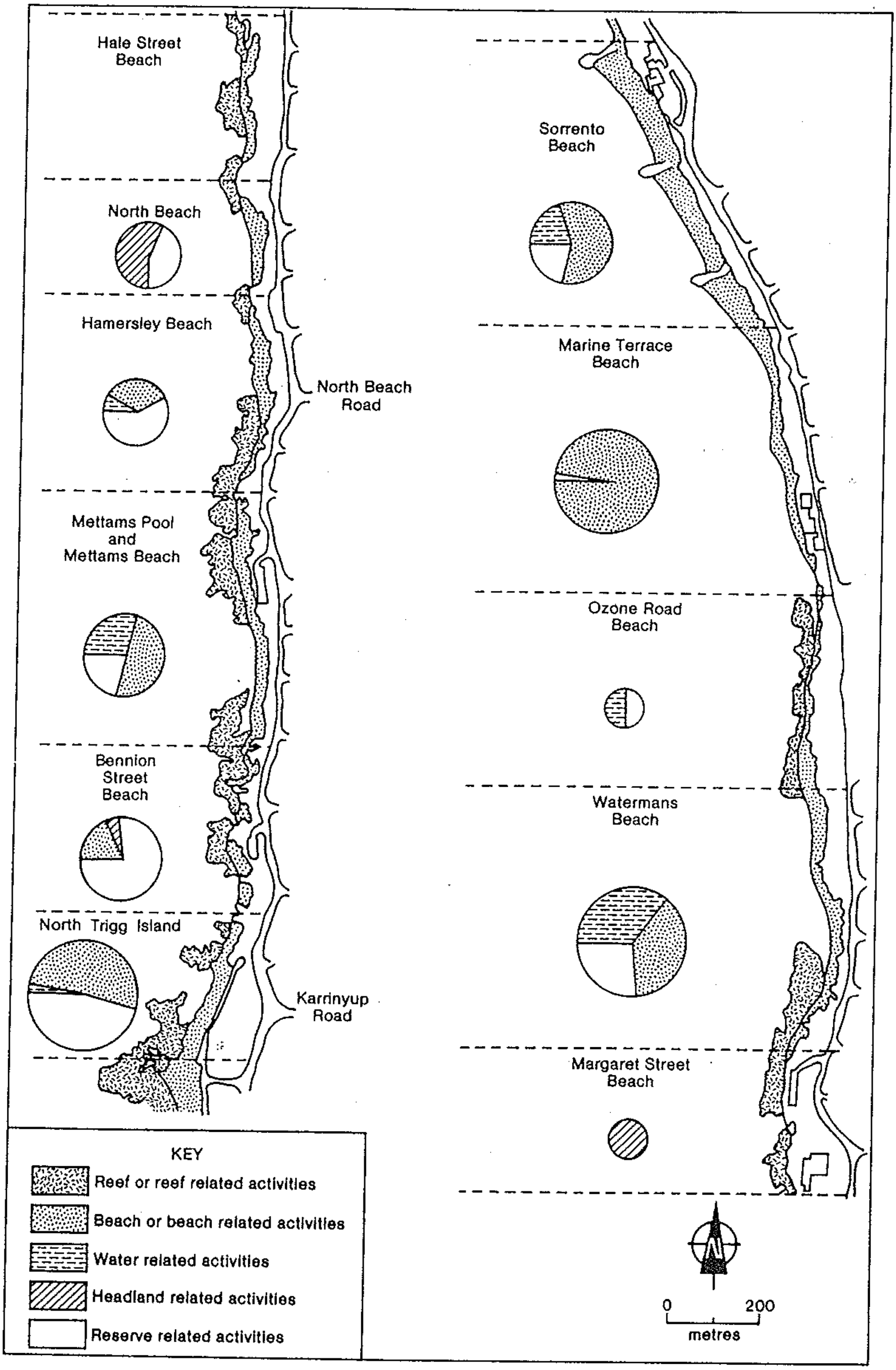


Figure 10. Variations in beach user activities at 1600 hours on Sunday, 10 March, 1985.

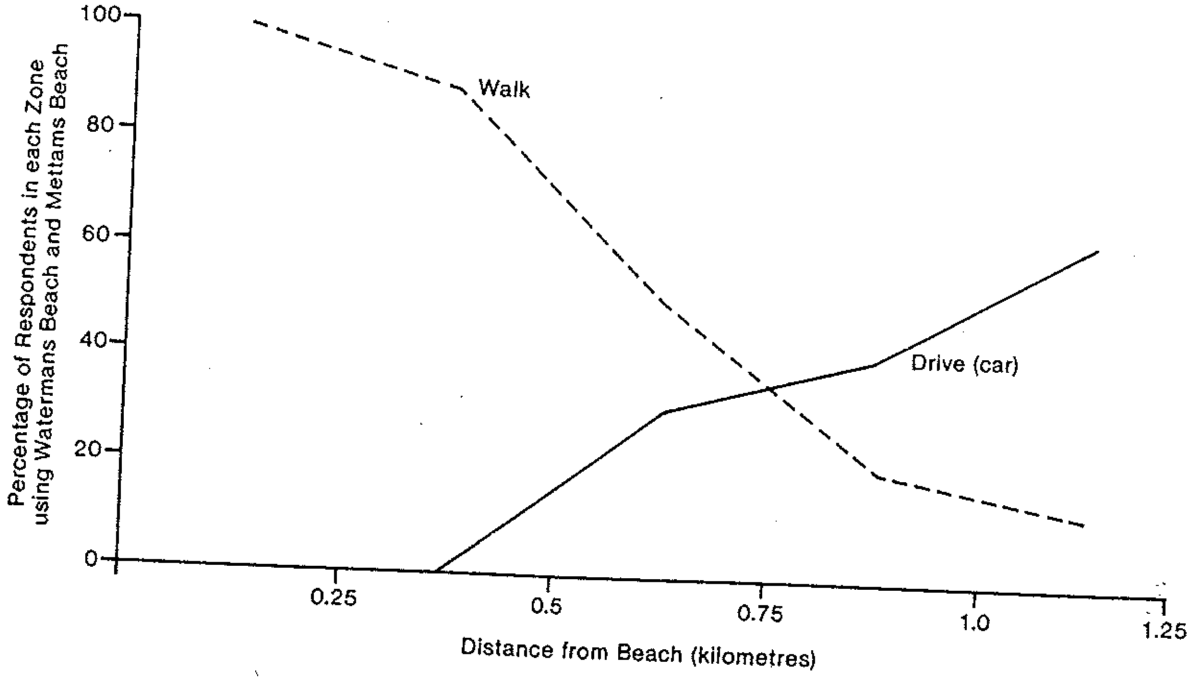


Figure 11. Mode of transport for residents of Trigg and Sorrento, when using Watermans beach and Mettams beach, related to distance of home from the beach (redrawn from Keating 1983).

COASTAL RESOURCES OF THE STUDY AREA

While collecting survey data consideration was given to defining and identifying the resources of the study area.

Coastal resources could be classified into two types: primary and secondary. The primary resource of the coastal zone is the area itself, including its physical and biological attributes, the space it provides for recreational activities, and the recreational activities practised on the coast. Together these are factors that attract other people to the coastal area. Secondary resources are those that support the activities occurring on the coastline. These include public and private facilities such as the retail outlets on the eastern side of West Coast Highway. They are not necessary for the maintenance of the primary resources, although they may enhance them.

Recreational Resources

Field observations showed that the intertidal limestone platforms and submerged reefs were resources upon which many recreational, educational and scientific activities were based. Recreational activities included fishing from the platform, walking on the platform and professional and amateur reef harvesting. Both platform and reef areas were used for snorkelling, scuba diving and spear fishing. Educational classes in scuba diving and snorkelling used the platform and reef resources. Examination of platform biota provided practical experience to supplement school biological lessons. All platforms could be used for scientific purposes, and the platform at Waterman could be used as a 'control area' in scientific research because it was the least disturbed of those in the study area.

Calm, protected water in the rock pools was important for swimming and wading, whilst the open water was used for surf board surfers. Open water was also used by swimmers, body surfers and for life-saving activities. The rock pools were used extensively for in-term swimming lessons and Mettams Pool was used for Education Department summer holiday swimming lessons. Scientific research of the water resource included investigation of nearshore coastal processes, (waves, swash and water circulation), and of nutrient and salinity regimes (Wood 1980; Robertson and Hansen 1982; Hatcher 1983; Johannes and Hearn 1984).

Recreational pursuits on open beaches included sunbathing, exercising, children's games, life-saving activities and exercising animals. Pocket beaches afforded more privacy than the open surf beaches, but were not sufficiently extensive to cater for more active recreation such as jogging. Beaches were also used for educational activities such as shell and seaweed collecting, and observation of other biota (birds, insects and lizards).

Limestone headlands were used for line fishing, rock climbing and exploring. Headlands also present opportunities for educational and scientific examination of biota and geomorhology. They are also scenic and provide the opportunity for people to view and photograph coastal vistas. From a planning point of view, they have been perceived as space to locate facilities and amenities such as carparks and formalised lookouts, for example, Centaur Lookout. There is considerable conflict of interest in these divergent uses. Provision of amenities has tended to pre-empt diversity of use.

Supporting Facilities

Amenities within the area generally facilitate the use of the area for recreational, educational and scientific purposes. Facilities fall into two categories; private facilities and public facilities, provided by the City of Stirling and the Shire of Wanneroo. There are two private buildings located on the western side of West Coast Highway. These are the Marmion Angling and Aquatic Club and the North Beach Rugby Club. In addition there is the CSIRO Watermans Research Laboratory.

Facilities supporting recreation along the rocky coast include the cycleway and grassed reserves, both are public facilities. Cycling, jogging, walking, animal exercising and skateboarding were the more popular recreational activities undertaken on the cycleway and in the reserve. Grassed reserves at Trigg Island and Watermans provide space for activities such as picnicking, children's games and other sporting activities, or for merely sitting and looking at the scenery. Educational uses of the grassed reserves appeared to be minimal, but pre-school groups used the playground equipment.

West Coast Highway could also be considered one of the supporting facilities of the area as it provides access to the coast for locals and non-locals. Designated use of this road as a major commuter thoroughfare, however, has mitigated its optimum use as a tourist and recreational road.

Many of the retail outlets on the eastern side of West Coast Highway, although not within the defined boundaries of the study area, are also a valuable amenity that enhances the use of this stretch of coastline. Traffic flow along West Coast Highway effectively acts as a barrier between the coastal reserve and the immediate hinterland. This prevents full integration of retail outlets, many of which have a direct relationship with recreational activities on the coast and activities occurring on the coastal side of West Coast Highway.

2.4 CONCLUSIONS

Data were collected during daylight hours on only three days in March, hence conclusions drawn from the beach survey results relate specifically to the late summer period. Patterns of beach use could well vary with the seasons and further research is needed to determine these variations. Summer data, however, are useful in as much as they represent the time of year when beach use is at its greatest.

Data from the aerial survey indicated a marked temporal variation in total numbers of people using the coastal reserve and nearshore environment. The two ground surveys confirmed this and indicated temporal variations in beach use numbers during the day, and also between midweek and weekend days. Furthermore, patterns of temporal variation differed from embayment to embayment.

The range of recreational activities undertaken on the coastal reserve differed markedly from embayment to embayment. Variations in both the range of activities and the numbers of people at embayments during 6 and 10 March showed that there were recreational focus points for beach activities along the rocky coastline. There was an informal zoning of activities along the coastal reserve with recreational focus points identified at Trigg Island north, Mettams Pool and Mettams Beach, Watermans Beach and Sorrento Beach. Embayments which showed consistently low levels of recreational activity were located at Hale Street, Margaret Street and Ozone Road.

3. GEOMORPHOLOGY AND WATER CIRCULATION

3.1 INTRODUCTION

If the high recreational amenity of the coastal reserve is to be maintained a knowledge of its geomorphology and nearshore water circulation patterns is necessary. Recreational use of the coast has already led to degradation of the physical environment. One example being the increased rate of erosion reported by the City of Stirling, (1984).

Water circulation flushes pollutants, such as body excretions, groundwater and stormwater discharge from an area. Thus a knowledge of patterns of nearshore water circulation can help to ascertain firstly whether water movements are sufficient to maintain water quality for recreation and, secondly, the position of rips and thus areas suitable for particular recreational activities. Large-scale patterns of circulation in waters offshore from the study area have been examined previously (Hearn 1983; Johannes and Hearn 1985; Searle and Semeniuk 1984) and these are discussed in Chapter 5. The specific aims of the work described here were:

. to examine the intertidal and supratidal morphology of rock platforms and inshore reefs;

. to ascertain the patterns of nearshore water circulation over the reefs during both low and high energy conditions; and

- to indicate which nearshore environments are particularly suitable for various types of water based recreation.

3.2 METHODS

GEOMORPHOLOGY

Morphology of the nearshore zone, comprising sandy seafloor, intertidal and supratidal rock platforms and submerged reef units was examined by interpretation of aerial photographs. The aerial photographs used were those from the Coast Run (Scarborough Beach - Ocean Reef) taken at 0800 hours on 3 March 1985 (Job 850018, WA2284(C), Scale 1:3000, Runs 2 and 3, Photographs 5045-5065). The study area was mapped as a mosaic from the aerial photographs at a scale of 1:3000, then reduced in size for final presentation. The map was slightly modified as a result of field verification.

Data were already available on the geomorphology and flora of the dune system (Smith 1973; Cockerton *et al* 1982; City of Stirling 1984). The present study therefore concentrated on the nearshore zone of the study area. The nearshore zone was regarded as comprising sandy seafloor, intertidal rock platform and submerged reef units (Figure 12). Other geomorphological units which were mapped included limestone outcrops and stacks, cliffed headlands and sandy beaches.

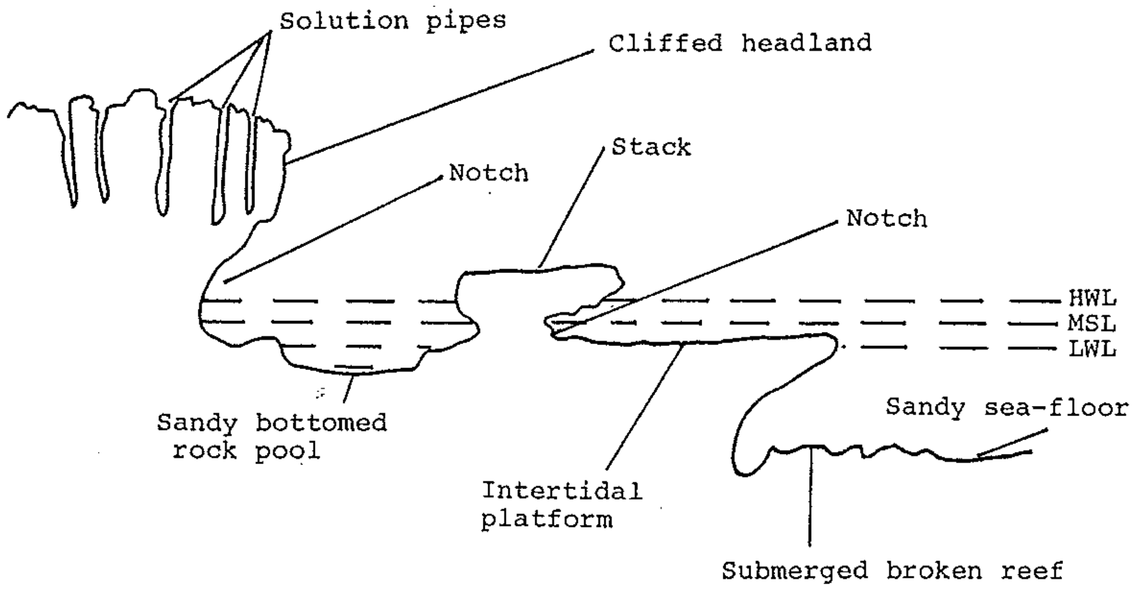


Figure 12. Cross section showing the main geomorphic units mapped in Figure 13.

The low water shoreline shown on the map (Figure 13) illustrated a low to rising tide condition; the tidal height at the time of photography was 48.3 cm above zero (Australian Height Datum). At Fremantle the tide ranges over 0.4 m, from 0.5 m Mean Low Low Water to 0.9 m at Mean High High Water. The Low Astronomical Tide to High Astronomical Tide range is 0.9 m (Anon, 1985). Extreme sea level conditions range from a low tide of -0.5 m (recorded 13.1.1896) to a high tide of 1.89 m (recorded 10.5.1910) (Steedman 1977 based on Easton 1970).

WATER CIRCULATION PATTERNS

The fieldwork to ascertain nearshore water circulation was undertaken on only two days, 13 and 29 April 1985. Water movement within six rock pools was examined on one day, 29 March 1985. The data, although useful as a pilot survey and representative of the conditions prevailing at the time of the fieldwork, are not presented here because of the very limited period over which they were collected. Water circulation, velocity, wave height and direction of flow can vary considerably from season to season, within a season and even hourly within a day.

The geomorphic and other attributes of the embayments were extracted from the geomorphic map and tabulated. The location and frequency of rips and turbulence in the study area were also tabulated. These tables were then used in conjunction with a table listing requirements for water based activities (Table 3, Chapter 2). From these the suitability of each embayment for various water-based activities could be assessed. These are discussed in Chapter 5.

3.3 RESULTS

GEOMORPHOLOGY

The geomorphology maps are presented in Figure 13. The geomorphic and other attributes of each embayment are listed in Table 5.

Extensive, sandy beaches at Trigg (south of Trigg Island) and at Sorrento (north of Clontarf Street) flank a coastal zone which is structurally controlled by its Tamala Limestone inheritance (City of Stirling, 1984; Searle and Semeniuk, 1984). The coastal zone is comprised of rocky shores and headlands encompassing pocket beaches. The rocky shores and headlands exhibit an interesting array of erosional features from both contemporary and earlier periods, including stacks, rock pools, intertidal platforms, raised benches and caves.

The rock platforms are cut in limestone. Between Trigg Island and Sorrento they are discontinuous and vary in extent (Figure 13). At Trigg Island the platform is large, extending out to sea for a distance of 100 m and alongshore for over 250 m. At Kathleen Street the distance to the seaward edge of the platform is also 100 m, but its alongshore distance is only 60 m, whilst in the vicinity of Troy Avenue the platform is very elongated but narrow. It extends out to sea for a distance of only 15 m in some places. Undercutting and notching occurs on the seaward edge of the platforms. Surge channels, and sometimes pools, are prolific on the seaward boundaries of platforms. One example is the channel south of Mettams Beach. Distinct rock pools occur in the middle of some platforms. They are frequently associated with headlands. The largest examples of this type of pool are those adjacent to Trigg Island. Strings of small rock pools occur along the shoreline on many of the platforms; for example, Trigg platform and the platform at North Beach Jetty.

Apart from the platforms, the remainder of the nearshore environment is comprised of submerged reef, covered in some areas by a mobile veneer of sediment. The submerged reef units are generally distinct from the

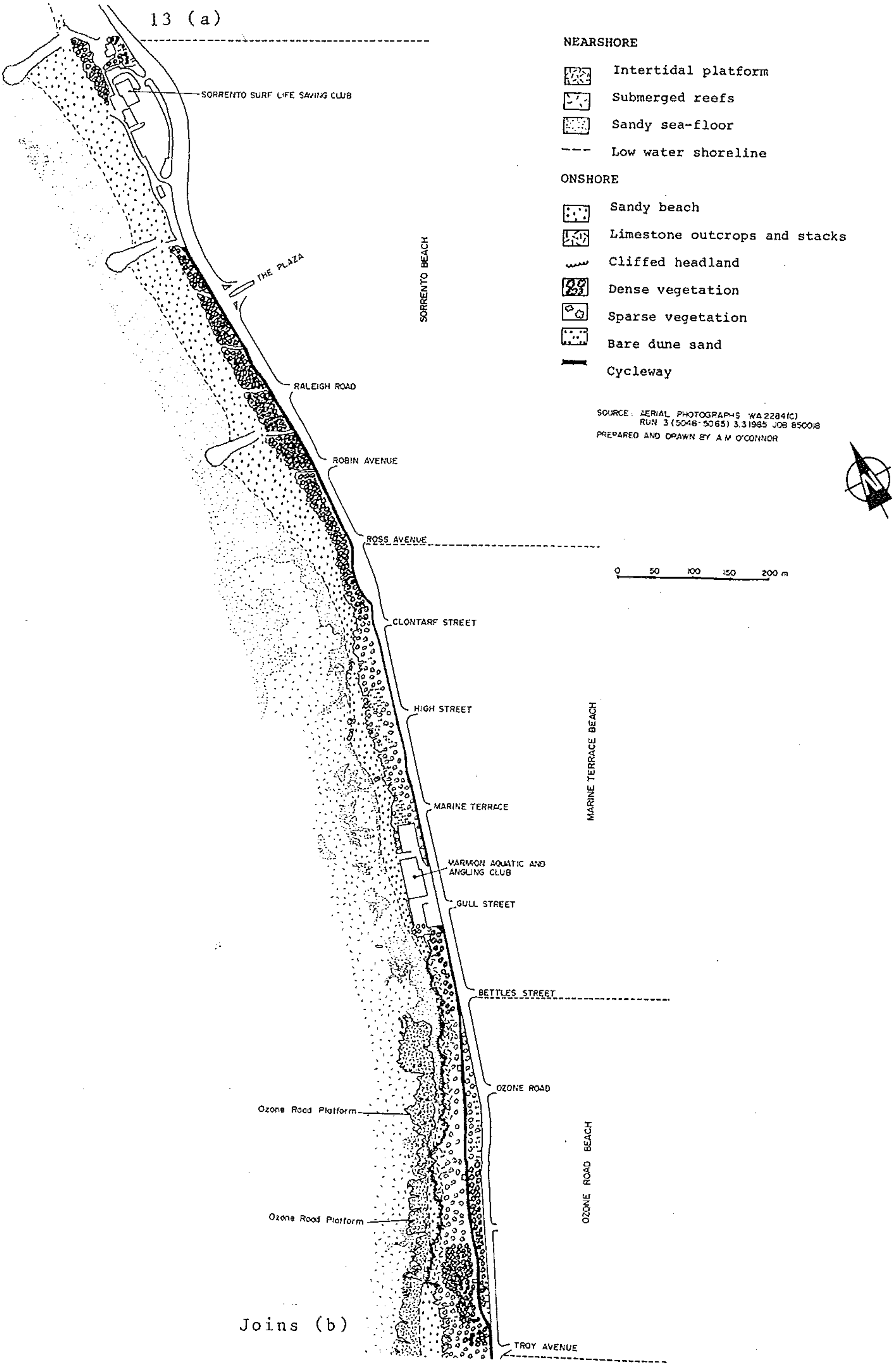
Table 5. Geomorphic and other attributes of each embayment, North Trigg Island to Sorrento Beach.

	INTERTIDAL ROCK PLATFORM	SUBMERGED REEF	RIPS AND TURBULENCE	SANDY BEACH		BEDROCK OUTCROPS ON SANDY BEACH	CLIFFS AND HEADLANDS	UNREHABILITATED BARE DUNE SAND	RESERVES & LOOKOUTS
				ROCK POOL	OPEN BEACH				
North Trigg Island	Extensive U-shaped platform. Extending north of Shag Rock on on the seaward side only. Smaller platforms at bottom of Kathleen Street and just to north.	On landward side of platform from north of Shag Rock, extending to edge of next platform. Intermittent to north of Kathleen St platform.	Rip and turbulence at northern end of Trigg platform under higher energy conditions. Weak rip off bottom of U-shape in Trigg platform - low energy conditions.	At bottom of carpark just north of Trigg Place. Four offshore pools: three adjacent to Trigg Island and one adjacent to Shag Rock.	Two small embayments one north and one south of Kathleen Street	Embayment south of Kathleen Street	Trigg Island Just south of Kathleen Street. Very northern end of embayment, between Bennion and Kathleen Streets. Blockfalls	North of Trigg Island carpark. On limestone headland at top of the Esplanade(pinnacles) Clarko Reserve.	Clarko Reserve.
Bennion Street Beach	Platform attached to Bailey Street headland. Southern portion of extensive Mettams platform.	Intermittent off Bennion Street Beach and at bottom of Bailey Street.	Rip guided by channel near South Mettams Pool under both low and higher energy conditions. Turbulence at edge of platform associated with above rip. Rips to north and south of Bailey Street platform on higher energy day.	South Mettams just south of Lynn Street	Three small embayments, one north and one south of Bennion Street, and one at bottom of Bailey Street.	Bennion Street Beach. Beach at bottom of Bailey Street carpark.	Bottom of Bennion Street. Bottom of Bailey Street carpark. Intermittent lower headlands between Bailey and Lynn Street	Seaward side of Bailey Street carpark. At base of path north of Bailey Street carpark.	No formal reserve or lookout.
Mettams Pool	Northern portion of extensive Mettams platform Extensive platform from Sholl Avenue past bottom of Saunders Street car park to northern boundary of embayment.	Intermittent between Mettams and Sholl Avenue platforms.	Rip at bottom of Saunders Street under both low & higher energy conditions. Under low energy conditions a weak rip at bottom of Giles St. Under higher energy condition a rip through platform channel north of Saunders Street carpark.	Mettams Rock Pool	Extensive from just south of Giles Street to Hamersley Street.	Scarce	Headlands south of Lynn Street and at Hamersley Street. Cliff line from bottom of Saunders Street car park north to Centaur lookout.	None present	Mettams lookout. Centaur lookout.
Hamersley Pool and Beach	Northern portion of platform from Hamersley Street to North Beach Road. Small platform at bottom of Sorrento Street carpark.	Between North Beach Road and Sorrento Street.	Weak rips under low energy conditions at Beechton Street and Sorrento Street.	Hamersley Street South. Hamersley Street North.	From south of North Beach Road to north of Sorrento Street.	Bottom of Sorrento Street	Headlands at Hamersley Street Beechton Street and northern border of embayment. Cliffline beside West Coast Highway from north of Hamersley toilet block to Beechton Street. Cliffline at bottom of Sorrento Street carpark.	Beside path south of Hamersley Pool toilets. Severe tracking in dunes between North Beach Road and Sorrento Street. Seaward side of north end of Sorrento Street carpark.	No formal reserve or lookout.
North Beach	Northern portion of Sorrento Street carpark platform. Southern half of narrow platform at North Beach jetty.	Intermittent between James Street and just north of Malcolm Street	None mapped, but probably a rip near bottom of Malcolm Street.	None present	James Street to to just south of North Beach jetty.	Below North Beach Rugby Club.	Headlands at southern border of embayment and at North Beach jetty. Cliffline beside West Coast Highway from North Beach Rugby Club to just north of Malcolm Street.	Northern end of Sorrento Street carpark.	North Beach jetty lookout.

Table 5. Geomorphic and other attributes of each embayment, North Trigg Island to Sorrento Beach (cont'd).

Hale Street Beach	Northern half of North Beach jetty platform. North of Castle Street to north of Lawley Street Southern portion of very narrow platform from south of Hale Street to northern boundary.	Intermittent, small area between north of Lawley Street and south of Hale Street.	North of Castle Street under higher energy conditions.	None present	Castle Street to Hale Street.	Bottom of Lawley Street.	Headlands at North Beach jetty, and Lawley Street. Cliffline from Castle Street to Hale Street.	Bottom of Hale Street. South of Marine Research Lab is severely tracked.	Waterman Marine Reserve.
Margaret Street Beach	Continuation of narrow platform to north of Elvire Street. Southern end of Watermans platform from south of Margaret Street to northern boundary.	Very small, intermittent, area midway between Elvire and Margaret Streets.	Two rips under higher energy conditions, one at bottom of Elvire Street and one just south of Margaret Street.	None present	Very small pocket beach Between Elvire and Margaret Streets.	Between Elvire and Margaret Streets.	Headlands below CSIRO and below Ada Street carpark north to Ada Street. Clifflines behind pocket beach between Elvire and Margaret Street and between Ada Street carpark and West Coast Highway.	Seaward side and north of CSIRO Watermans. South of Ada Street carpark. Bottom of Ada Street, beside path to Ada Street pool (severe)	CSIRO Waterman Reserve
Watermans Beach	Northern half of Watermans Platform to Elsie Street.	Intermittent from Elsie Street to Troy Avenue.	Rips at bottom of both Beach Road and Lennard Street under both low and higher energy conditions.	Ada Street south. Ada Street north. A third pool north of Ada Street north.	From between Ada and Mary Streets to north of Troy Avenue.	Minor at bottom of Beach Road and bottom of Troy Avenue.	Continuation of Ada Street headlands between the three rockpools. Headland at bottom of Beach Road. Cliffline beside West Coast Highway from south of Mary Street to south of Beach Road.	Beside path seaward of Waterman Beach lookout. Between Beach Road and Elsie Street. South of Lennard Street bottom of Troy Avenue and Lennard Street.	Watermans Playground Watermans lookout.
Ozone Road Beach	Very narrow platform from Troy Avenue to Bettles Street, that is, whole distance of this embayment.	None present	Rip between Troy Avenue and Ozone Road under low energy conditions.	None clearly defined.	Occasional very narrow stretches mostly affected by waves.	Along all narrow beaches.	Cliffline from just north of Troy Avenue to Bettles Street. Blockfall.	North of Troy Avenue both beside West Coast Highway and on seaward side of cycleway. South of Ozone Road both beside West Coast Highway and near limestone cliff. Bottom of Bettles Street.	No formal reserve or lookout.
Marine Terrace Beach	None present.	Intermittent from Bettles Street to Ross Avenue.	Rip at bottom of MAAC under higher energy conditions. Turbulence in same position under lower energy conditions. (Reflected waves observed 10.5.1985).	None present.	From between Bettles and Gull Streets to Ross Avenue	Bottom MAAC service area. Intermittent between Marine Terrace and Clontarf Street.	Cliffline beside West Coast Highway from Bettles Street to Ross Avenue (except where marked by MAAC roadworks).	North of MAAC. All through dunes between Marine Terrace High Street and Clontarf Street.	No formal reserve or lookout.
Sorrento Beach	None present.	None present.	Rip at bottom of Ross Avenue.	None present.	Ross Avenue to northern groyne (whole embayment).	None present.	Low cliffline beside West Coast Highway from Ross to Robin Avenue	None present.	No formal reserve or lookout.

13 (a)


NEARSHORE
Intertidal platform
Submerged reefs
Sandy sea-floor
Low water shoreline
ONSHORE
Sandy beach
Limestone outcrops and stacks
Cliffed headland
Dense vegetation
Sparse vegetation
Bare dune sand
Cycleway
SOURCE: AERIAL PHOTOGRAPHS WA 2284(C) RUN 3 (5046-5065) 3.3.1985 JOB 850018
PREPARED AND DRAWN BY A M O'CONNOR
0 50 100 150 200 m
SORRENTO SURF LIFE SAVING CLUB
THE PLAZA
SORRENTO BEACH
RALEIGH ROAD
ROBIN AVENUE
ROSS AVENUE
CLONTARF STREET
HIGH STREET
MARINE TERRACE BEACH
MARINE TERRACE
MARMION AQUATIC AND ANGLING CLUB
GULL STREET
BETTLES STREET
OZONE ROAD
Ozone Road Platform
OZONE ROAD BEACH
Ozone Road Platform
TROY AVENUE

Joins (b)

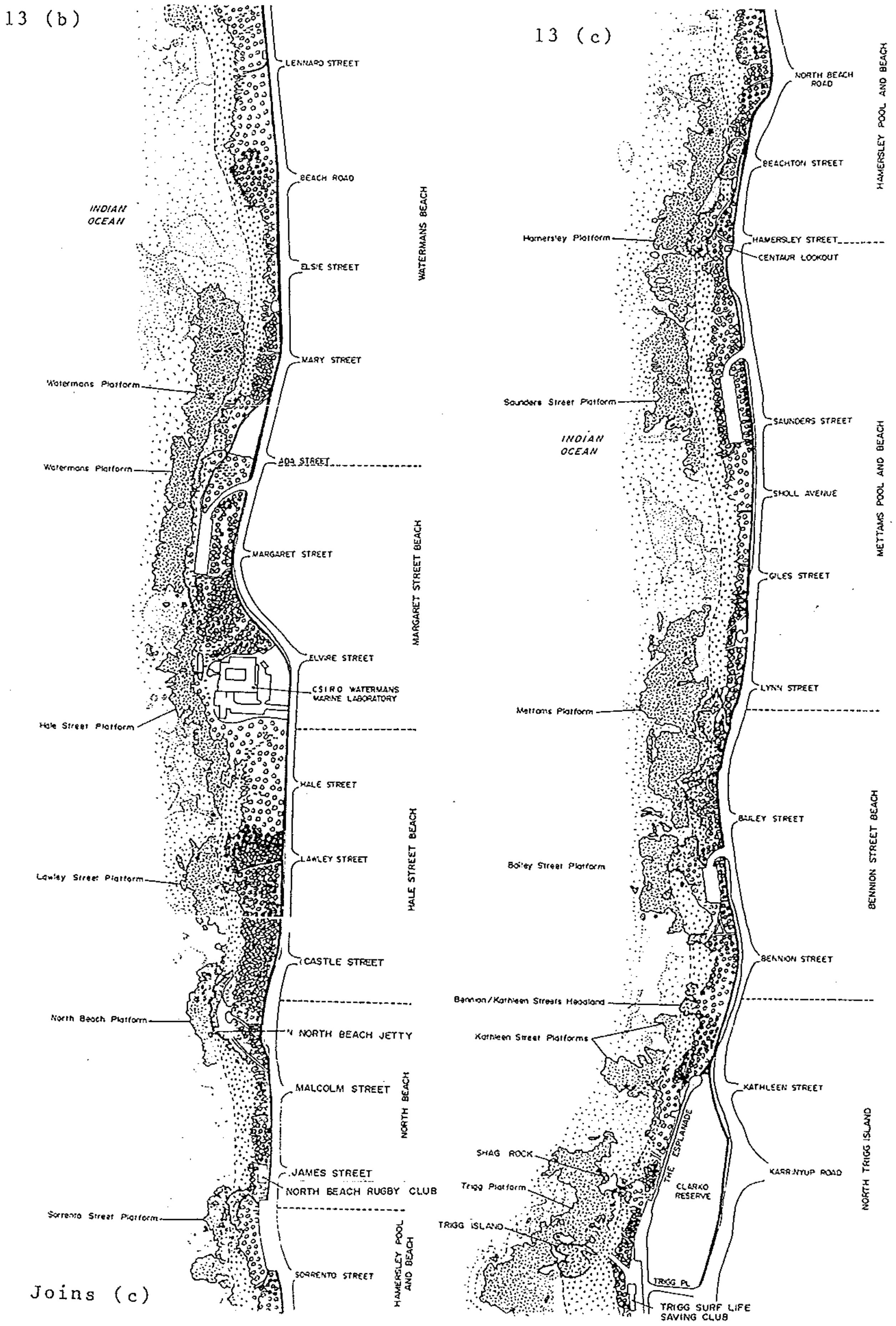


Figure 13. Geomorphology of the nearshore intertidal and supratidal environments North Trigg Island to Sorrento Beach.

intertidal limestone platforms, but in some areas, such as west of Saunders Street carpark, an apparent block fall of the platform edge has caused the units to merge. To the north of Ross Avenue, offshore from Sorrento Beach, the nearshore accumulation of sediment was greater than in the southern part of the study area. Sorrento Beach was the only part of the study area where no submerged reef was visible in the nearshore environment.

The dimensions of the sandy beaches are given in Table 6, and their morphology is described in City of Stirling Coastal Report (1984).

Limestone headlands usually back the intertidal platforms (Figure 14), but there are exceptions. For example, neither of the Bennion Street headlands have an associated platform, whilst the Saunders Street platform has no associated headland. Headlands vary in height from 1m to a maximum of about 6 m. Even though the intertidal platforms afford some protection, the headlands are still prone to erosion. Rates of erosion have not been measured, but Figure 15, a photograph taken west of Kathleen Street, illustrates a 'small' block fall less than 1 m in diameter. A nearby block fall was more than 3 m in diameter. Both these falls are in areas where the limestone is riddled with solution pipes. Block falls also occur in the absence of solution pipes. For example jointing of the limestone has been exploited by wave quarrying at the base of a cliff or headland. Figure 16 shows a block in a tilted position ready to collapse. Several other examples of jointing parallel to the shore were observed between Troy Avenue and Bettles Street. Jointing at right angles to the shoreline also occurs, for example the low headlands at Ada Street where the joint carries on through the associated intertidal platform.

Two types of morphological formation caused by differential erosion occur in the study area. One type is stack formation which developed when resistant rock was left standing and separated from the shore. Shag Rock is the best example of this (Figure 17). The other includes caves, solution pipes and cliffed headlands (Figures 18 and 19). The surfaces of the limestone headlands and cliffs, as well as the interior walls of solution pipes are travertinised and therefore harder than the surrounding limestone. In time the harder surface of the headland has remained as the 'roof' of the cave and solution pipes have been left standing like chimneys. On the headlands near the northern end of The Esplanade, and between Troy Avenue and Bettles Street, the solution pipes have formed pinnacles.

The headland between Bennion and Kathleen Streets (Figure 19) is an interesting case study of morphology. Not only does it show the beginning of cave formation, with the resistant roof and chimneys, but it also feature a segment of limestone, whose layers dip in an easterly direction, away from the sea. Furthermore, a low bench (0.8-1m) stands at the north of this headland (foreground of photograph). This may be a remnant of an intertidal platform from an earlier period or have resulted from differential weathering effects.

Clifflines which occur behind the back-beach line, such as those at the seaward side of Saunders Street carpark, were not mapped. Their individual positions, however, are described in Table 6. Some clifflines were very close to West Coast Highway, for example from north of Hamersley toilet block to Beachton Street and from Bettles Street to Ross Avenue.

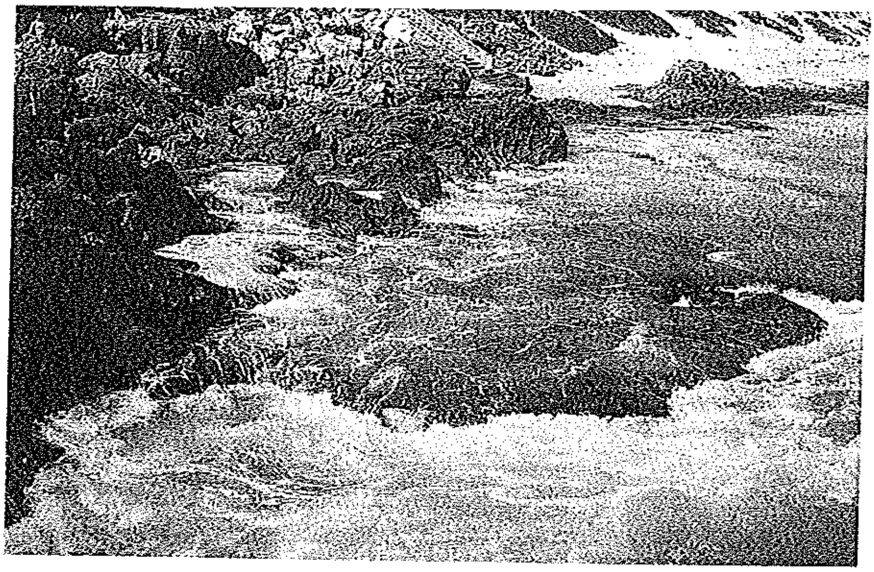


Figure 14.

North Beach jetty intertidal platform. As each wave retreats, water is shed from a bench located approx 6 cm above the platform (left side of photo).

A M O'Connor

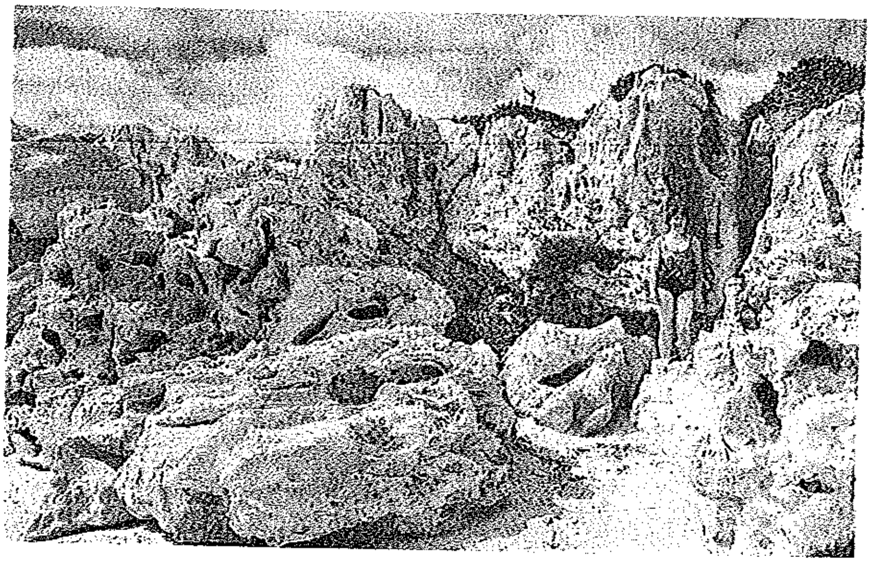


Figure 15.

Cliff erosion at Trigg Island. Fallen blocks of limestone lay in front of 3 m cliff. Block in foreground was <1 m in diameter and block behind it was about 2 m. Note many solution pipes in top of 2 m fallen block (left side of photo).

A M O'Connor

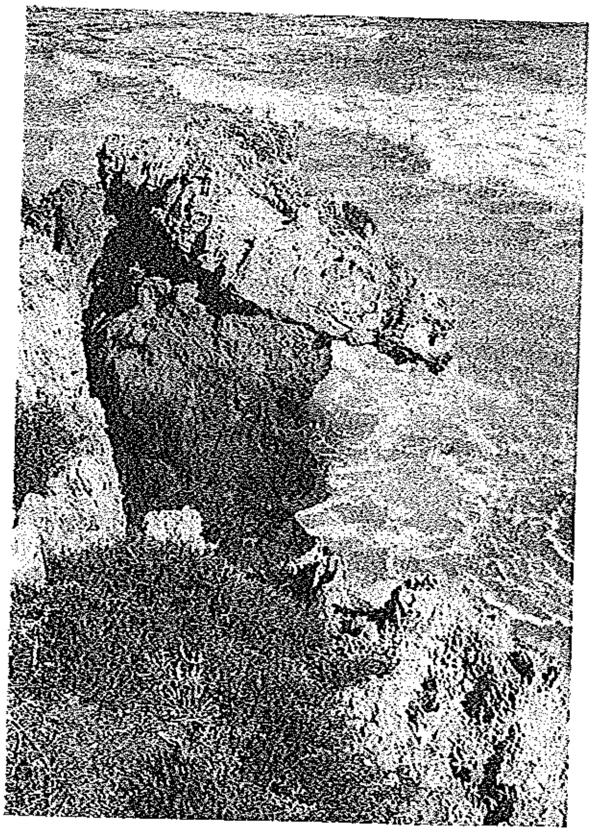


Figure 16.

Cliff erosion between Troy Avenue and Ozone Road. Jointing of the limestone cliff has led to a 'leaning' block. Note notching on the seaward side, the blocks travertinised surface and erosion of the underlying less resistant aeolianite.

A M O'Connor

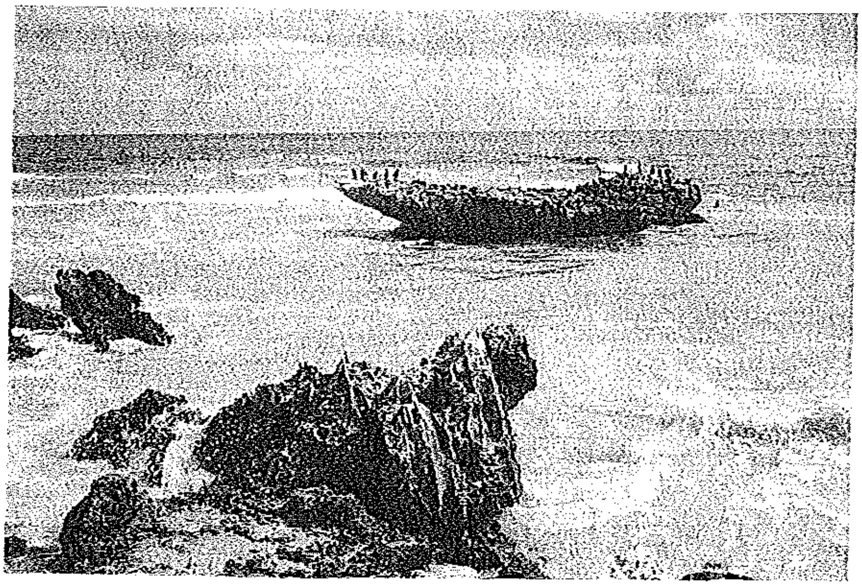


Figure 17.

Shag Rock. A stack off the headland at the bottom of Karrinyup Road. Note notch and overhanging visor.

A M O'Connor

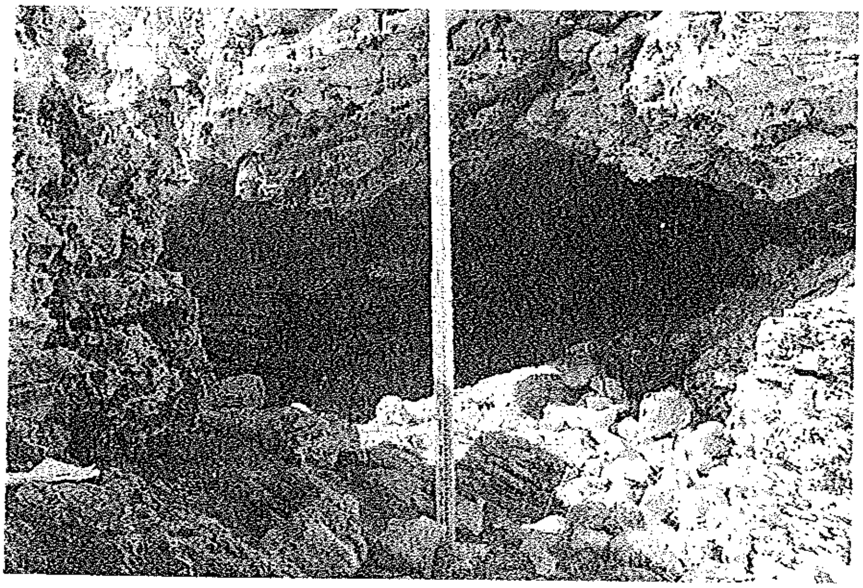


Figure 18.

A cave in the cliff-face between Troy Avenue and Ozone Road. The cave height is about 1.6 m and the depth 4.5 m. The depth partly caused by human excavation.

K Elliott

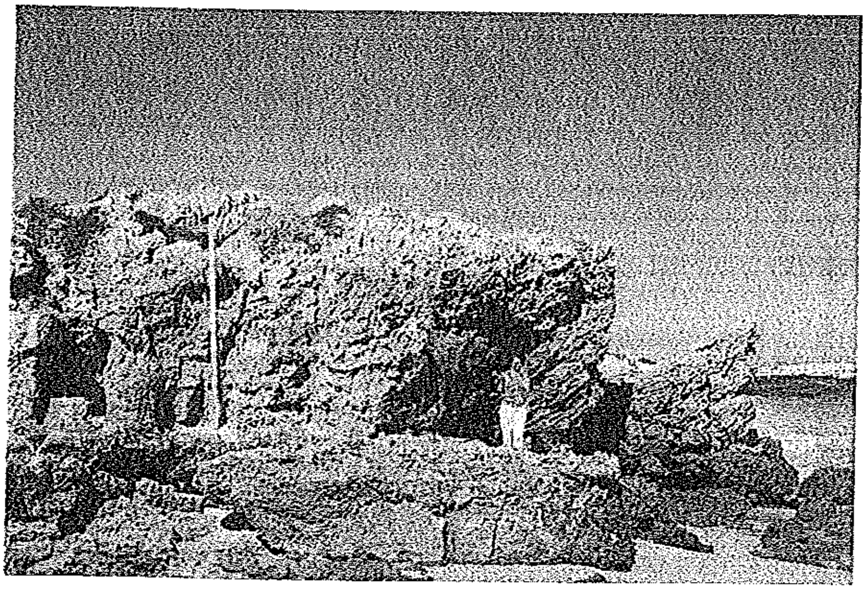


Figure 19.

Cliffed headland between Bennion and Kathleen Streets. Low benching in the foreground is 0.8 and 1 m above beach sand. The main cliff rises another 3 m above the lower bench. Travertinised solution pipes form karst 'chimney' features (left of photo).

K Elliott

Table 6. The length and area of sandy beaches between Trigg Island and Sorrento beach (modified from Keating (1983)).

BEACH	LENGTH (km)	AREA OF SANDY BEACH (m^2)
North Trigg Island	0.22	5 500
Bennion Street	0.30	4 200
Mettams Pool and Beach	0.60	12 100
Hamersley Pool and Beach	0.34	6 250
North Beach	0.24	4 800
Hale Street	0.36	6 625
Margaret Street	0.30	little sandy beach
Watermans	0.60	13 375
Ozone Road	0.30	little sandy beach
Marine Terrace	0.50	7 575
Sorrento	0.60	24 000

WATER CIRCULATION PATTERNS

The details of the water circulation fieldwork results, including maps showing the direction of water flow in the nearshore zone and over rock platforms are held as unpublished data at the Geography Department, University of Western Australia.

Water circulation patterns, on the days measured in autumn, had a northerly longshore component although on the day when energy conditions were low an oscillatory onshore-offshore movement was more dominant. The limestone headlands reflected waves whilst the intertidal platforms shed water between the passage of successive wave crests. The shedding fed currents and rips in much the same way as a nearshore sand bar.

Table 7 shows the location and frequency of rips and turbulence between North Trigg Island and Sorrento Beach. Two types of rips were observed. One type had its position fixed by the topography of the intertidal rock platforms. The other type was mobile and although it occurred in roughly the same place, energy conditions caused its position to migrate. These types are indicated in Table 7. The positions of the observed rips and rip heads were found to correlate well with sediment deposits noticeable in the aerial photographs taken six weeks before the circulation fieldwork. This in itself lends further credence to the belief that some rip positions were stable.

Table 7. Location and frequency of rips and turbulence between North Trigg Island and Sorrento Beach.

LOCATION OF RIPS AND TURBULENCE	OCCURRING ON 13 APRIL 1985 ONLY	OCCURRING ON 29 APRIL 1985 ONLY	OCCURRING ON BOTH 13 AND 29 APRIL 1985
Blue Hole, Trigg	*		*
Off Trigg Platform	*		
North of Trigg Platform		* (turbulence)	
Further North of Trigg Platform		*	
North Bennion Street		*	
Bailey Street		*	
Through Platform Channel between Mettams & South Mettams	*		*
Seaward of above	* (turbulence)		
Giles Street	*		
Saunders Street	*		*
Nth of Saunders Street Car park		*	
Beachton Street	*		
Sorrento Street	*		
Malcolm Street	*	No data	No data
Castle Street		*	
Elvire Street		*	
South of Margaret Street		*	
Beach Road	*		* (but migratory on open beach)
Between Troy Ave and Lennard Street	*		*
Between Troy Ave and Ozone Road	*		
Marmion Angling and Aquatic Club	* (turbulence)	*	
Ross Avenue		*	

3.4 CONCLUSIONS

Between North Trigg Island and Sorrento Beach, the geomorphology of the coastal reserve was comprised of intertidal rock platforms, generally backed by limestone headlands. In the nearshore environment the intertidal platform was surrounded by submerged reef, which was covered in part by a mobile veneer of sediment. Sandy beaches were contained in the pockets between headlands. They were backed by small areas of dune, some of which were covered with closed vegetation, some sparsely vegetated and the remainder were bare and subject to erosion. The limestone headlands and intertidal platforms were also liable to erosion, especially in the form of block fall. All components of the geomorphology were used for a variety of recreational activities; for example intertidal rock platforms were used by snorkellers and scuba divers, headlands for rock climbing and as lookouts and beaches for sunbathing or exercising.

Water circulation patterns during autumn had a northerly longshore component, although an oscillatory onshore-offshore movement was more dominant in calmer conditions. Two types of rips were observed; those with a fixed position and those that were mobile. Sediment deposits correlated with the position of rips. Water circulation associated with the rip current systems also contributed to 'flushing' of rock pools and therefore to water quality. The rips were hazards to swimmers and waders, but were used by surf board riders.

4. BIOLOGICAL SURVEY OF INTERTIDAL PLATFORMS

4.1 INTRODUCTION

The ecology of intertidal limestone platforms has received some attention in the Perth coastal region during the last three decades. The emphasis of the studies has been on those platforms and reefs that surround the offshore islands, particularly Rottnest Island. Studies along the Perth Metropolitan coast have investigated only the biology and population dynamics of certain organisms. General ecological studies have been done at Mudurup Reef, Cottesloe, by Smith (1952) and Marsh (1955). Similar work has not been undertaken on the intertidal platforms between North Trigg Island and Sorrento Beach. The intention of the present survey was to establish a list of biological species and a habitat classification, as an introduction to the ecological processes on intertidal platforms of this stretch of coastline.

The study area is adjacent to a large urban population. As a preliminary investigation of the extent of disturbance by recreational pressure on the natural environment the biota on platforms adjacent to rock pools were examined.

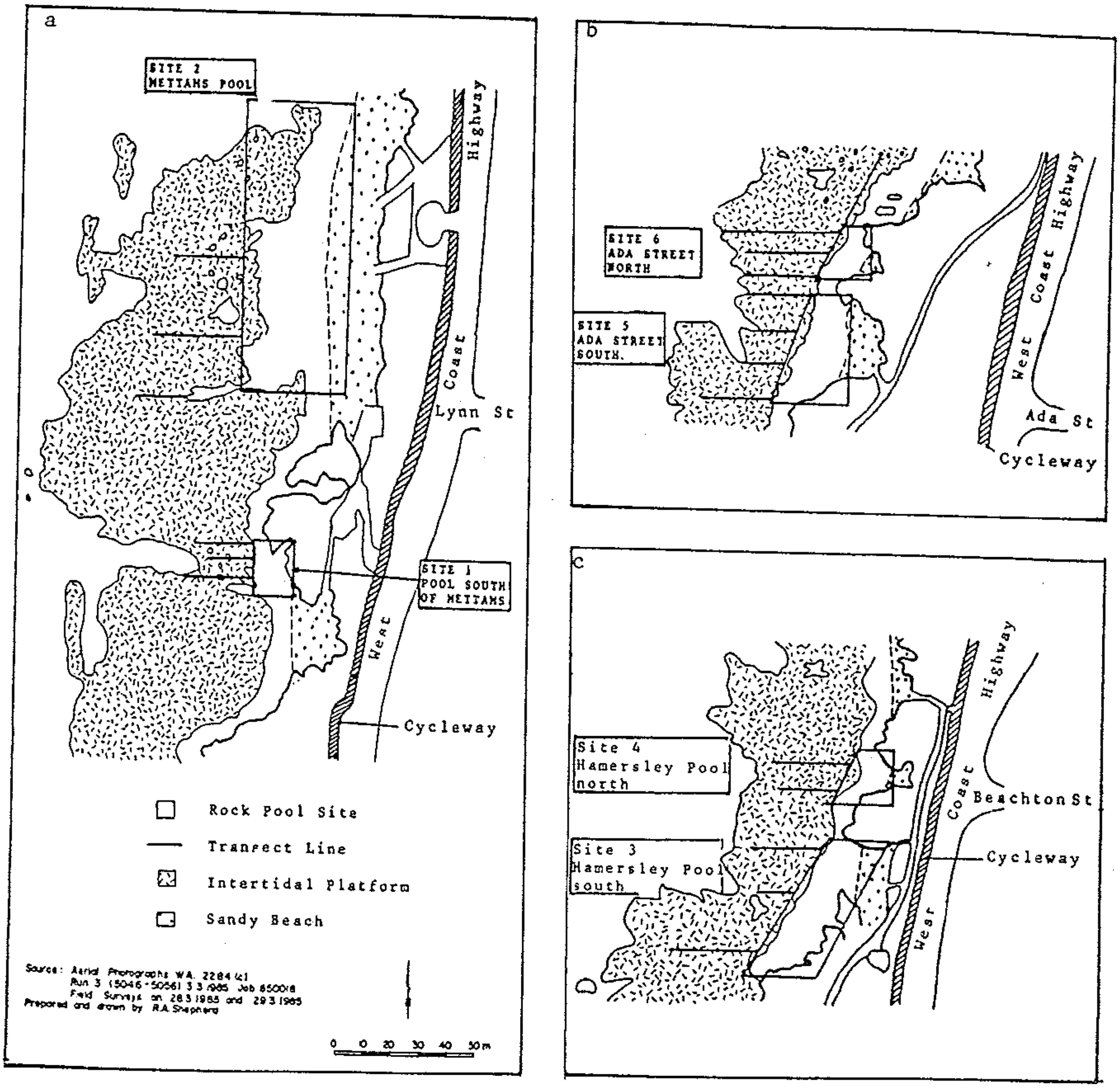
Specific aims were to:

- compile a species list of the flora and fauna on rock platforms and rock pools subject to different recreational pressures;
- develop a habitat classification for rock platforms in the coastal nearshore environment;
- compare the biota of selected rock platforms adjacent to rock pools; and
- determine whether the recreational uses of the areas surveyed have affected species diversity of biota and percentage cover of flora.

4.2 METHODS

Habitat classifications were developed from field observation throughout the study and data collected on 28 and 29 March 1985. The boundaries for each habitat type were located by field observations and interpretation of aerial photographs. They were then drawn onto a map.

The existing type, diversity and zonation of biota were investigated on rock platforms adjacent to selected rock pools. For the purpose of this study a rock pool was defined as a body of water with a sandy bottom, bounded on the seaward side by the inshore rock platform and by a sandy beach on the landward side. Six sites were selected. These were Mettams Pool, the pool south of Mettams, Hamersley Pool south, Ada Street south and Hamersley Pool north (Figure 20).



Source: Aerial Photographs WA. 2284 (c)
Run 3 (5046-5056) 3.3.1985 Job 850018
Field Surveys on 28.3.1985 and 29.3.1985
Prepared and drawn by R.A.Shepherd

Figure 20. Biological survey sites.

Field work was undertaken on 28 and 29 March 1985. At each site, three or four transects were taken across the rock platform from the edge of the rock pool towards the seaward boundary of the rock platform, or until 30 metres had been reached.

A one metre square quadrat was placed every five metres along each transect, and the types and abundancies of the obvious species were determined. Macroalgae and porifera were considered obvious if they exceeded one percent cover in the quadrat. The fauna, excluding porifera, were considered obvious if they exceeded three centimetres in length. Samples of species were collected, identified and listed.

From the field data the percentage cover of macroalgae and *Haliclona* spp, and species diversity were graphed for each site. The percentage cover of the most abundant species, *Ulva lactuca* and *Metagoniolithon* spp, were also graphed.

To determine whether the recreational use of the site affected the species diversity of biota and percentage cover of macroalgae and *Haliclona* spp, an index of recreational pressure was calculated for each site. The index (I) was defined as follows:

$I = P/A$,

where, I was the recreational index;

P was the total number of people using rock pool and reef platform resources (values determined from beach use data); and,

A was the area of rockpool and rock platform.

The area of rock pool and rock platform was determined from the geomorphological map and from direct field measurements. Using the recreational index formula and the beach use data for the rock platforms and rock pool, area indices were determined and tabulated.

4.3 RESULTS

The biological survey of rock platforms between Trigg Island and Sorrento Beach identified 25 obvious species (Table 8). Seven of these species were macroalgae and nine were molluscan species. The most common species was sea lettuce, *Ulva lactuca*. No animal species appeared to be common throughout the study area.

HABITAT CLASSIFICATION OF THE NEARSHORE

The habitat classification map (Figure 21) was developed to illustrate the biological diversity of the rocky coastline from Trigg Island to Sorrento Beach. Five zones were identified: a sand zone, broken reef, an inner platform, a mixed algal zone, and a platform margin. These zones indicated where similar biological associations occurred in the study area.

The sand zone was characterised by a sandy bottom which showed no visible macroalgae or fauna on its surface. Schools of fish were observed in this zone.

Table 8. Species of marine plants and animals (macrobiota).

- PHAEOPHYTA (brown macroalgae)
  - *Padina* spp
  - *Sargassum* spp
  - *Ecklonia radiata*
- RHODOPHYTA (red macroalgae)
  - *Metagoniolithon* spp
  - *Hypnea* spp
- CHLOROPHYTA (green macroalgae)
  - *Colpomenia sinuosa*
  - *Caulerpa* spp

- PORIFERA (sponges)
  - *Haliclona* spp

- ACTINIARIA (sea anemones)
  - *Oulactis macmurrichi*

- MOLLUSCA
  - AMPHINEURA (chitons)
    - *Clavarizona hirtosa*
  - GASTROPODA (snails, limpets, abalone)
    - *Haliotis roei*
    - *Prothallotia pulcherrimus*
    - *Turbo torquata*
    - *Patelloida alticostata*
    - *Patella peronii*
    - *Thais orbita*
    - *Dentimitrella lincolnensis*
  - PELECYPODA (mussels)
    - *Brachidontes ustulatus*

- ECHINODERMATA
  - ASTEROIDEA (starfish)
    - *Patiriella calcar*
  - ECHINOIDEA (sea-urchins)
    - *Heliocidaris erythrogramma*
  - OSTEICHTHYES (bony fish)
    - *Omobranchus germaini*
    - *Torquigener pleurogramma*
    - *Pictilabrus laticlavius*
    - *Cheilodactylus rubrolabiatus*
    - *Microcanthus strigatus*

The broken reef consisted of submerged reef units that were covered in areas by a mobile veneer of sediment. The macroalgae noted on the reef units were *Ulva lactuca*, *Metagoniolithon* spp, and *Sargassum* spp. Animals observed were the sea anemone, *Oulactis macmurrichi*, and the bivalve, *Brachidontes ustulatus*, which were found in the sand at the base of the broken reef units.

The inner platform with low species diversity was dominated by *Ulva lactuca* and *Metagoniolithon* spp. Clumps of *Brachidontes ustulatus* and a few individuals of *Oulactis macmurrichi* were found in sand pockets on the platform.

The mixed algal zone covered most of the rock platform, excluding the inner and outer margins. This zone had the greatest macroalgal diversity. There was less cover by *Ulva lactuca* and *Metagoniolithon* spp, than on the inner platform zone. The obvious macroalgal species noted were *Sargassum* spp, *Ulva lactuca*, *Metagoniolithon* spp, *Padina* spp, *Colpomenia sinuosa* and *Hypnea* spp. Fewer sand pockets meant that *Oulactis macmurrichi* and *Brachidontes ustulatus* were less abundant than in the inner platform zone while the large gastropods, *Turbo torquata*, *Thais orbita* and the starfish, *Patiriella calcar*, were common. The small gastropods, *Prothalotia pulcherrimus* and *Dentimitrella lincolnensis*, were often observed in association with *Padina* spp and *Sargassum* spp. Browsing fish *Omobranchus germaini* and *Torquigener pleurogramma*, were noted roaming in this zone.

The platform margin contained a low cover of macroalgal species. Species observed were *Ecklonia radiata*, *Ulva lactuca*, *Metagoniolithon* spp, *Sargassum* spp, and *Hypnea* spp. This zone was characterised by the wide diversity and abundance of invertebrate species. Species found only on the platform margin were the abalone, *Haliotis roei*, the chiton, *Clavarizona hirtosa*, and the limpets, *Patelloida alticostata* and *Patella peronii*. Occasionally, a few individuals of the starfish, *Patiriella calcar*, were noted. The width of the platform margin zone increased with the length of the wave breaker zone over the platform.

The boundaries between the sand zone and the broken reef represent the situation only of the time of the aerial surveys. The boundary position changed with mobilisation of inshore sediment.

In the area between Trigg Island and Shag Rock, the zoning did not closely follow the geomorphology (Figure 13). The inner margin of the rock platform has been classified as broken reef. The surface of the platform was extremely rough and creviced, with crevices containing sediment. Thus, the micromorphology of the platform at this locality was more characteristic of a submerged reef unit and the biological associations reflect this.

DISTRIBUTION OF BIOTA ON ROCK PLATFORMS ADJACENT TO SELECTED ROCK POOLS.

Percentage cover of macroalgae and *Haliclona* spp, on the rock platform tended to increase with distance from the rock pool margin (Figure 22 & 23) The extent of the increase ranged from 10% at Hamersley Pool south to 50% at Ada Street north. Mettams differed from this trend: the percentage cover declined from 75% at the rock pool edge to 30% on the seaward margin of the rock platform. At all sites, the seaward margin (reached only in calm conditions) of the rock platform had a low percentage cover of macroalgae and *Haliclona* spp (Figure 22).

Percentage cover of *Metagoniolithon* spp across the rock platform followed the above trends. The exception was Mettams Pool, where the percentage cover of *Metagoniolithon* spp remained constantly low across the platform.

21 (a)

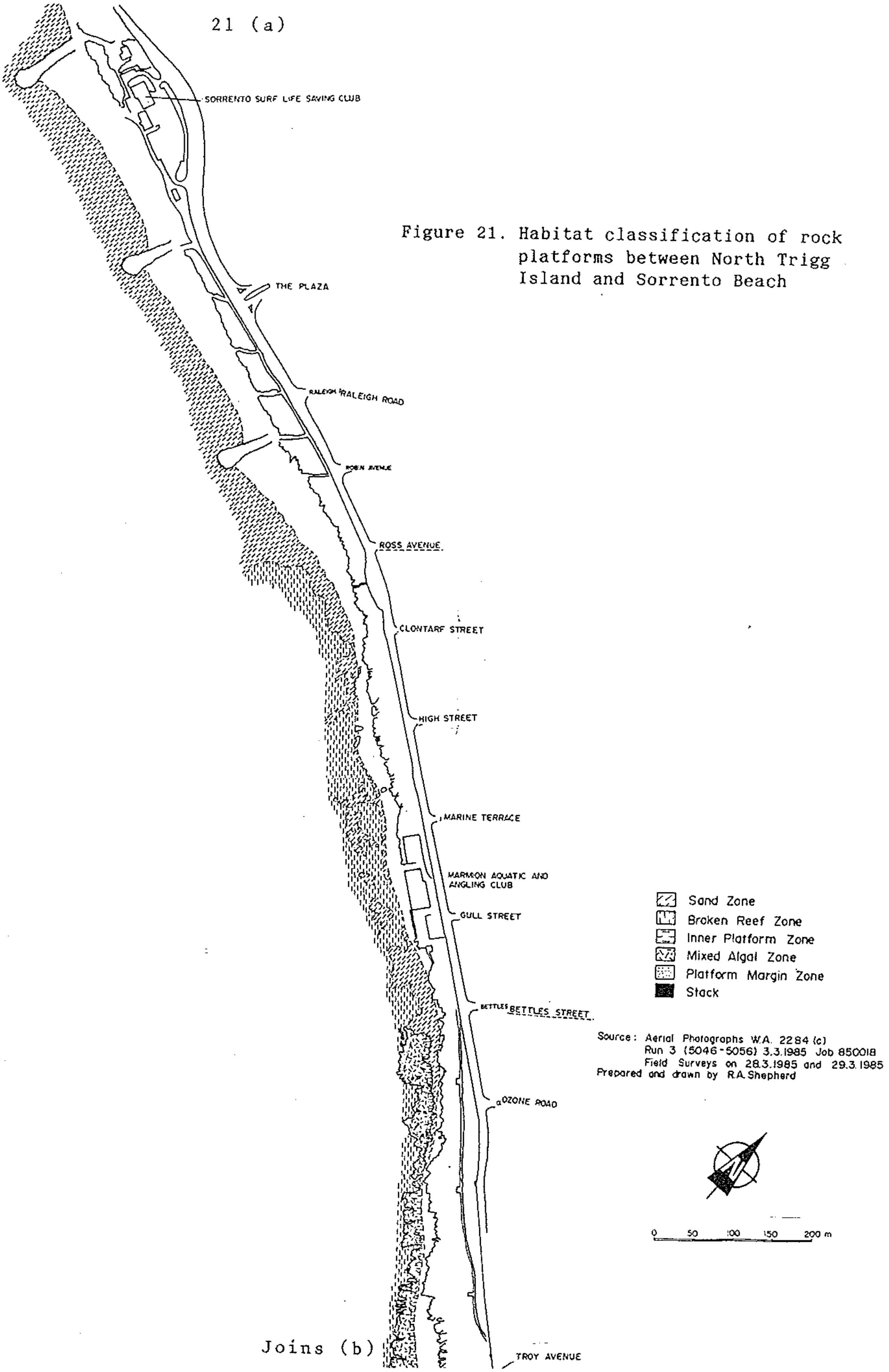
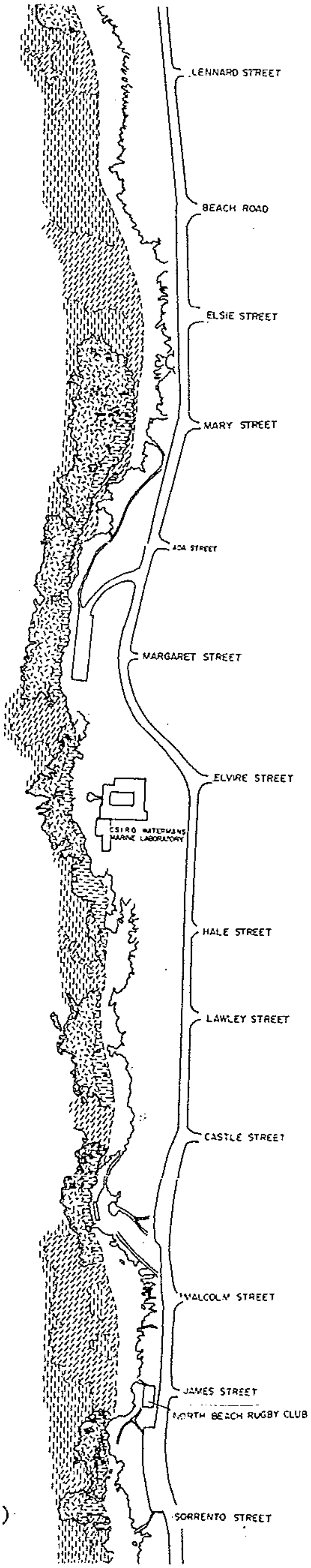


Figure 21. Habitat classification of rock platforms between North Trigg Island and Sorrento Beach

Source: Aerial Photographs W.A. 2284 (c)
Run 3 (5046-5056) 3.3.1985 Job 850018
Field Surveys on 28.3.1985 and 29.3.1985
Prepared and drawn by R.A. Shepherd

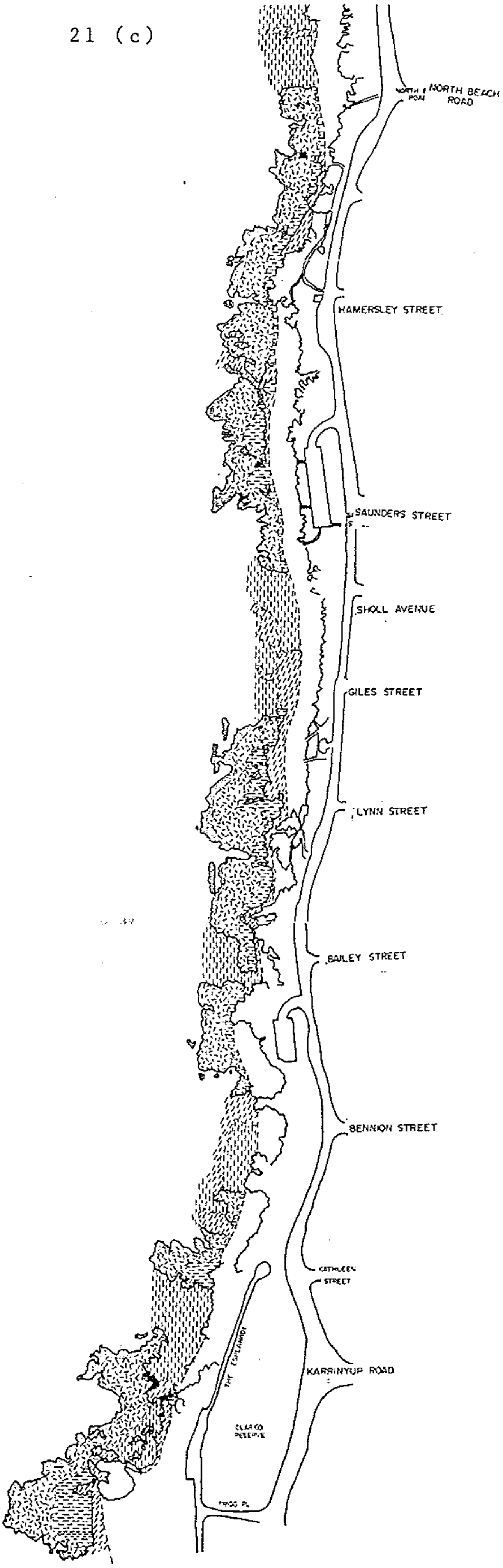
Joins (b)

21 (b)



Joins (c)

21 (c)



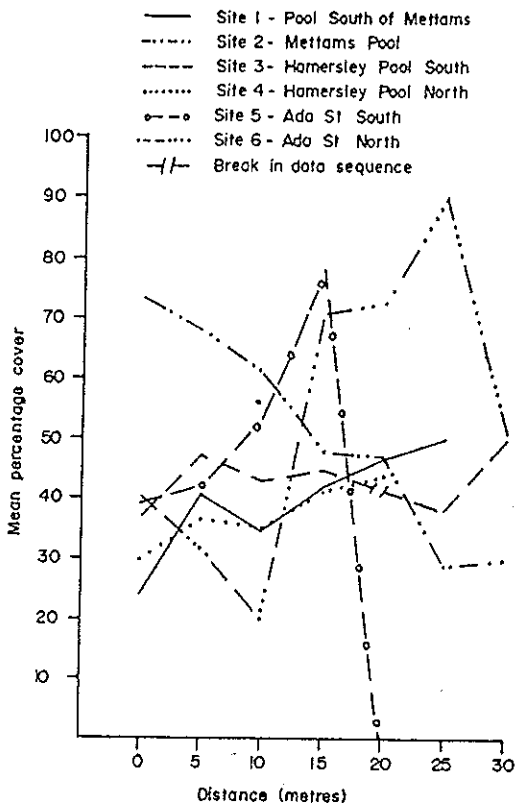


Figure 22. Mean percentage cover of macroalgae and *Haliclona* spp on rock platforms adjacent to selected rock pools.

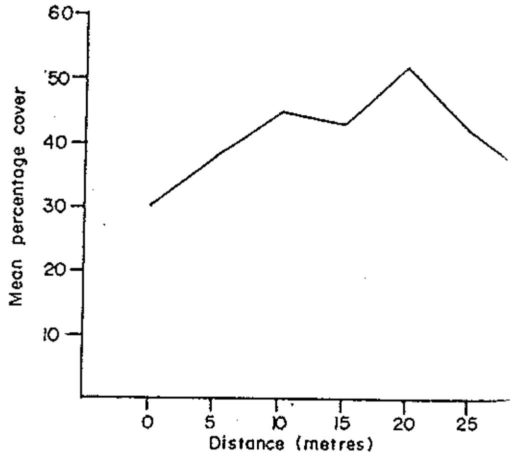


Figure 23. Mean percentage cover o macroalgae and *Haliclon* spp for all rock poo sites.

There was no distinct trend in the percentage cover of *Ulva lactuc* although there was a general tendency for it to decrease with distance aw from the rock pool edge (Figure 24). The trend at Mettams Pool aga differed from other rock pool sites; the percentage cover of *Ulva lactu* increased from the rock pool edge across the rock platform towards th seaward margin, where it rapidly declined in abundance.

Species diversity increased from the rock pool edge to the outer margin the rock platform for all sites except the pool south of Mettam (Figure 25). This site had a fairly constant species diversity across th rock platform and fewer species than other sites. Generally the invert brate species diversity was greatest on the outer margins of the roc platform (Figure 26).

RECREATIONAL USE OF SIX SELECTED ROCK POOLS AND PLATFORMS

The degree of recreational pressure on the rocks pools and adjacent roc platforms, measured by an index (I), was graded from highest to lowe (Table 9). The rock platform adjacent to the pool south of Mettams a Mettams Pool itself had the highest recreational pressure.

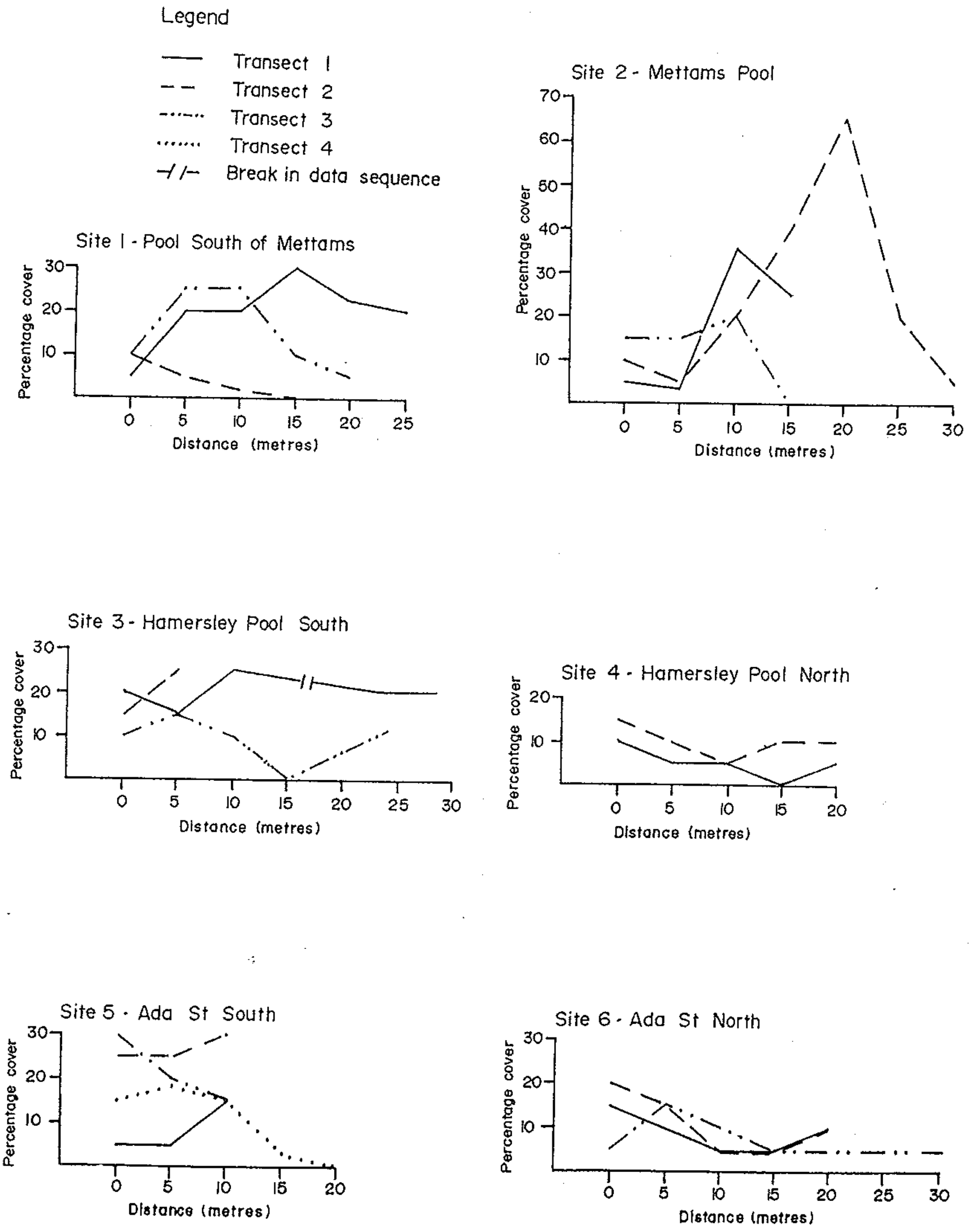


Figure 24. Mean percentage cover of *Ulva lactuca* on rock platforms adjacent to selected rock pools.

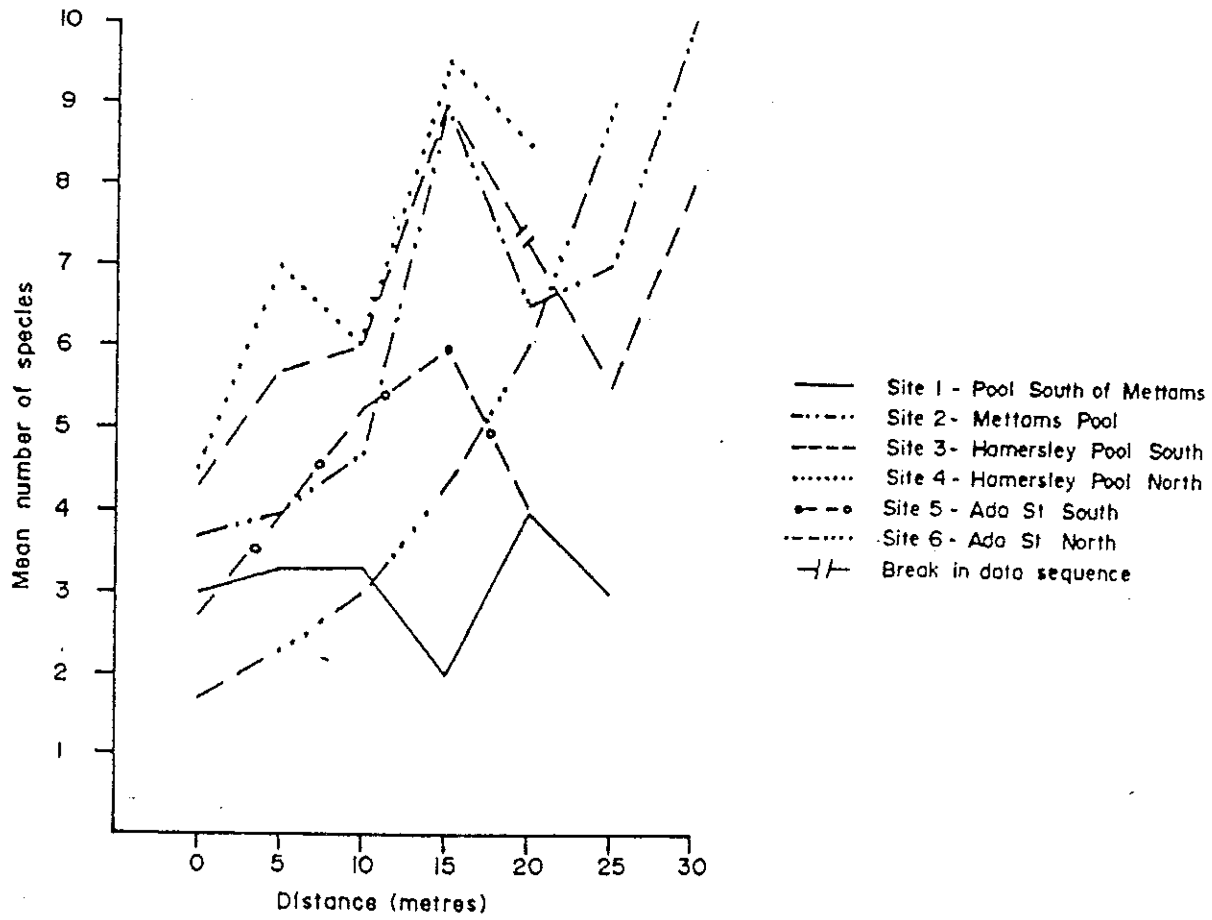


Figure 25. Mean number of species on each rock platform adjacent to selected rock pools.

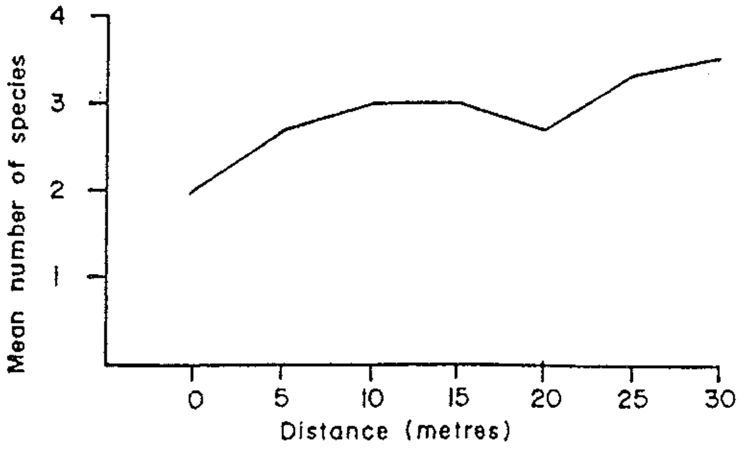


Figure 26. Mean number of species for all rock platforms adjacent to selected rock pools.

Table 9. The area, recreational use and index of recreational pressure at six selected rock pools and adjacent platforms.

SITE/GEOMORPHIC SEGMENTS	AREA (m^2)	RECREATIONAL USE (TOTAL NUMBER OF PEOPLE)	INDEX OF RECREATIONAL PRESSURE	
			SEGMENT INDEX	OVERALL SITE INDEX
<u>Mettams Pool</u>				
rock platform	6 250	30	0.5	4.4
rock pool	1 940	332	17.1	
<u>Pool south of Mettams</u>				
rock platform	490	22	4.5	4.2
rock pool	150	5	3.3	
<u>Ada St north</u>				
rock platform	610	0	0	2.9
rock pool	140	22	15.7	
<u>Hamersley Pool south</u>				
rock platform	2 240	0	0	2.9
rock pool	680	84	12.4	
<u>Ada St south</u>				
rock platform	1 100	7	0.6	1.7
rock pool	350	17	4.9	
<u>Hamersley Pool north</u>				
rock platform	1 010	0	0	0.5
rock pool	260	6	2.3	

4.4 CONCLUSIONS

The intertidal rock platforms supported a diversity of flora and fauna. In this study, seven species of macroalgae and 16 species of animals were identified. This is a considerable underestimate of the biological resource as it includes only species obvious at the time of the survey.

Ottaway and Simpson (1986), for example, recorded over 400 species of macroepibenthos in the survey undertaken by the Department of Conservation and Environment study team.

The present study identified five distinct habitat types on the rock platform. The habitats were highly dynamic and the biological assemblages likely to vary seasonally and between sites. This study showed considerable variation between rock pool sites.

The different trends, in biotic distribution on the rock platform adjacent to Mettams Pool, from those on other rock platforms may result from the intense recreational use and nutrient enrichment of the Pool's water. This is discussed further in Chapter 5.

5. DISCUSSION

Chapter 1 defined the broad aims of this pilot survey. The following discussion should be viewed with the aims and limitations in mind.

Here spatial patterns of recreation are discussed in relation to both the provision of facilities and the physical characteristics of the rocky coastline. The impact of coastal recreation on the environment is reviewed.

5.1 RECREATIONAL USE AND THE PROVISION OF FACILITIES

The beach survey results (Section 2.3) identified Trigg Island, Mettams Pool and Beach, Watermans Beach and Sorrento Beach as focus points of recreation whereas Hale Street, Margaret Street and Ozone Road were least used. The variations in numbers of people and range of activities occurring in the study area could be explained partly by the availability of facilities (including access and parking) (Figure 27) and partly by the physical characteristics of each embayment (including water and beach cleanliness, as well as safety factors).

Facilities within the study area have developed at places that were historically popular holiday centres (Easton 1971) so that, in this study, popular areas where many activities occurred also had good facilities. The area immediately north of Trigg Island had an area for parking, changerooms and toilets. Mettams Pool had access for disabled people, changerooms and toilets and parking immediately south of the pool. Watermans Beach was serviced by changerooms, sun shelters, parking to the south or rationalised kerbside parking. Sorrento Beach had a surf life saving-club and shopping centres as well as extensive parking areas, changerooms and toilet facilities. North of Trigg Island and Watermans Beach grassed reserve areas were an added attraction to the coast. Boat launching facilities were found at Trigg Island and Marmion Angling and Aquatic Club. Trigg boat ramp was designed for small boats only and for use by general public but parking facilities for cars and trailers was limited. Facilities at the Marmion Angling and Aquatic Club were available to club members only, and the development was one of only two private buildings located on the western side of West Coast Highway. Parking at this facility was also limited.

Thus it seems reasonable to assume that facilities attract people. Hamersley Pool and North Beach, however, had facilities but the beaches were not extensively used. Physical characteristics of the environment were also important and these are discussed below (5.2).

The beach surveys indicated that, although zoning was not formalised, there was potential for the encouragement of informal zoning through the provision of appropriate facilities. Such facilities should enhance, as well as support existing recreational use of the major recreational focus points. Table 3 lists the onshore support facilities that are desirable or necessary for coastal recreation and beach use.

5.2 RECREATIONAL USE AND PHYSICAL CHARACTERISTICS OF THE COASTLINE

The sandy beach at Sorrento was the major landform that attracted beachgoers. This, together with protection afforded by the three groynes, helped account for high levels of recreational activity. Similarly, Mettams and Watermans have fairly extensive stretches of sandy beach, and although the sandy beach areas at North Trigg Island are not extensive, they were popular recreation places. At North Trigg Island, Mettams and Watermans, the sandy areas are augmented by a diverse range of attractive physical characteristics: sandy bottomed rock pools sheltered by intertidal limestone platforms, which attenuate the strength of incoming waves. The platforms not only protect swimming areas they are also suitable for snorkelling, scuba-diving and education purposes, especially at Trigg Island and Mettams where the platforms are extensive. Headlands between Mettams Pool and the pool south of Mettams, and in Trigg Island embayment that are suitable for rock climbing, viewing scenery and fishing attract people. Clearly, the diversity for potential and present recreational activity is an important feature of these areas.

Hale Street and Margaret Street Beaches were unpopular partly because they were both within the CSIRO Watermans Marine Reserve. Furthermore, Margaret Street Beach, in contrast to the more heavily used beaches, has very little sandy beach (Table 6), with outcrops of limestone bedrock. Neither embayment has much sandy sea bottom adjacent to a beach nor is there a rock pool or a safe swimming area (Table 6). Margaret Street headlands and Bennion Street headland, however, did attract early morning fishermen.

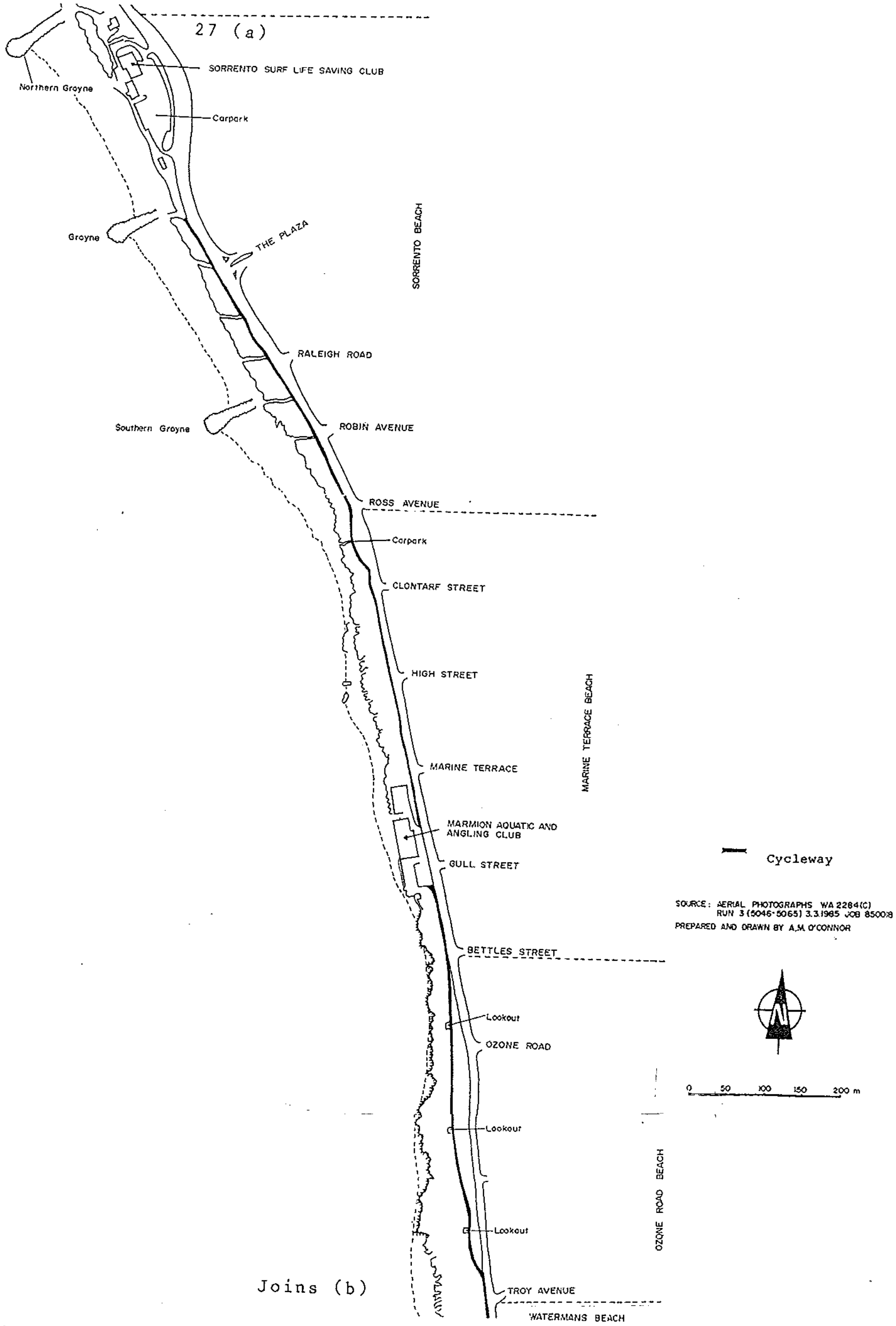
Recreational use was also low at Ozone Road Beach. The southern portion of the embayment is sandy and appeared to be suitable for surfers, who used a rip for a 'lift' offshore (Table 7). The rip made this portion of the beach unsafe for swimming. Furthermore, the sandy beach is extremely narrow and interspersed with outcrops of bedrock. High clifflines make access difficult and because the intertidal platform is continuous there are no rock pools or sandy-bottomed areas for swimming.

Use of Hamersley Pool and Beach was not as great as the provision of facilities would suggest. The extensive sandy beach could also be expected to attract people. Some outcrops of bedrock, however, make the beach less attractive. There is very little sandy-bottomed swimming area and, unlike Mettams or Trigg Island, the rock pools are separated from the extensive sandy beach by limestone headlands. Less access is provided than at other popular beaches and the proximity of West Coast Highway reduces its privacy. Despite this the beach was used by locals for sunbathing. Apparently the limiting factor was a lack of space. A concrete revetment built behind a pocket beach has reduced the amenity value of Hamersley Pool. The protection afforded by the revetment was necessary to prevent the loss of poorly sited facilities, such as the access path adjacent to West Coast Highway.

5.3 SUITABILITY OF EMBAYMENTS FOR WATER-BASED ACTIVITIES

The requirements for various types of water-based use of the coastal reserve were listed in Table 3 and discussed under 5.1 above. Physical characteristics of the marine environment in the study area were summarised in Table 5 and discussed under 5.2.

When these characteristics and requirements are considered in conjunction with one another, it becomes obvious that several embayments are more suitable for some water-based purposes than others (Table 10). For example, Mettams Pool and Beach, Watermans Beach and Sorrento Beach were eminently suitable not only for swimming and wading but also for a range of other activities. North Trigg Island also had the physical characteristics to make it suitable for a wide range of activities, but the presence of a boat ramp



SOURCE: AERIAL PHOTOGRAPHS WA 2284(C)
RUN 3 (5046-5065) 3.3.1985 JOB 850018
PREPARED AND DRAWN BY A.M. O'CONNOR

Figure 27. Location of facilities between North Trigg Island and Sorrento Beach.

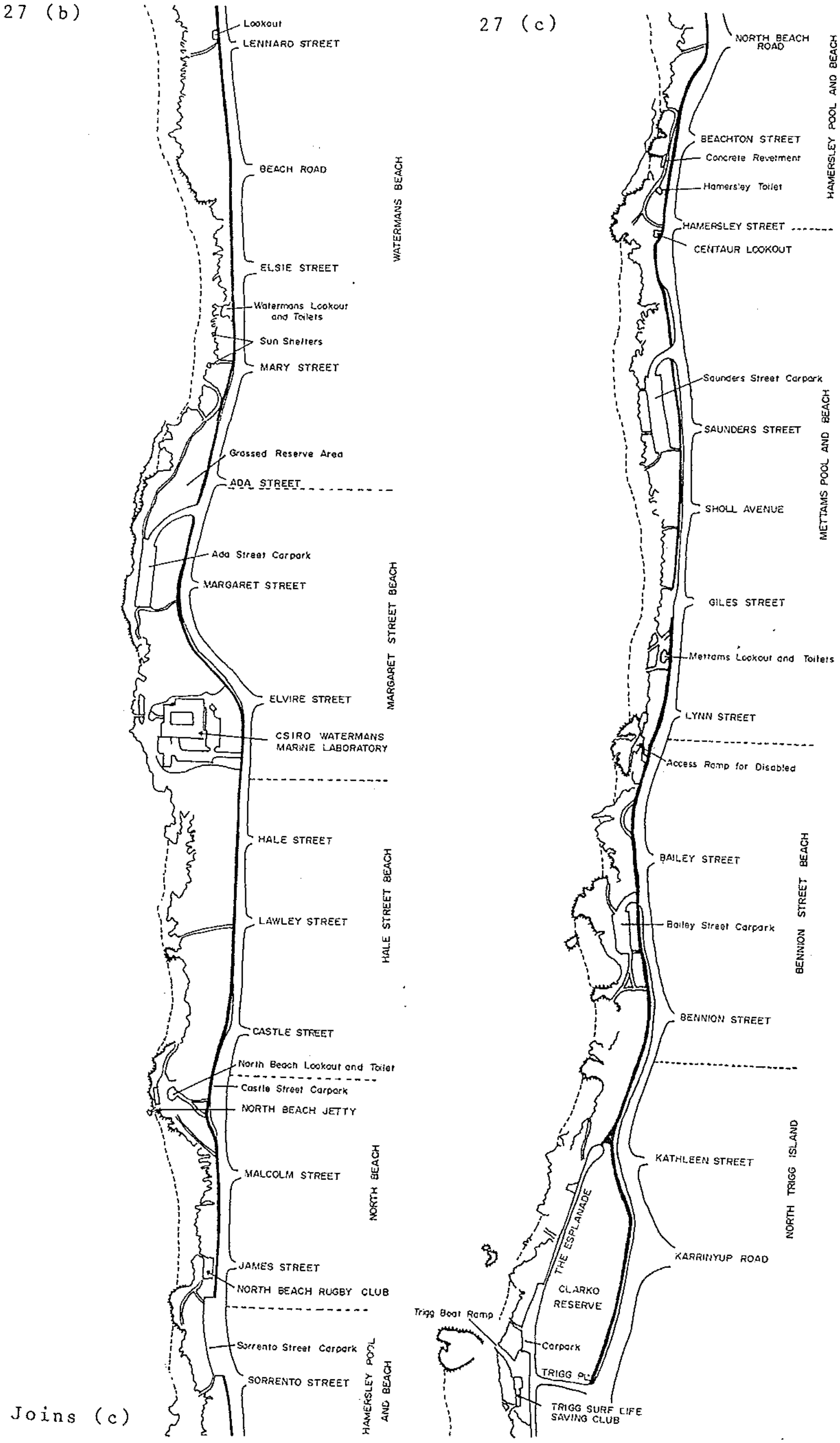


Figure 27. Location of facilities between North Trigg Island and Sorrento Beach (cont'd).

reduced its suitability for activities such as swimming and wading. It must be noted that not all of each embayment shown in Table 10 would be suitable for the activities indicated. Hamersley Pool and Beach, for example, had a 2-star rating for swimming and wading. The embayment was not suitable for reasons given above under 5.2.

Table 10. Suitability of embayments for water-based recreational educational, scientific and conservation purposes.

	ROCK POOLS AND OPEN SANDY BEACHES			ROCK PLATFORM AND SUBMERGED REEF			LINE FISHING	BOAT LAUNCHING	MARINE RESERVES
	SWIMMING	WADING	BOARD SURFING, SURF SKIING WIND SURFING	SNORKELLING	SCUBA DIVING	REEF-HARVESTING			
North Trigg Island	** (*** if boat ramp removed)	** (*** if boat ramp removed)	-	***	***	-	*	*	**
Bennion Street Beach	*	*	*	**	**	-	***	-	**
Mettams Pool and Beach	***	***	***	***	***	-	*	-	**
Hamersley Pool and Beach	**	**	***	**	**	-	-	-	**
North Beach	**	**	**	*	*	*	***	-	**
Hale Street Beach	*	*	*	**	**	-	*	-	*** (as a'control')
Margaret Street Beach	-	-	-	**	**	-	***	-	*** (as a'control')
Watermans Beach	***	***	***	**	**	-	*	-	**
Ozone Rd Beach	-	-	**	*	*	-	*	-	*
Marine Terrace Beach	**	**	*	*	*	-	*	**	-
Sorrento Beach	***	***	***	*	*	-	**	***	-

*** indicates 'highly suitable'

5.4 IMPACT OF RECREATION ON THE ENVIRONMENT

Recreational use of the coast has contributed to degradation of the physical and biological environment, by exacerbating the effects of natural processes such as erosion (City of Stirling 1984) and changes in species composition and abundance (Chapter 4). Degradation of beach environments is indicated by the purported decrease of the abundance and species diversity of biota, in the decline of water quality and beach cleanliness, in the erosion of limestone features (including headlands and platforms), and in the increase in dune tracking and the erosion of sand (Chapter 3). Such degradation needs to be more closely researched, monitored and minimised if the high recreational amenity of the coastal reserve is to be maintained. The various problems and environmental conflicts identified in this study are now described.

The abundance and diversity of biota varied considerably between and within rock platforms; however, all the species identified are known to exist on other rock platforms along the Perth coastline and on nearby islands (Hodgkin 1960; Marsh & Hodgkin 1962). The zones developed in this study for a habitat classification of the area were similar to those formed for Mudurup Reef, Cottesloe (Smith 1952; Marsh 1955). It should be noted, however, that the zones only represented the types of biological associations that were expected to be found, and did not describe the diversity and abundance of species at any one site. Whether the biological associations observed have been affected by anthropogenic factors is not known, as environmental parameters, such as water quality, were not measured.

Molluscs are removed from the intertidal platform by indiscriminate, uncontrolled harvesting, as well as by professional fishing of abalone, *Haliotis roei* (The West Australian, 19 December 1986). Professional abalone fishing is controlled by regulations, which allow removal of the species only at certain times and only from the seaward sub-surface notch o the platform. Monitoring and control of the professional fishing will prevent depletion of the abalone stock. On the other hand, indiscriminate harvesting of molluscs by amateur collectors will affect the mollusc stocks (including the abalone stock for professional fishing), and may result in changes in community structure. There was evidence of this at the pool south of Mettams where species diversity was low and the recreational use of the platform was intense (Chapter 4). An indirect effect of faunal community degradation may be the reduction of grazing pressure on macroalgae, resulting in increased percentage of cover over the platforms; however, this might be complicated by other factors such as water quality.

Water quality, measured at the end of the summer season, may help determine the amount of recreational pressure within an embayment, and conversely, different concentrations of recreational pressure result in varying levels of water cleanliness. Water circulation flushes pollutants, such as body excretions (especially urine), groundwater and stormwater discharge, from an area. Johannes and Hearn (1985) studied water circulation in the inner shelf of the Marmion area, of which our study area was a part. They found that flushing time was very variable from day to day because of varied wind strength acting on the circulation of the lagoon. Offshore reefs acted as a barrier to flushing, but the average turnover time in the wider waters of the inner shelf lagoon was 1.3 days. This should be more than adequate to keep water in the small, onshore rock pools sufficiently clean for recreational purposes. (Clark 1977, specifies a maximum turnover time or flushing rate of 2 to 4 days for water in marinas). However, during late summer when periods of extended calm and low currents often prevail, turnover of water within the lagoon may take up to 4 or 5 days (Public Works Department 1984). Water exchange between the onshore rockpools and swimming areas, and the offshore waters are further impeded by the intertidal rock platform, so flushing times for nearshore areas under intensive recreational use may be greater than 4 or 5 days. Since intensity of beach use and the associated pollution of onshore rock pools are apparently high during late summer, there are serious ramifications concerning cleanliness of the waters and the number of people able to safely use the water. At Mettams Pool with highest recreational pressure, the trends in distribution of biota differed from other sites. For example, the percentage cover of macroalgae and *Haliclona* spp. was greater at the rock pool edge than at other pools and decreased from the rock pool edge to the seaward margin of the platform (Figure 22). Various species of macroalgae are known to grow more prolifically when there is an increased nutrient supply. Although the response of the sponge *Haliclona* to a nutrient enriched environment is not necessarily similar to that of macroalgae, the overall trend in biotic cover may result from recreational pressure in the adjacent rock pool. Thus, the trends on this platform may result from recreational pressure.

Limestone erodes due to natural physical and biological processes. Physical processes may be chemical or mechanical. Chemical weathering of limestone stems from contact with the salt water, facilitated by alternating wetting and drying. Mechanical erosion occurs through physical breakages in areas of weakness, mostly by wave action. Biota can also erode limestone by biochemical and biomechanical processes (Hodgkin 1964; McLean 1974). Removal of invertebrates by man may cause physical breakage of the limestone substratum, but on the other hand, bioerosion may be diminished when gastropods are removed. Physical damage to intertidal platforms is also caused by the erection of fishing tripods at the platform edge, although this damage would be minimal. Natural caves in the limestone headlands have been further excavated by people, many of whom leave rubbish and light fires inside the caves. Blowouts occur in sand dunes. In many places, for example at Watermans Beach between Troy Avenue and Lennard Street (City of Stirling 1984), these have been initiated by tracking through dune sand. Tracking is difficult to control, but ringlock fencing seems to have been effective in controlling access in this area. Provision of formalised access paths, such as those at Sorrento, has also helped control tracking and dune degradation. Discharge from storm water drains may increase dune erosion. The City of Stirling has carried out maintenance work to minimise these effects.

Consideration of recreational resources between North Trigg Island and Sorrento Beach, together with the recreational pressures exerted upon the area, has led to an identification of problems as well as an assessment of potential uses of this section of rocky coastline. The most significant problem is the proximity of West Coast Highway to the beach. As was pointed out by the City of Stirling Coastal Report (1984), this reduces the area of coastal reserve available for recreation. It also results in a demand for engineered protection of amenities, including West Coast Highway itself (at Hamersley and Sorrento), causes segregation of the recreational area from the local residential community, and severely constrains planning for recreation. In an environment where recreational use is concentrated in distinct clusters, West Coast Highway would not be necessary in a recreational planning context, or resource exploitation context.

6. RECOMMENDATIONS

Two sets of recommendations are given: the first relates to potential uses of the coastal reserve and the second suggests future research which would assist long-term management of the area and which might usefully be pursued in subsequent coastal study courses.

6.1 RECOMMENDATIONS FOR POTENTIAL USES OF THE COASTAL RESERVE, NORTH TRIGG ISLAND TO SORRENTO BEACH

- Conserve the natural environment for continued diverse recreational and educational use. Arrange a programme to increase public knowledge of the environment and appreciation of the coastline's primary resources.

- Increase policing of bans on spearfishing. Consideration could be given to banning the removal of biota from the rock platforms and submerged reef units. For safety reasons spearfishing, which conflicts with other recreational activities, could be allocated an area by itself. Removal of abalone by professional fishermen could be exempt from this ban but nevertheless still controlled stringently.

- Restrict the flow of traffic along West Coast Highway by means of a diversion (to Marmion Avenue), traffic management (such as traffic islands and lights) and possibly by partial closure of West Coast Highway itself (just north of Karrinyup Road, immediately south of North Beach Road and Hepburn Avenue).

- Rationalise access paths to beaches from West Coast Highway and carparks where this work has not already been undertaken. Take measures to prevent tracking through dunes. Landscape carparks to provide shelter and ameliorate their harsh visual impact.

- Promote as recreational focus points areas that already have high levels of recreational activity and good facilities. This would create informal zoning of the reserve with some areas for much activity and others for less activity. This study found recreational focus points at North Trigg Island, Mettams Pool and Beach, Watermans Beach and Sorrento Beach. In addition North Beach could be promoted for recreation. This could be done through an informal declaration of recreational zones. Some suggestions are given below for developing these focus points:

NORTH TRIGG ISLAND

- Close The Esplanade immediately north of the carpark to permit some integration between Clarko Reserve and the beach itself.
- Install gas barbeque facilities at Clarko Reserve.
- Conserve the geomorphology of the limestone headlands and platforms in the North Trigg Island and Bennion Street embayments. Public information could be provided by the erection of vandal-proof boards.
- Remove the boat ramp at Trigg Island altogether or do not upgrade its capacity.

METTAMS POOL AND BEACH

- Provide sun shelters in the beach zone.
- Develop seating and shade facilities near the access ramp.
- Provide more parking facilities.

WATERMANS BEACH

- Provide gas barbeque facilities in the grassed reserve area at Watermans Beach.
- Provide sun shelters and plant shade trees in the grassed reserve.
- Provide shade and seating facilities at the look-out above the Watermans toilet block.

NORTH BEACH

- Extend the Apex building or convert a section of it to a restaurant and coffee lounge.
- Extend North Beach jetty (as recommended by the City of Stirling), incorporating an underwater observation deck.
- Ensure that the cycleway between the proposed restaurant/coffee lounge and the jetty/observation deck is kept in good repair so that it may be used as a 'promenade' facility.
- Provide seating and sun shelters above the North Beach toilet block.

SORRENTO BEACH

- Provide a kiosk at the surf life-saving club. Such a facility might usefully be manned by club members to cover kiosk rents and to support the surf life-saving club.
- Extend the cycleway from Ross Avenue to Sorrento Beach.
- Provide seating along the pathway between the toilet block and the surf life-saving club.
- Establish a botanical garden of native dune vegetation between Troy Avenue and Bettles Street.

  - Label plants with aluminium plaques set in cement.

  - The small pinnacles could also be preserved and those of particular interest could be labelled in the same manner as the vegetation.

  - Formalise tracks through this area by construction of limestone paths.

  - Restrict access to the embayments between Troy Avenue and Bettles Street so that limestone features are conserved.

  - Replace the toilet block south of Marmion Angling and Aquatic Club with a lookout/toilet block combination such as that found at Mettams Pool so that those people unable to walk through the botanic garden will be able to sit and view the gardens and the coastal scenery as far south as Trigg Island. The lookout could be on the same level as the ca park.

  - In conjunction with the replacement of the toilet block, a tree planting programme could be undertaken at the southern end of the Marmion Angling and Aquatic Club. This would soften the harsh outlines of the building and provide a more pleasant aspect to the north of the proposed lookout.

6.2 FURTHER RESEARCH

This pilot study presents a limited amount of data. The data do not include a description of seasonal fluctuations which would assist future planning strategies and management.

Hence the following projects are recommended for long-term study:

- A more detailed investigation of recreational use of the coastline could be undertaken. Information gathered might include demographic characteristics of recreators (for example, place of residence, age) and actual activities being undertaken.

- Ascertain the rates of erosion by quantitatively measuring the long term changes in the morphology of limestone intertidal platforms, headlands and cliffs. Similarly, shoreline variability in this area could be examined.

- Sample and monitor water cleanliness to confirm whether or not pollution is a problem, and if so, its magnitude.

- Investigate the environmental parameters of biota. This might include the response of species to long-term factors such as nutrient supply, presence of pollutants and recreational pressure.

- Investigate the seasonal changes in composition and abundance of biota on the intertidal rock platforms. This would supplement the existing species list.

Councils could continue programmes of public education and extend these to inform the public of the unique geomorphological and botanical features of the area. Local newspapers might also be considered as a medium through which public awareness could be increased.

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DESCRIPTION AND NUMERICAL CLASSIFICATION OF MARINE MACROEPIBENTHIC COMMUNITIES IN THE PROPOSED MARMION MARINE PARK NEAR PERTH, WESTERN AUSTRALIA

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Abstract

Multivariate computer techniques are used to classify marine macrobiotic communities in the proposed Marmion Marine Park. Classification is based on the presence or absence of macroepibenthic species.

The proposed Marmion Marine Park and adjoining areas have a rich, diverse assemblage of macroalgae, seagrasses and sessile invertebrates with over 400 species of macroepibenthos being recorded at 63 transect sites.

Six major geomorphological habitat groups were identified. Species richness of these groups measured as the mean number of species per sampling site, was correlated directly to the amount of 'hard' substrate and to seabed 'roughness'. Of the two major species assemblages, species richness of the 'reef' assemblage was correlated directly to the amount of 'hard' substrate, whereas species richness of the 'inshore' assemblage appeared to increase with the diversity of substrate types. Substrate type, seabed 'roughness' and water depth are all possible influences on the species richness and composition of macroepibenthic communities in this area and the high diversity of macroepibenthos recorded in this study reflect the wide range of habitats available.

Some evidence is given to show that human interference has had a considerable impact on the community structure of onshore reefs.

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1. INTRODUCTION

1.1 HISTORICAL PERSPECTIVE OF THE PROPOSED MARMION MARINE PARK STUDY

Porter (1986) has detailed the history of the System 6 study and report.

In March 1984 State Cabinet approved, in concept, the progressive implementation of the recommendations made by the Environmental Protection Authority (EPA) from the System 6 study (EPA, 1983). Recommendation M10 was concerned with the marine environments and associated offshore reefs between Trigg Island and Ocean Reef, that are, part of the proposed Marmion Marine Park. These reefs were described as 'biologically rich and unsurpassed, locally, as an underwater spectacle' and, owing to their proximity to Perth, were considered to have high conservation, recreation and education value. In addition, because the reefs had been 'heavily exploited', it was considered essential they be afforded reserve status to conserve the remaining marine communities.

One part of the recommendation (M10.2) was that a study of the area be commissioned by the EPA with the aim of establishing a marine park to be managed for the purposes of scientific research, education, conservation and recreation. This recommendation was not given a high priority until the necessary impetus was provided by the proposal to build a 1000 berth boat harbour, within the proposed Marmion Marine Park. The Government then directed the Department of Conservation and Environment, on 1 February, 1985, to proceed with an urgent, high priority study of the proposed Marmion Marine Park with the following terms of reference:

(i) to characterise and describe the marine environments and marine communities of the area and produce a report on the findings of the study;

(ii) to identify and evaluate present and future impacts on the proposed Marmion Marine Park; and

(iii) after consideration of (i) and (ii) above, and in consultation with representatives of the user groups with interests in the proposed Marmion Marine Park areas, to frame a management plan for the proposed reserve, with respect to scientific research, education, conservation and recreation.

This report addresses the first term of reference (above); it discusses the findings of a survey of the macroepibenthos of marine communities within the proposed park. Numerical classification techniques are used to identify major community types. The distribution, composition and species richness of these communities is discussed in relation to geomorphological and hydrological factors.

1.2 RECENT AND CURRENT RESEARCH IN THE PROPOSED PARK

The coastline, waters and marine communities of the proposed park are, and have been, the subject of a number of scientific investigations. Wood (1980) investigated the role of kelp in sedimentary and erosional processes. The importance of decomposing seagrass in recycling nutrients (Robertson and Hansen, 1982) and in surf zone food webs (Robertson, 1983) was assessed. Stoddart (1984) studied the population genetics of the coral, *Pocillopora damicornis*, Kirkman (1984) made estimations of the standing crop and annual production of the common kelp, *Ecklonia radiata*, and Johannes and Hearn (1985) investigated the contribution of groundwater to nutrient input of the Marmion Lagoon.

Circulation of water, within the proposed marine park, has been modelled (Hearn, 1983), and various studies of sediment movement and shoreline processes have been completed (Allison, 1980-81, unpublished data; Public Works Department 1984; Eliot and Clarke 1986; McLachlan *et al*. 1986).

At the time of this survey a number of projects were undertaken, which dealt with various aspects of the ecology of the marine communities within the proposed park. These included the effects of nutrient addition on benthic communities (B Hatcher, personal communication), the interaction between light and kelp canopy structure (W Wood, personal communication), and community and ecophysiological studies on the encrusting organisms on the inner patch reefs (A Hatcher, personal communication). A study was made of molluscs with emphasis on the abalone, *Haliotis roei*, on inshore intertidal reefs within the study area (J Penn, personal communication).

Other studies include hydrodynamical and geomorphological effects of groundwater discharge on sandy beaches (I Eliot, personal communication); diurnal and spatial variation in recreational activity, nearshore circulation patterns and mapping of shoreline morphology and nearshore environments (Elliott *et al*, this Technical Series).

2. MATERIALS AND METHODS

2.1 STUDY AREA AND TRANSECT SITES

The proposed marine park is located along the northern coast of the Perth metropolitan area and extends from Trigg Island to Ocean Reef to about 5.5 km offshore. As described in the System 6 Report (EPA, 1983), it covers approximately 6 000 ha (Figure 1).

Approximate transect locations were selected, by reference to aerial photographs and relevant bathymetric charts (PWD WA51346, WA51347), in areas that appeared to be representative of the marine macroepibenthic communities in and near the park area. Sixty-three transects were sampled (Figure 1).

2.2 DATA COLLECTION AND PROCESSING

To quantify the species composition of the macroepibenthic (specimens >10 mm) communities at each site, all species present in each of 15 quadrats (0.5 m^2), at 10 m intervals, along a 150 m transect line were collected. In addition, an independent collection was made of all the species present, in a belt 6 m wide along each transect. In later transects the dominant species at each site (eg *Ecklonia radiata, Posidonia sinuosa*) were recorded but not collected. At Sites 7, 38, 39, 40, 44 and 45, the species present were determined using only the belt transect method.

Each transect was oriented west to east, and only approximately horizontal, upper surfaces, were sampled; hence, vertical surfaces, caves, overhangs and infauna were not sampled. If a quadrat marker fell on a vertical surface, the nearest horizontal surface was sampled.

The total number of species collected at each site, was compiled from the quadrat and belt transect data. Owing to considerable species diversity and taxonomic uncertainty, each specimen was designated a number from a reference collection kept in the laboratory. Specimens, that could not be matched to a reference specimen were considered a new species (to this study), were added to the reference collection and designated a new number. Calcareous species, in the reference collection, were preserved in 70% alcohol and non-calcareous species in 4% formalin. Where possible, the most common species in each phyla were identified to species level.

In addition to the collection of macroepibenthos, the most common substrate type and the water depth (± 0.2 m) were recorded for each quadrat. The mean depth and standard deviation of the depth (SDD) were calculated for each transect. SDD has been used in this study as an approximate index of seabed 'roughness', based on the assumption that, over a 150 m transect, the effect of seabed slope on the SDD was negligible compared to the effect of variation in seabed topography. Substrate was divided into five types with the following criteria: '**high reef**'- hard substrate in <2 m depth of water; '**reef**' - hard irregular (fragmented) substrate in >2 m depth of water; '**pavement**' - hard, regular (smooth) predominantly limestone substrate in >2 m depth of water; '**bare sand**' - loose, bare sand; '**sandy**' - consolidated sands, calculated as the remaining quadrats. 'Hard' substrate in this study was defined as the total amount of '**high reef**", '**reef**" and '**pavement**', and 'soft' substrate as the amount of '**sandy**' substrate.

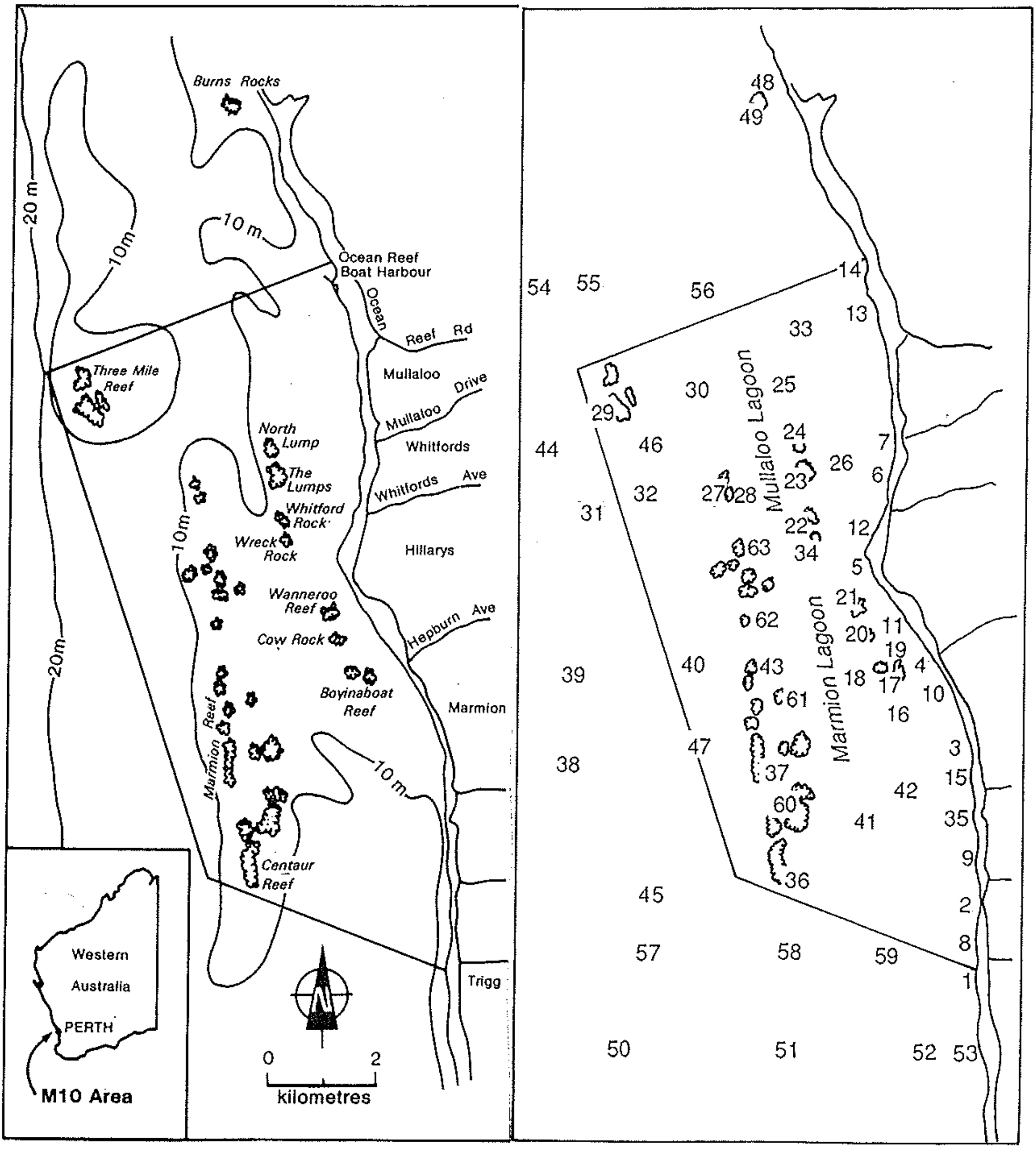

Figure 1. Location of proposed Marmion Marine Park, formerly known as the M10 Area, and study sites.

2.3 STATISTICAL ANALYSIS

Hierarchical classification was used to determine the relationships between the sites and species. This multivariate technique provides a dendrogram which suggests an hierarchical relationship between groups of sample units (normal classification) or attributes (inverse classification). It involves the comparison of the species found at all of the sites with each other, so that sites with similar species are grouped together ('clustered'). A computer package (TWINSPAN) was used to accomplish this. This programme constructs a classification of the species according to their ecological preferences (Hill, 1979). The two classifications are then used together to obtain a two-way table (sites by species) that indicates the relationship between species (ie which species tend to occur together).

To facilitate computer analysis, a complete species list of all biota was compiled. Rare species (those occurring at one site only) and species from Phylum Porifera were excluded (owing to taxonomic difficulties). Sites with no macroepibenthos were excluded from the cluster analysis (ie bare sand).

TWINSPAN was used to classify sites into similar groups (clusters) to four divisive levels. Clusters derived from this process were examined on the basis of known physical and biological characteristics of each site. These included site depth, predominant substrate and macroepibenthos as well as location in relation to wave action.

3. RESULTS

3.1 SPECIES DIVERSITY

Excluding over 50 species of sponges (Porifera), 346 species from 10 phyla were recorded from the 63 transects (Table 1). One hundred and twenty-seven species of red algae (Rhodophyta) and 58 species of brown algae (Phaeophyta), comprising 60% and 28% respectively of the floristic diversity, were recorded. Eight species of seagrasses (Angiosperma) were also recorded in this study .

Table 1. Distribution of species in phyla at 63 sites.

Phylum	Number of species	Percentage of total number of species	Percentage of flora/fauna
Flora			
Rhodophyta (RHO)	127	36.7	60.5
Phaeophyta (PHA)	58	16.8	27.6
Chlorophyta (CHL)	17	4.9	8.1
Angiospermae (ANG)	8	2.3	3.8
Total	210	60.7	100.0
Fauna			
Mollusca (MOL)	39	11.3	28.7
Chordata (CHO)	36	10.4	26.4
Echinodermata (ECH)	30	8.7	22.1
Cnidaria (CNI)	23	6.6	16.9
Arthropoda (ART)	6	1.7	4.4
Bryozoa (BRY)	2	0.6	1.5
Total	136	39.3	100.0
TOTAL	346	100.0	

A list of the identified species, their phylum name and number is given in Appendix I.

The faunistic diversity was more evenly distributed within the represented phyla and belonged mainly to four phyla (Mollusca, 29%; Chordata, 26%; Echinodermata, 22%; Cnidaria, 17%). Species richness (number of species) ranged from nil, in areas of bare sand where no species of macroepibenthos were recorded, to 98 species at Site 24.

3.2 SITE ASSOCIATIONS (GROUPS I-VI) AND GEOMORPHOLOGY

Classification of the macroepibenthic communities within the proposed park and adjacent areas was based on the presence or absence of the 241 most common species of macroepibenthos at 54 sites, using the multivariate computer analysis TWINSPAN (9 sites were bare sand and were excluded from the analyses). This defined eight geomorphological habitat units, at four divisive levels. Two of these groups contained only two sites each and were added to adjoining groups (Site 42 to Group III, Site 23 to Group IV, Sites 50, 38 to Group VI) to reduce the overall number of clusters to six. The indicator species of each division is also shown (Figure 2). The relative position of sites (within a group) and groups (Figure 2) implies degrees of association or similarity; for example, Group I was more like Group II than Group III, and Site 19 was more like Site 17 than Site 5.

Mullaloo Lagoon and Marmion Lagoon referred to here are the areas, between the outer line of reefs (Three Mile Reef to Centaur Reef) and the shoreline, north and south of Mullaloo Point respectively.

The type of substrate, mean depth of water and seabed roughness (SDD) for each site are shown in Table 2. Group I was confined mostly to the relatively protected northern section of the Marmion Lagoon (Figure 3a). Sites in this group varied from the deep (>10 m) areas of mainly **'bare sand'** (Site 41) to shallow (< 5 m) areas of dense seagrass cover (Site 19). Site 17 (Boyinaboat Reef) was the only site within this group that contained hard substrate (Table 2). Variation in seabed topography ('roughness') was high (2.01) at site 17 and low at other sites in this group (Table 2).

Group II included Cow Rocks (Site 20) and Wanneroo Reef (Site 21) in the Marmion Lagoon and three sites within the southern section of the Mullaloo Lagoon (Figure 3b). All substrate types were represented in this group (Table 2) with the shallower Sites (21, 20) having a higher proportion of **'reef'** and **'high reef'** than the deeper sites. In comparison with Group I, this group had more hard substrate, (Figure 4b), was shallower (Figure 4c), and had a greater variation in seabed topography (Figure 4a).

Group III was located mainly in the Mullaloo Lagoon and included one site at Burns Beach and one at Burns Rocks (Figure 3c). A wide variation in substrate and seabed roughness characterised this group (Table 2). Substrate varied from all **'high reef'** at Site 49, mainly **'sandy'** at Site 48 to approximately equal proportions of **'high reef'**, **'reef'** and **'sandy'** at Site 22. Mean depth ranged from 0.5 m (Site 49) to 10.5 m at Site 42; seabed 'roughness' varied from uniformly flat reef platform, at Site 49 (0.0), to extremely variable reef topography (2.27) at Whitford Rock (Site 22).

Group IV consisted of all nearshore reefs and onshore, intertidal reef platform sites (except Site 35) along the shoreline, two sites either side of the Ocean Reef marina (13 and 14), and two lagoon patch reefs (The Lumps, Site 23; North Lump, Site 24) (Figure 3d). This group was characterised by a predominance of hard substrate (mainly **'high reef'** and **'reef'**), low mean water depth and a wide variation in seabed topography (Table 2). In addition, by comparison with Groups I to III, these sites were exposed to relatively higher wave energy ('authors' personal observations).

The sites located along the Marmion Reefs/Three Mile Reef complex were included in Group V (Figure 3e). Site 35 (Waterman Marine Reserve), an onshore, intertidal reef geomorphologically similar to the sites in Group IV, was included in Group V. As in Group IV, this group had a predominance of hard substrate; however, where the nearshore reefs had a high proportion of **'high reef'** this shallow, offshore group had more **'pavement'** which was reflected in the lower mean value of bottom roughness (Figure 4a) and greater depth (Figure 4c). Many of these sites were close to surf zones during heavy swells, and all of the sites were exposed to high wave activity ('authors' personal observations).

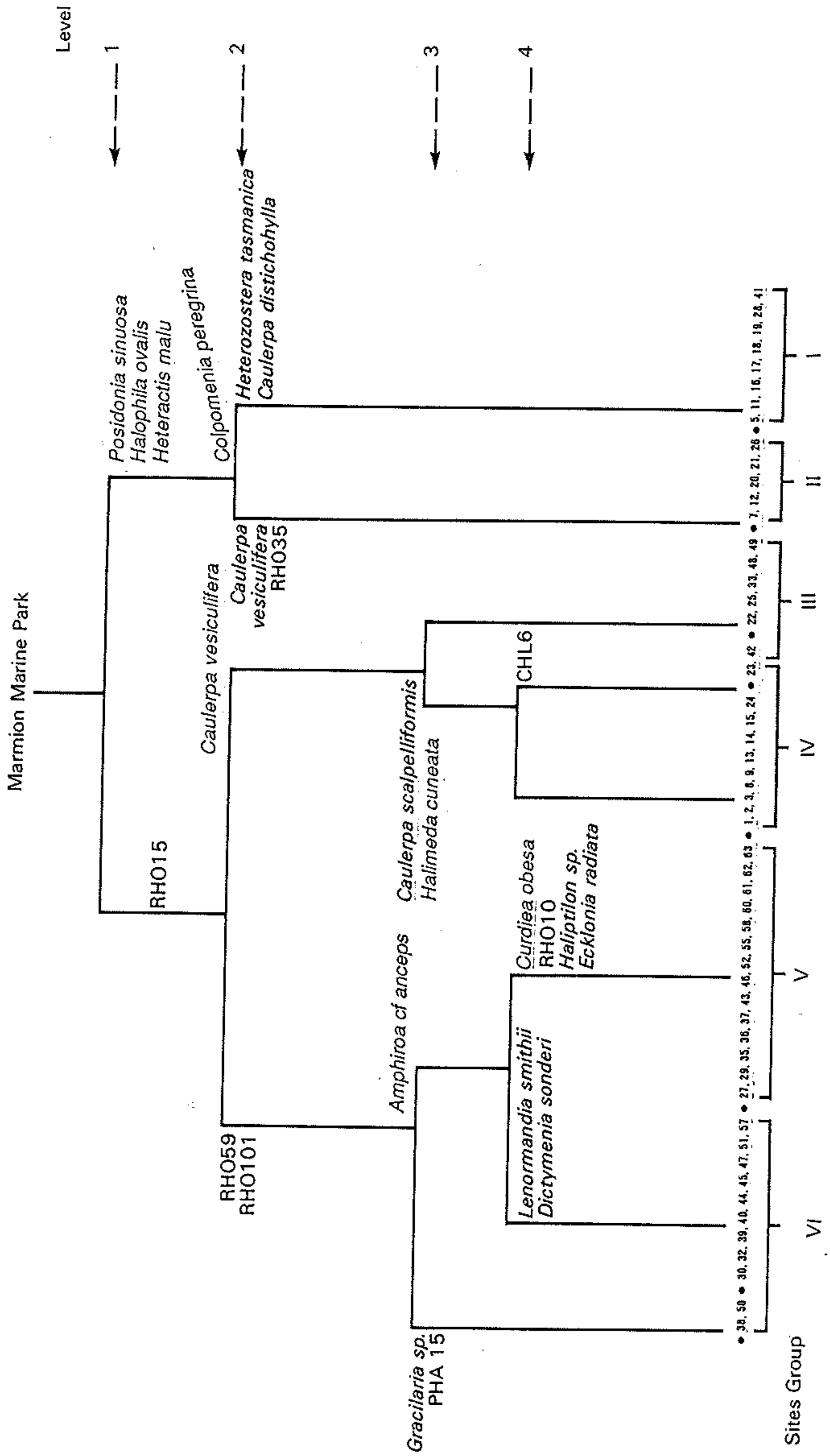

Figure 2. Dendrogram showing hierarchical classification by TWINSPAN of 54 sites into six groups. Indicator species are given at each divisive level.

Table 2. Substrate type, mean and standard deviation of water depth, total number of species recorded and used in cluster analysis.
(NQ: no quadrats sampled, belt transect only; *: substrate type present).

Group No.	Site No.	Substrate (number of quadrats)					Mean Depth (m)	Standard Deviation of Depth	Species	
		High Reef	**Reef**	**Pavement**	**Sandy**	**Bare Sand**			Total No.	Cluster No.
I	41				2	13	16.0	0.00	3	2
	28				9	6	2.1	0.38	21	19
	19				14	1	4.7	0.38	35	34
	18				10	5	7.6	0.68	38	34
	17	1	7		6	1	3.0	2.01	79	70
	16				13	2	7.8	0.39	57	54
	11				3	12	4.0	0.44	24	18
	5				8	7	3.6	0.32	30	22
II	26			2	10	3	8.3	0.00	76	67
	21	6	4	1	4		2.1	1.43	55	51
	20	2	4		8	1	2.7	0.84	59	58
	12			2	4	9	4.0	0.48	38	32
	7			*		*	4.0	NQ	22	21
III	49	15					0.5	0.00	39	37
	48			4	11		4.6	1.10	57	57
	33			9	4	2	7.2	1.94	82	77
	25			4	3	8	8.0	0.00	41	40
	22	6	4		5		3.6	2.27	72	65
	42				9	6	10.5	0.00	14	13
IV	23	4	10		1		3.5	1.75	76	70
	24	5	3	4	3		3.3	1.62	98	88
	15			12		3	8.5	0.68	75	68
	14	6	7			2	2.7	1.43	63	61
	13	2	13				4.8	2.02	67	66
	9	3	11			1	3.5	1.82	46	45
	8	5	10				3.2	1.63	65	60
	3	10	5				1.9	1.10	53	49
	2	9	6				2.2	1.76	54	52
	1	9	6				1.9	2.00	36	31
V	63		15				4.5	1.68	57	57
	62		10	3		2	4.3	0.73	55	55
	61		14	1			5.2	1.09	50	50
	60		11	3		1	6.5	0.84	44	42
	58			10	1	4	10.8	0.97	42	42
	55		8	7			10.0	0.80	44	44
	52		5	4		6	10.4	1.46	41	40
	46			12		3	12.0	0.00	27	25
	43	3	11			1	4.1	2.05	40	39
	37	3	10	1		1	3.7	1.29	57	44
	36		13	2			4.0	1.00	75	61
	35	2	7			6	4.3	2.15	49	45
	29		4	3		8	10.6	0.42	58	55
	27		8			7	4.9	0.32	63	58

Table 2 (cont'd)

Group No.	Site No.	Substrate (number of quadrats)					Mean Depth (m)	Standard Deviation of Depth	Species	
		High Reef	**Reef**	**Pavement**	**Sandy**	**Bare Sand**			Total No.	Cluster No.
	57			11	2	2	20.0	0.00	45	45
	51		5	6	2	2	8.9	0.53	69	63
	47		4	10		1	7.7	0.77	90	55
	45			*		*	23.0	NQ	20	18
	44			*	*	*	28.0	NQ	26	25
VI	40			*	*	*	18.0	NQ	47	39
	39			*		*	24.0	NQ	11	7
	32		9	5	1		12.6	1.39	85	69
	30		6	6	2	1	10.0	0	82	68
	50			1		14	19.0	0	11	11
	38			*	*	*	24.5	NQ	46	30

The remaining sites (Group VI) were found mainly in the deep (mean depth 19 m), offshore zone seaward of the Marmion Reef (Figure 3f). This area consisted of mainly flat, limestone pavement, with a thin veneer of sand (Table 2). Interspersed between these areas of hard substrate were extensive areas of bare sand (K Grey, personal communication).

3.3 SPECIES ASSOCIATIONS

Eight major species associations (Assemblages A-H) were identified at three divisive levels. Appendix II lists all species included in each assemblage. They varied in species composition from 48 species in Assemblage A (MOL 30 to PHA 5), which occurred almost exclusively in Site -Groups I-IV (lagoon sites) to 46 species in Assemblage H (CNI 15 to PHA 45) which occurred predominantly in Site - Groups V and VI (offshore sites) (Figure 5, Appendix II). Between these extremes, the remaining 147 species were found with different frequencies in Groups I to VI.

At the first divisive level, two major species associations occurred, nominally an 'inshore' assemblage made up of species that occurred predominantly in the inshore Groups I-IV, and a hard substrate or 'reef' assemblage consisting of species that occurred mainly in Groups III to VI.

Figure 6a shows the species richness (mean number of species per site), of each Group within each assemblage. In the 'inshore' assemblage a maximum mean species richness of 32 occurred in Group II, and declined to a minimum of seven species per site in Group VI. Conversely for the 'reef' assemblage, maximum and minimum species richness occurred in Group V (38) and Group I (9) respectively. Groups III and IV had many species in both assemblages.

Figure 6b indicated that of the 131 species listed in the 'reef' assemblage, 70% (92 species) occurred in two phyla: Rhodophyta (54%) and Phaeophyta (16%). The other phyla were represented by relatively few species. This dominance by red algae was not found for the 'inshore' assemblage where 110 species were distributed more evenly across seven main phyla (Figure 6c). Six species of seagrasses and approximately equal numbers of species of Rhodophyta, Phaeophyta and Mollusca were recorded in this assemblage.

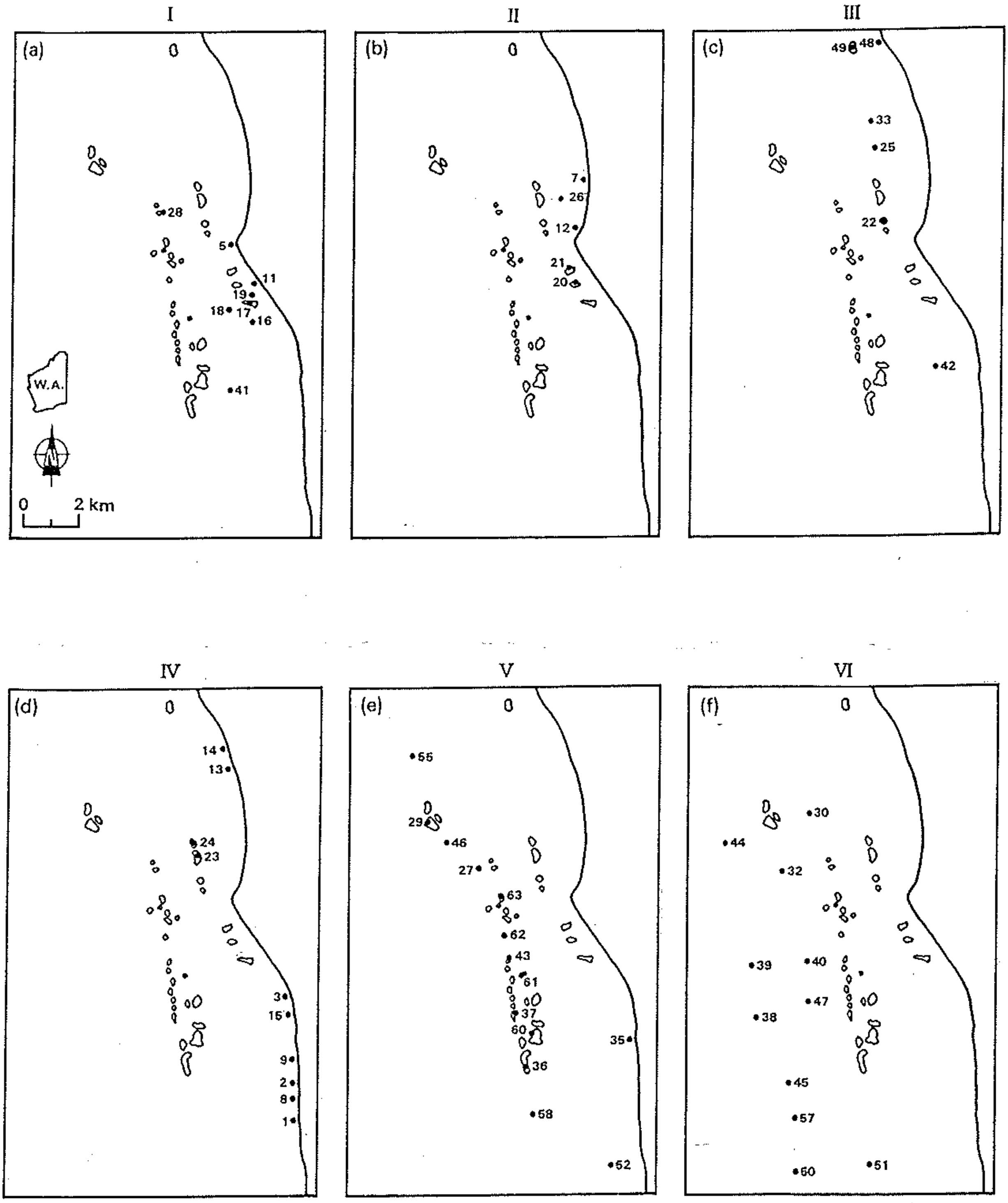

Figure 3. Location of sites classified into six groups, by multivariate computer analysis technique, TWINSPAN. Groups I to VI are shown in Figure 3a to 3f respectively.

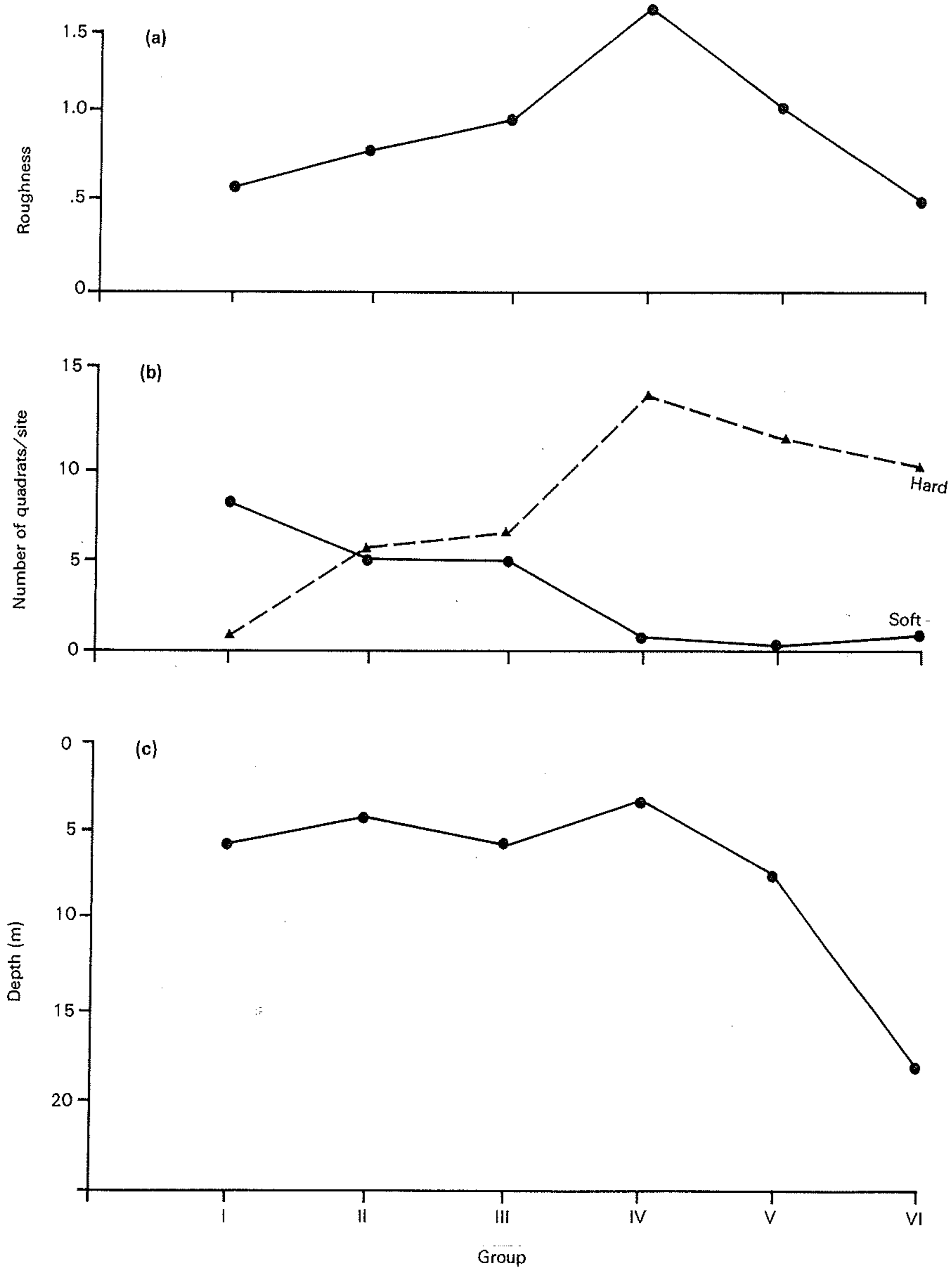

Figure 4. (a) Mean seabed 'roughness' for Groups I to VI, measured as the mean standard deviation of water depth (SDD) for all sites in each group.

(b) The relative proportion of 'hard' (**'high reef'**, **'reef'** and **'pavement'**) to 'soft' (**'sandy'**) substrate in each group.
Measured as the mean number of quadrats per site of 'hard' and 'soft' substrate.

(c) Mean depth of water for each group.

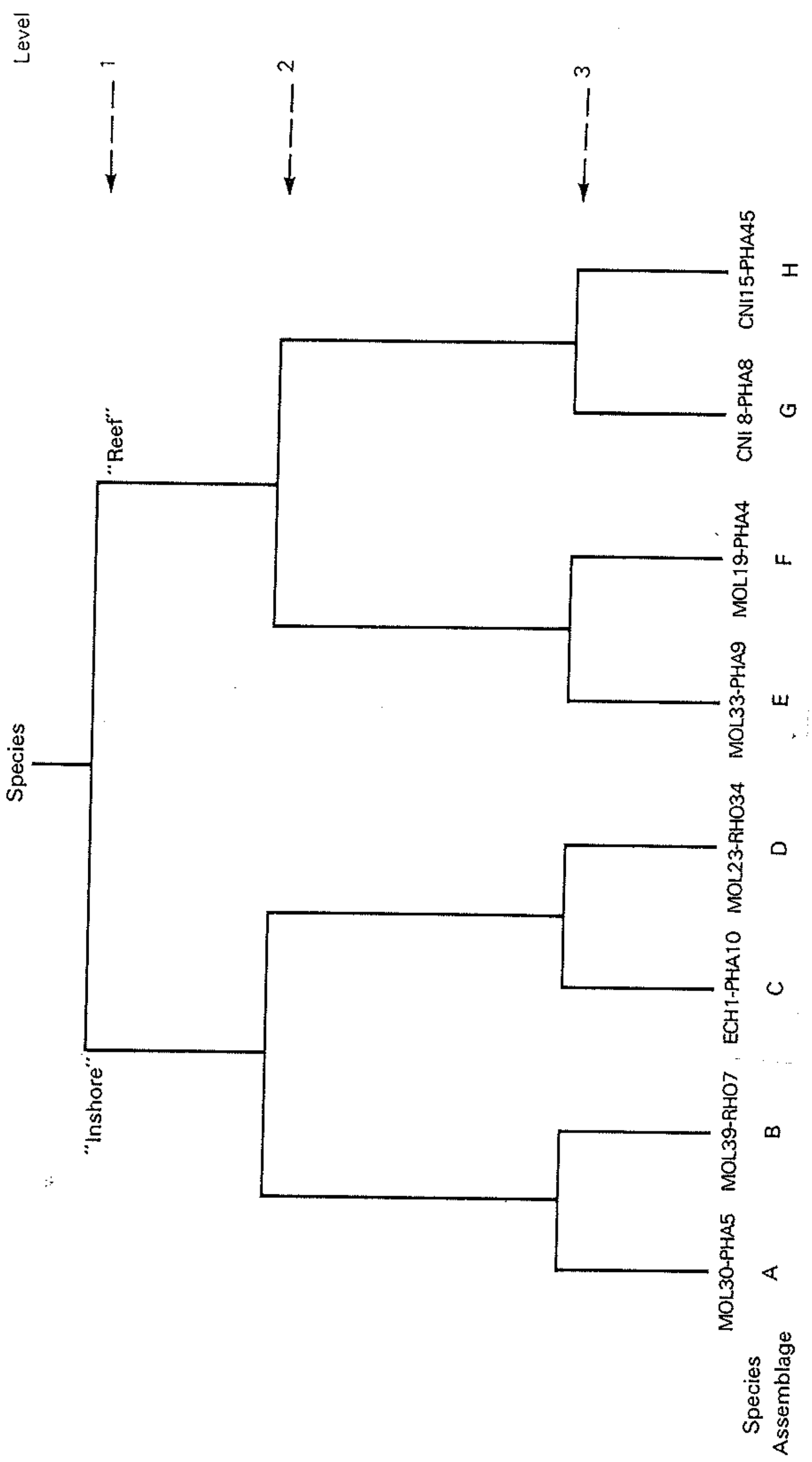

Figure 5. Dendrogram showing hierarchical classification of 241 species into eight species assemblages. See Appendix I for identified species list and Appendix II for species within each assemblage.

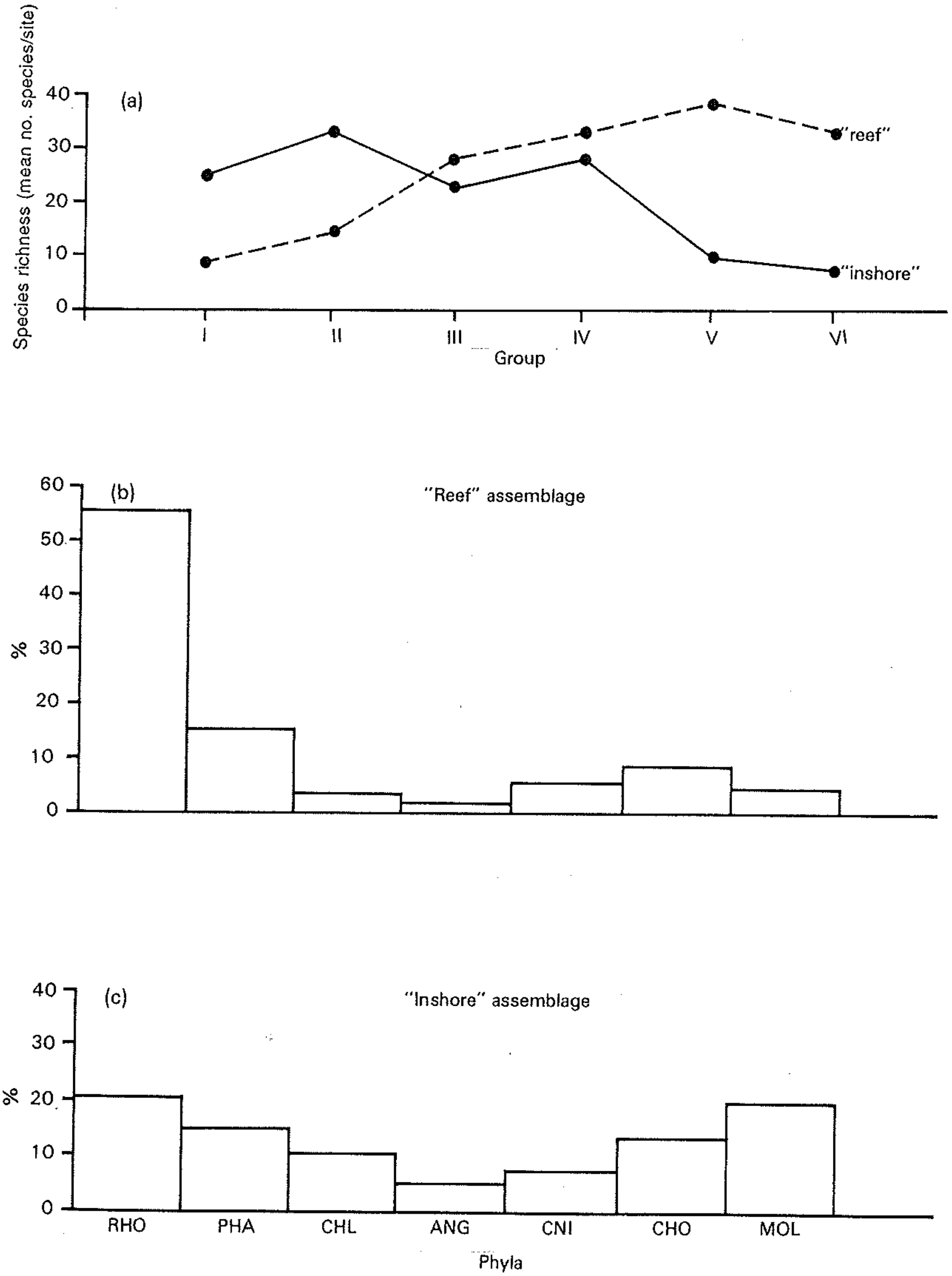

Figure 6. (a) Mean species richness of 'reef' and 'inshore' assemblages for each group, measured as the mean number of species per site.

(b) and (c)
Percentage of species represented in the main phyla for the 'reef' (b) and 'inshore' (c) assemblages. See Appendix I for phyla names.

Many of the more common species in the 'inshore' assemblage, were not recorded in the offshore areas. The seagrasses *Posidonia sinuosa*, *Halophila ovalis* and *Heterozostera tasmanica* were common in Group I. Other seagrasses recorded included *Amphibolis antarctica* and *Syringodium isoetifolium*. The most common macroalgae recorded in Group I included *Caulerpa cactoides* and *Caulerpa distichophylla*. Of the fauna associated with this habitat the cnidarians *Actinia tenebrosa* and *Heteractis malu*, the ascidian *Polycarpa clarata* and the mollusc *Prothalotia pulcherrimus* were the most common. Species richness was least of the 6 groups, with an average of 36 species of macrobiota being recorded at each site and 114 species recorded for the whole of Group I. The number of species recorded at sites, within this group, ranged from three (Site 41) to 70 (Site 17).

In Group II, the most common seagrass was *Amphibolis antarctica*, with *Posidonia sinuosa* and *Halophila ovalis* relatively common. The seagrasses *Heterozostera tasmanica*, present in Group I, was not recorded in Group II. The green algae, *Caulerpa vesiculifera* and *Caulerpa cactoides* were common, as was the brown alga *Colpomenia peregrina* and the red alga *Hypnea episcopalis*. The fauna present in this group were similar to Group I, although some molluscs (Mollusca 30, 25, 14) and chordates (Chordata 10, 11, 12) which were common in Group I, were uncommon in this group. Mean species richness for Group II was 50 and a total of 133 species were recorded at the five sites within this group.

Most of the seagrasses that occurred in Groups I and II were present in Group III, but were far less common. In Group III *Amphibolis antarctica* was the most common and occurred at three of the six sites. The red algae (*Dictymenia sonderi*, *Hypnea sp1*, *Galaxaura* sp, *Vidalia spiralis*, *Hypnea episcopalis*) and the brown algae (*Dictyopteris* sp, *Lobophora variegata*, *Halopteris* sp, *Lobospira bicuspidata*) were common. Kelp, *Ecklonia radiata*, occurred at three of the six sites. A mean of 51 species per site and a total of 154 species occurred in this group.

In Group IV, mainly the onshore reefs along the coast, *Ecklonia radiata* was common at all ten sites. Other common brown algae include *Lobospira bicuspidata* and *Dictyopteris* sp. Common red algae that occurred include *Pterocladia* sp, *Jania* sp, *Dictymenia sonderi*, *Peyssonelia* sp, *Rhodymenia australis*, *Galaxaura* sp, *Vidalia spiralis*, *Hypnea sp1* and *Hypnea episcopalis*. The green algae, *Caulerpa scalpelliformis*, *Halimeda cuneata*, *Codium spongiosum* and *Codium duthieae*, uncommon in Groups 1 to III, were common in this group. The abalone, *Haliotis roei*, was common, especially on the intertidal reef platforms, as was the turban shell, *Turbo torquatus*. Mean species richness (63) and total number of species (189) were the highest recorded for all groups.

On the offshore, shallow sites on the Marmion Reef (Group V) kelp, *Ecklonia radiata*, appeared to be the most dominant organism. Other brown algae found included *Lobospira biscuspidata*, *Phaeophyta* spp 4, 48, 2, and *Halopteris* sp. A large number of species of Rhodophyta occurred in this group, and the most common included *Hypnea episcopalis*, *Haliptilon* sp, *Galaxaura* sp, *Rhodymenia australis*, *Peyssonelia* sp, *Amphiroa* sp, *Pterocladia* sp, *Metamastophora flabellata*, *Curdiea obesa*, *Gelidium glandulaefolium* and *Rhodophyta* spp 101, 103, 2, 5, 10, 15 and 39. Mean species richness was 51 and the total number of species recorded was 169.

The deep offshore sites in Group VI had a diverse flora predominantly red algae which included *Phacelocarpus* sp, *Dictymenia sonderi*, *Rhodymenia australis*, *Metagoniolithon stelliferum* and *Rhodophyta* spp 36, 21, 49, 15, 5, 101, 59. At the shallower sites (Sites 47, 40, 32, 30) *Ecklonia radiata* was present. Other brown algae that occurred in this habitat included *Lobospira bicuspidata* and *Halopteris* sp. Species richness for Group VI was 48 and total species recorded was 166.

The relative occurrence (mean number of species per site) of the main phyla for the six groups is summarised (Figure 7). The occurrence of red (Rhodophyta) and brown (Phaeophyta) algae was lowest in Group I, and steadily increased to high and relatively constant levels in Groups III to VI. The occurrence of seagrasses (Angiosperma) was inverse to the pattern of red algae; the maximum number of seagrasses species per site occurred in Group I and the minimum in Group V. The occurrence of green algae (Chlorophyta) was highest in Group IV. Species of Chordata and Mollusca were generally greater in number in the 'inshore' groups (I to IV) than in the 'offshore' groups (V, VI).

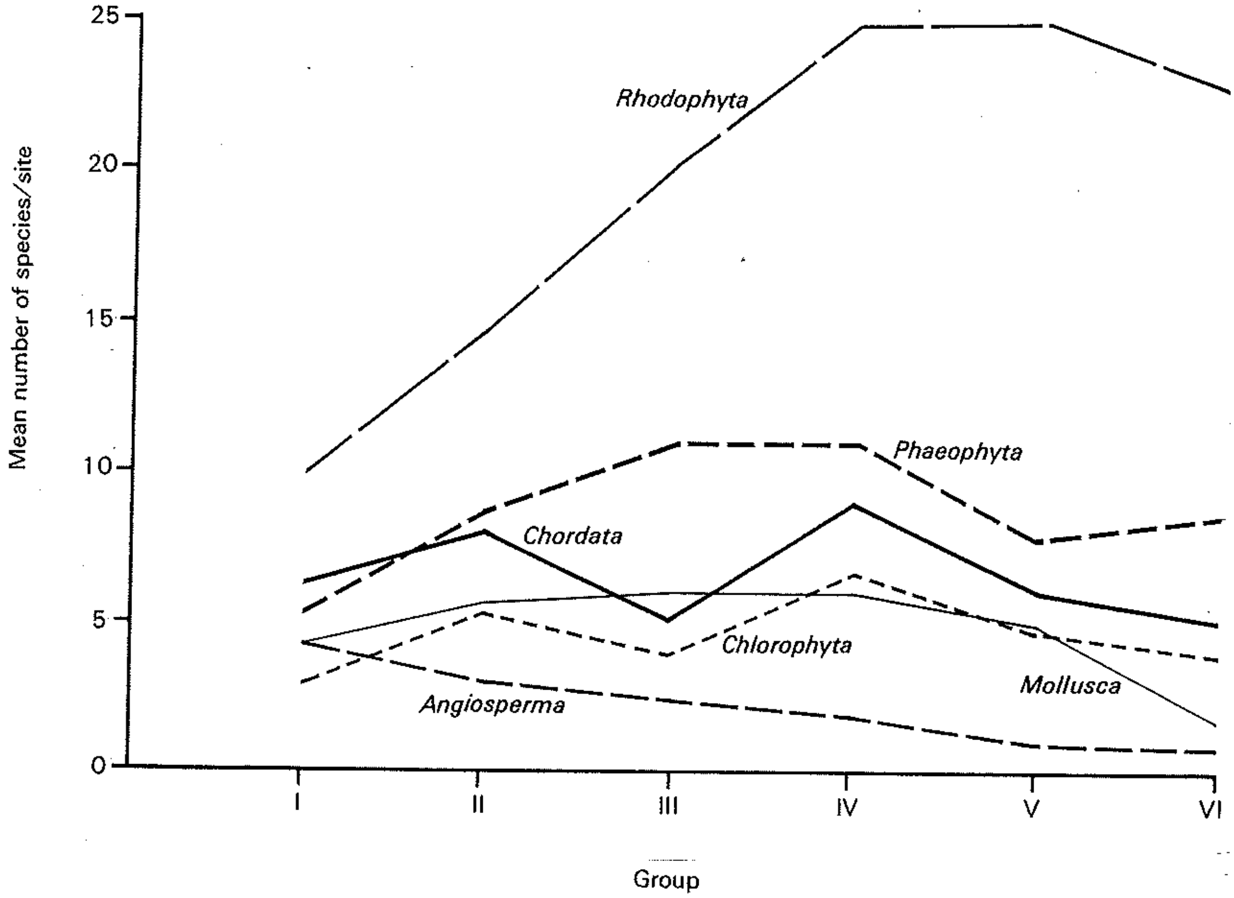

Figure 7. Relative occurrence (mean number of species per site) of six main phyla for each group.

4. DISCUSSION

The area within the vicinity of the proposed Marmion Marine Park has a rich, diverse assemblage of seagrasses, macroalgae, and sessile invertebrates with over 400 species of macroepibenthos being recorded at 63 transect sites (Figures 8 and 9). Teleosts, mobile invertebrates (such as cephalopods), infauna and microbiota were not sampled in this study. About one third of the total areas sampled was bare sand. In addition 34% (Ottaway and Simpson, 1986) of the total area of the marine park, as proposed in the System 6 Report, consists of bare sands with little or no macroepibenthos.

Six broad community types were identified, on the basis of presence or absence of species, using the numerical classification package TWINSPAN. These communities range from relatively low diversity seagrass communities (Group I), in the protected inshore areas near Mullaloo Point, to the more diverse nearshore (Group IV) and offshore (Group V) shallow reefs exposed to long period wave action. Between these extremes are communities that appear to be influenced predominantly by the relative proportions and amounts of hard and soft substrate, and the degree of seabed roughness (Groups II, III) and depth (Group VI).

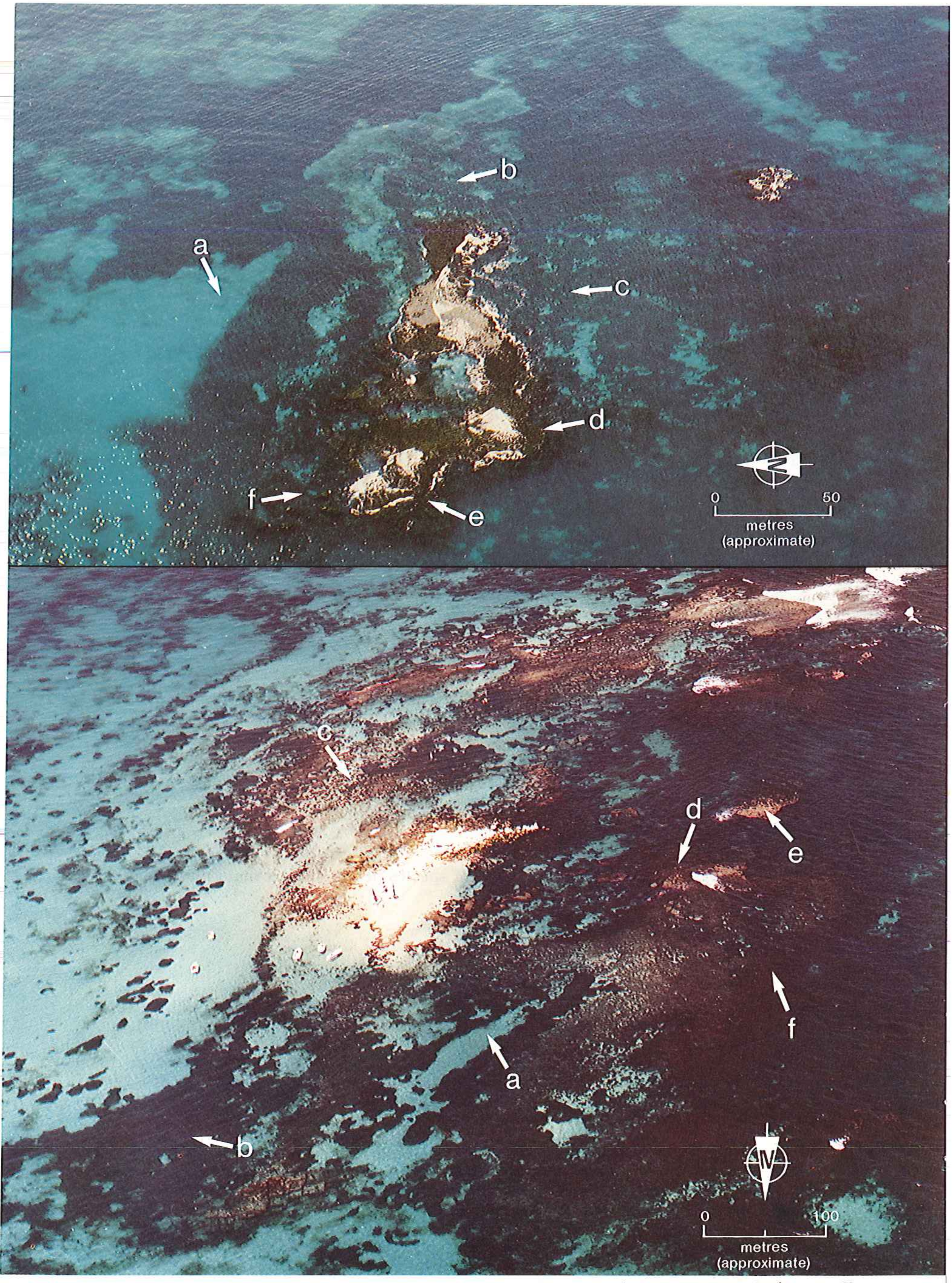

Figure 8. Diversity and patchiness of marine habitats in the proposed Marmion Marine Park area. Upper: Boyinaboat reef. Lower: Little Island. a: loose sand, often forming ripples. b: seagrass meadow. c: limestone pavement with attached flora and small patches of sand. d: vertical high reef faces, with seasquirts, anemones, other attached fauna and algae. e: reef platform, predominantly covered with various forms of encrusting and turf algae. f: high reef, with a canopy of *Ecklonia radiata*. (see Figure 9). (Photos: Boyinaboat reef: Stuart Chape; Little Island: Aerial Survey section, Department of Lands and Surveys, Perth).

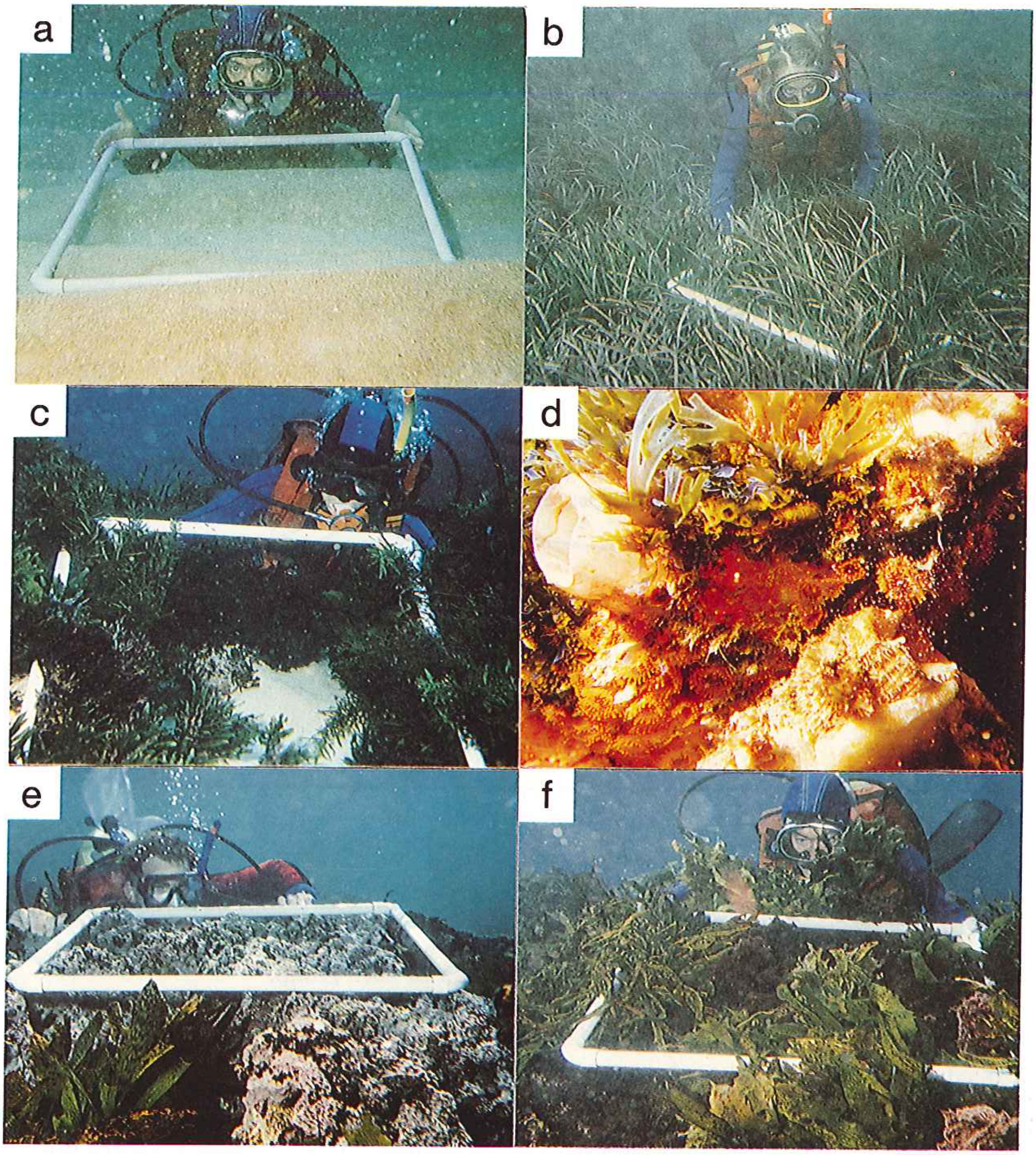

Figure 9. Marine habitats and communities in the proposed Marmion Marine Park. a: loose sand ripples, typically devoid of large flora and attached fauna. Quadrat is 0.71 m by 0.71 m (0.5 m^2). b: seagrass meadow. c: limestone pavement with attached plants and small patches of sand. d: seasquirts, anemones and algae on vertical high reef face. e: reef platform with patchy *Ecklonia radiata* (left foreground) and various forms of encrusting calcareous red algae (right foreground). f: high reef with a canopy of *Ecklonia radiata*
(Photos: a, f: John Robinson; b: Jennie Cary; c: Kim Grey; d: John Ottaway; e: Mark Neave)

Many of the more common species that occurred in Groups I, and II were not found in Groups V and VI; for example, several species of seagrasses were very common in Groups I and II, but were absent or uncommon in Groups V and VI. Similarly, many species of Rhodophyta that were very common in Groups V and VI either did not occur or were rare in Groups I and II. In contrast, there were relatively few species that were unique to Groups III and IV (see Appendix II). The total species number curve for each group, for the species used in the numerical classification (ie the most common 241 species) indicates that the maximum values occur in these areas of overlap (Figure 10).

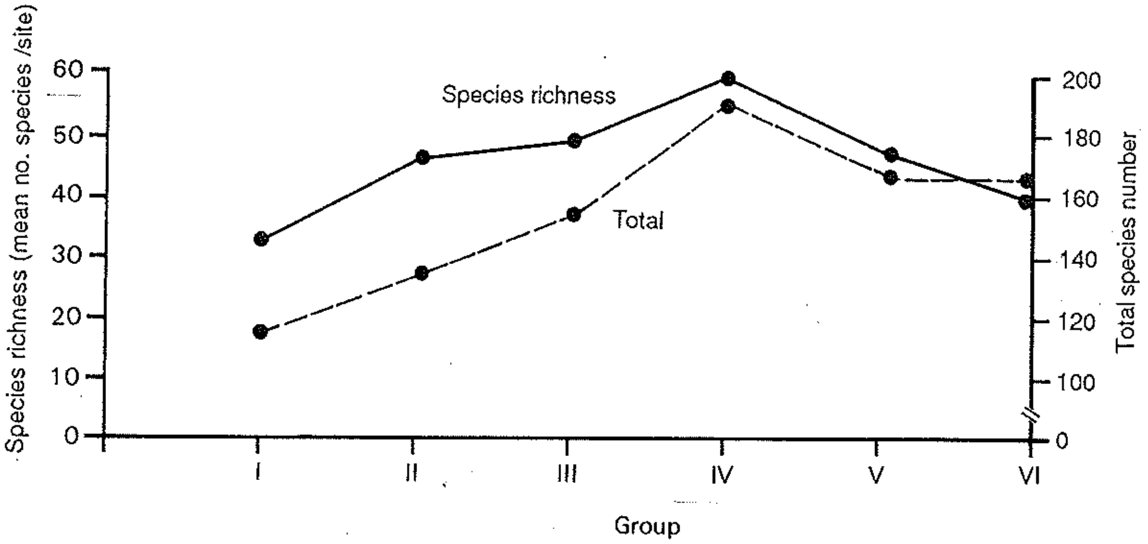

Figure 10. Total species number and species richness for each group.

The maximum species richness of macrobiota occurred along the nearshore reefs (Group IV; Figure 10) and coincided with maximum mean number of quadrats of 'hard' substrate and maximum mean bottom 'roughness'. Minimum species richness occurred in the sand/seagrass habitat in the northern section of the Marmion Lagoon (Group 1; Figure 10). For groups with similar mean depths (ie Groups I to V), mean species richness is significantly correlated with mean seabed 'roughness' ($r = 0.903$, $P < 0.05$) and the amount of 'hard' substrate ($r = 0.900$, $p < 0.05$; Figure 11).

Although these relationships appear to account for much of the observed variation in species richness, it is also a reflection of the numerical dominance of the attached macrophytes (Table 1) in the species sampled. Examining relationships between substrate (Figure 4b) and the mean species richness for each of these groups (I to V), within the 'reef' and 'inshore' assemblages, species richness of the 'reef' assemblage is significantly related to the amount of hard substrate ($r = 0.904$, $P < 0.05$) and inversely related to the amount of soft substrate ($r = -0.911$, $p < 0.05$). These data support the observation that most of the macroepibenthos in this 'reef' assemblage, is confined to hard substrate and consists predominantly of attached red and brown macroalgae.

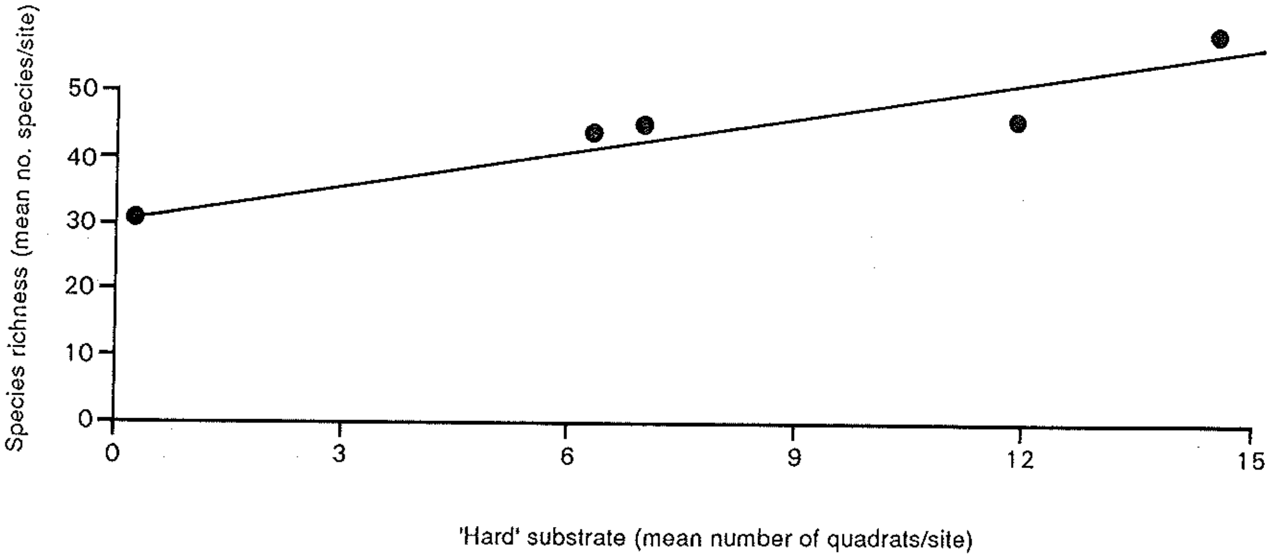

Figure 11. Relationship between total species richness (mean number of species per site) and the proportion of 'hard' substrate for Groups I to V.

There are, however, no significant correlations between either 'hard' ($r = -0.295$, $p > 0.05$) or 'soft' ($r = 0.431$, $p > 0.05$) substrate and species richness within the 'inshore' assemblage although a general positive trend between species richness and '**sandy**' substrate is evident. This suggests that a single substrate type is not greatly influencing the overall species richness (all phyla) in these 'inshore' areas. This conclusion is supported by the correlation coefficients (Table 3) between the relative occurrence (Figure 7) of the six main phyla, in Groups 1 to IV, and substrate type (Figure 4b). The amount of 'hard' substrate is positively correlated more strongly with the occurrence of species of Rhodophyta and Chlorophyta, and 'soft' substrate with species of seagrass (Angiosperma).

Table 3. Correlation coefficients between substrate type and relative occurrence of six main phyla for Groups I-IV.

	Phylum					
Substrate	PHA*	RHO	CHO	CHL	ANG	MOL
Hard	0.830	0.943	0.598	0.912	-0.943	0.664
Soft	-0.767	-0.905	-0.681	-0.933	0.901	-0.604

* See Table 1 for phyla name. If $r > 0.878$ then r is significant at 0.05 probability level.

The relative occurrence of the remaining phyla are either not significantly positively correlated or negatively correlated with substrate. These correlations explain the lack of overall significant correlations between total (all phyla) species richness and substrate for the 'inshore' assemblage and suggest that community structure in these inshore areas may be influenced more by the diversity of substrates rather than the amount of a particular substrate present. These two components of total substrate (ie amount and type) are intrinsically related to seabed 'roughness', as defined in this study. For example, sites with approximately similar substrate types but with different proportions of each will, by definition have different seabed 'roughness' (eg Sites 21, 20 in Table 2). The converse also applies (eg Sites 52 and 22). If these assertions are valid, sites with mainly one substrate type (excluding 'reef') would have, on average, lower 'roughness' and lower species richness than sites with a range of substrate types. Sites in Group 1 (mostly **'sandy'/'bare sand'**) and Site 40, a shallow, intertidal reef platform, support the former conclusions, and Site 24 (North Lump) which has approximately equal proportions of **'high reef'**, **'reef'**, **'pavement'** and **'sandy'** support the latter (Table 2).

Although the mean number of species per unit of 'hard' substrate in Groups IV and V are not significantly different (t = 0.792, d.f. = 23), the species composition of these two groups are different(Appendix II). Some 34% of all the species in Group IV (189) are not common to Group V. Conversely, 21% of all the species present in Group V (165) do not occur in Group IV. The mean depth for Group V (6.8 m) is significantly greater (t = 2.884, d.f. = 23) than for Group IV (3.6 m). In addition, mean seabed 'roughness' at Group V (0.99) is significantly lower (t = -2.699, d.f. = 23) than at Group IV (1.58). This suggests that the species composition between these two areas may be related to either depth and 'roughness', or to a combination of these two factors. Differences in wave activity may also contribute to the differences in community structure of these two groups

In the deep offshore group (Group VI), species richness is significantly negatively correlated ($r = -0.723$, $p < 0.05$) with depth, indicating that, in this group at least, depth may be an additional influence on species richness; however, owing to the depth and consequent bottom-time limitations for the SCUBA divers, five of the sites in this group were not sampled with the quadrat technique. Results from this offshore group should, therefore, be interpreted with caution.

Of the 54 sites which were grouped into six main geomorphological habitat units by the cluster analysis, onshore Site 35 (Figure 3e) is the most obvious anomaly. It clusters into Group V, the shallow, offshore sites on the Marmion Reef/Three Mile Reef complex. This site is the Fisheries Department Waterman Marine Reserve, where restrictions on the taking of marine animal or plant life (apart from fish by line) by any means have been in force since 1967-1968. These macroepibenthic communities therefore, have been protected for amost 20 years. Grouping of this site with the offshore, shallow reef sites is a reflection of macroepibenthic community similarity, and possibly is related to the lower intensity of human pressure on the marine communities at this site. It is suggested that human interference has significantly affected the community structure of the onshore reefs, but that the Waterman Marine Reserve data indicate that declaring and enforcing reserve status can result in effective protection.

Although this study achieved its primary objectives which were to describe and characterise the marine communities of the proposed marine park, several deficiencies, mainly owing to time and resource constraints, are apparent in this study. These deficiencies limit the interpretation and, therefore, the applicability of these data to wider issues:

The conclusions of this study are pertinent only to the macroepibenthic assemblages; that is, to the visually obvious, sessile plants and animals living attached to the seafloor or other substrata. Cryptic organisms found in caves and crevices, burrowing organisms in the seafloor, and swimming or floating organisms were not sampled and have not been considered. Thus, comparing species richness, in areas where these communities are abundant ('lagoon' patch reef such as Boylnaboat Reef, Whitford Rock) to areas where they are less abundant, may be misleading if the sampling procedure is ignored. Furthermore, particular areas may be of high recreational value for their geomorphological structures, particular forms of biota (for example, gorgonians in caves) or rare species (presence of particular cowries or fish species). None of these would be indicated by our sampling technique and results.

The classification of communities, on the basis of presence or absence of species, ignores an important component of community structure; that is, the abundance of the organisms present. This, again, was a consequence of the area to be covered and the time and resources available. Hence, in this study all species were considered equally significant, when clearly this is an extreme simplification; for example, particular species (such as seagrasses) may contribute disproportionately to overall community biomass and productivity. Therefore, the relative ecological significance of different communities cannot be determined from these data.

Field work for this study was completed over 16 weeks, during March to June 1985, and, as such, has no temporal perspective. Community structure (composition and abundance) is not static. Colonisation during winter, of intertidal onshore reef platforms along the coast by the green alga, *Ulva lactuca*, illustrates that the distribution, of this species at least, is seasonal. Hard substrate becomes available when sand, covering the reef platforms in summer, is removed by winter storm waves. In addition, the large quantities of detached macrophytes, mostly seagrass wrack and kelp, that accumulate on the beaches, in early winter, are indicative of seasonal changes in the standing crop of these species.

5. CONCLUSIONS

(1) The proposed Marmion Marine Park and adjacent areas were found to have diverse assemblages of over 400 species of macroepibenthos recorded from 63 sampling locations.

(2) These organisms were concentrated in reef areas and seagrass meadows.

(3) Six broad geomorphological habitat units, based on the presence or absence of the most common 241 species of macroepibenthos, were identified.

(4) For the proposed park area, species richness for Groups I to V, was directly related to the amount of 'hard' substrate and seabed 'roughness'.

(5) Species richness of the offshore 'reef' assemblage was directly related to the amount of 'hard' substrate. This assemblage consisted mainly of attached macrophytes.

(6) Species richness of the 'inshore' assemblage appeared to increase with the diversity of substrate type. Species were relatively evenly distributed over a number of phyla.

(7) The species richness of the offshore, deep site (Group VI) was inversely related to depth.

(8) Substrate type, the degree of seabed 'roughness' and depth appeared to be the main determinants of species composition. It should be noted, however, that crevice, infauna, planktonic and nektonic assemblages were not sampled owing to constraints of time and resources.

(9) The grouping of Site 35 (Waterman Marine Reserve) with offshore sites on the Marmion Reef suggests that other onshore reef community structures may have been altered by human pressures.

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E Moore and B Stewart prepared this report for publication.

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APPENDIX I

FLORA AND FAUNA SPECIES IDENTIFIED FROM THE PROPOSED MARMION MARINE PARK

RHODOPHYTA (RHO) *T=127	Reference No
Rhodymenia australis	RHO 1
Dictymenia sonderi	RHO 3
Peyssonelia sp	RHO 6
Hypnea episcopalis	RHO 7
Pterocladia sp	RHO 11
Jania sp	RHO 12
Hypnea sp	RHO 14
Pterocladia sp	RHO 17
Lenormandia smithii	RHO 21
Galaxaura sp	RHO 22
Haliptilon sp	RHO 23
Metagoniolithon stelliferum	RHO 25
Vidalia spiralis	RHO 26
Hypnea musciformis	RHO 28
Botryocladia oborta	RHO 29
Gracilaria cf secundata	RHO 30
Jania sp	RHO 36
Amphiroa cf anceps	RHO 39
Gracilaria sp	RHO 46
Phacelocarpus sp	RHO 49
Sargassum sp	RHO 55
Gelidium glandulaefolium	RHO 57
Amphiroa sp	RHO 84
Curdiea obesa	RHO 85
Metamastophora flabellata	RHO 97

ANGIOSPERMAE (ANG) T=8	Reference No
Amphibolis antarctica	ANG 1
Posidonis sinuosa	ANG 2
Heterozostera tasmanica	ANG 3
Halophila ovalis	ANG 4
Struvea plumosa	ANG 5
Syringodium isoetifolium	ANG 6
Posidonia australis	ANG 7
Amphibolis griffithii	NI
Thalassodendron pachyrhizum	NI

BRYOZOA (BRY) T=2	Reference No
Triphyllozoon sp	BRY 1

CHLOROPHYTA (CHL) T=17	Reference No
Caulerpa scalpelliformis	CHL 1
Halimeda cuneata	CHL 2
Caulerpa vesiculifera	CHL 4
Caulerpa racemosa	CHL 5
Codium spongiosum	CHL 8
Codium duthieae	CHL 9
Caulerpa distichophylla	CHL 10
Caulerpa cactoides	CHL 13

PHAEOPHYTA (PHA) T = 58	Reference No
Ecklonia radiata	PHA 1
Halopteris sp	PHA 9
Lobophora variegata	PHA 10
Colpomenia peregrina	PHA 13
Dictyopteris sp	PHA 14
Sporochnus comosus	PHA 18
Sargassum sp	PHA 19
Lobospira bicuspidata	PHA 21
Sargassum sp	PHA 24
Dictyota sp	PHA 35
Zonaria sp	PHA 44

MOLLUSCA (MOL) T = 39	Reference No
Thais orbita	MOL 1
Turbo torquatus	MOL 4
Haliotis roei	MOL 6
Prothalotia pulcherrimus	MOL 8
Brachidontes ustulatus	MOL 12
Clavarizona hirtosa	MOL 13
Astralium squamifera	MOL 23

CHORDATA (CHO) T = 36	Reference No
Pyura pachydermatina	CHO 1
Pyura australis	CHO 4
Ascidia sydneyensis	CHO 8
Herdmania momus	CHO 9
Polycarpa sp	CHO 10
Polycarpa clarata	CHO 11
Isaurus cliftoni	CHO 13

FLORA AND FAUNA SPECIES IDENTIFIED FROM THE PROPOSED MARMION MARINE PARK

(cont'd)

CNIDARIA (CNI) T=23	Reference No
Actinia cf tenebrosa	CNI 1
Heteractis malu	CNI 4
Favites sp	CNI 9
Astrea versipora	CNI 10
Stereotheca elongata	CNI 11
Pocillopora damicornis	CNI 17

ECHINODERMATA (ECH) T=30	Reference No
Patiriella brevispina	ECH 1
Holopneustes porosissimus	ECH 2
Amblypneustes leucoglobus	ECH 4
Austrofromia polypora	ECH 8
Comatula purpurea	ECH 9
Petricia obesa	ECH 22
Centrostephanus tenuispinus	ECH 27
Phyllacanthus irregularis	ECH 30

* : Total number of species in each phylum.
NI : not included in cluster analysis.

APPENDIX II

OUTPUT OF TWINSPAN CLUSTER ANALYSIS

```
Species Assemblage
Group             VI           V           IV      III   II    I
Site          3533344445522333445556666     11122422344 1222 1111124
number        300290457177956736258012312389345432253897201651678981
   PHA    45  --1-----11--1------11---11----------------------------  0000
   PHA    48  --------1--11---1---11-11-------------1---------------  0000
   RHO    57  --11-11-1--11-11---1-11-1-----------1--1--------------  0000
   RHO    59  --11-1--111111---1-1--1-1-------------------------1---  0000
   RHO    83  --11-1-----11---1-----------------1-------------------  0000
   RHO    85  ---1-------11-1111-11-111---------1-1-----------------  0000
   RHO    87  ---1-1----11---------1--------------------------------  0000
   RHO    94  --11----1---1------11-11------------------------------  0000
   RHO    95  ---1-------11--1---111-1------------------------------  0000
   RHO    97  ---1-----1-111-11-1---1-1-----------------------------  0000
   RHO    99  --11--------------------------------------------------  0000
   RHO   101  1-11-11-111--11--1111-1-1--------------1--------------  0000
   RHO   102  11-1--------1-1---11----------------------------------  0000
   RHO   103  --11-1---1-1-111-11111111--------------11-------------  0000
   RHO   108  --11----1-------1-----1---------------1---------------  0000
   RHO   118  --1---------1-11--11111-------------------------------  0000
   RHO   125  --1-----1---1------1----------------------------------  0000
   CHO    19  ------1-111-1---11---111----------1-------1-----------  0000
H  CHO    31  ---1-1--11--11-----1-111------------------------------  0000
   PHA     2  --11-1-11111-111-1-1-111111-1--1-----1-11--11---------  0001
   PHA    33  1-1---1-1-1-----------11--------1---1-1---------------  0001
   PHA    41  1-11---1--1-----------1-1-----------11--1-------------  0001
   PHA    47  ---1------------1---------------------1---------------  0001
   RHO     2  ----11-1-111-1111-1-1---1-1-111-1---------------------  0001
   RHO     5  --111-1-11-111111-1111111-11-1--111---1------1--------  0001
   RHO    10  ----------1-1111-1111-1-1-11-1---1--------------------  0001
   RHO    11  ---1--1-1-1111111-1-111-1-1111---11----1---------1----  0001
   RHO    15  --11-11-1111-111111-111-11--1111-----11-1---1---------  0001
   RHO    20  --1--1--11-------11--1-1-1---1-1-----1-------1--------  0001
   RHO    39  --11--111-1111111111111111---111111-11--1--1----11----  0001
   RHO    49  ---1-111111---1-1-1---11-----1-11---11--1---1---------  0001
   RHO    54  -----11--1--1-----1----1-------------111--------------  0001
   RHO    58  ---1-1---------------1---------1----------------------  0001
   RHO    82  ---1------------1-------1-----------1-----------------  0001
   RHO    84  --1------1-1-111---11---1--------11-------------------  0001
   RHO    86  --1--------11111----1-1-----------1----------1--------  0001
   RHO    90  -------------------1---1---------1--------------------  0001
   RHO   105  --1------1--1---------1----------------1--------------  0001
   RHO   114  --1---1-11---1----1-----1------------111--------------  0001
   BRY     2  ---1-1---1----------------------1---------------------  0001
   CHO    21  1----1--11---111111111111------1--11--1-1-------------  0001
   CHO    32  --1------1--1--1-------11-----1----1-1----------------  0001
   CHL     3  1--1-1---11---------------11--------------------------  0001
   CHL     6  1-----1--11-----1---11-11---------11---1-1------------  0001
   CNI    15  ---------1---1-11--1-1111---------1---111-------------  0001
   PHA     8  --------------------------1-----------1---------------  0010
   PHA    11  -----------------1-------1-1------1-------------------  0010
   PHA    27  1-----------------------------11-----1--1-------------  0010
   PHA    51  -------1--------1--------------------11---------------  0010
   RHO    13  ---1------------11----1---1----1-1--------------------  0010
   RHO    19  --1--1--1----------11--1-11-1-1-11--111---------------  0010
   RHO    27  -------------------1--------1-1--1--------------------  0010
   RHO    33  ----------------1-----------1----1-----1--------------  0010
   RHO    40  ------------------1111-1-----111----1-11--------------  0010
   RHO    44  ---1-------------------------11-1---------------------  0010
   RHO    52  --1--------------------1------1111--------------------  0010
   RHO    55  --1----------------------------------11---------------  0010
   RHO    56  -----------------1-1----------11-1--------------------  0010
   RHO    60  ---1-1--1---------------------11----------------------  0010
   RHO    62  ---------------1---------------1--1-------------------  0010
G  RHO    63  --1------------------------------1--1-----------------  0010
   RHO    66  --1----------------1--1--------1--1--1----------------  0010
   RHO    67  --1----------------------------11------1--------------  0010
   RHO    70  --------------------------------1-----1---------------  0010
   RHO    88  --------11----11-------11--------1--1-11--------------  0010
   RHO    89  ---1-----------------------------1--------------------  0010
   CHO    14  ---------1-----------------------11-------------------  0010
   CHO    22  ------11-1----1-1-----1111-----11------11-------------  0010
   CHL    15  --1---------1---------------------1-1--1--------------  0010
   CNI     6  --------------111---111-----1--1-1------1-------------  0010
   CNI    17  -----------1--1-------------------1-1---1-------------  0010
   MOL    16  --------------1--------------1------1---1-------------  0010
   ECH     2  --------------------------111---1---------------------  0010
   ECH     5  ---------1-----------------11-1111--------------------  0010
```

APPENDIX II (cont'd)

OUTPUT OF TWINSPAN CLUSTER ANALYSIS

```
Species      Group        VI          V              IV        III    II     I
Assemblage   Site     35333444455 22333445556666      11122 422344  1222  1111124
             number   30029045717 79567362580123 1238934543 225389 72016 51678981
     RHO   9  ----------11-111--11-1----111-1---1--------------1----  0011
     RHO  12  1----1--11-------1-1---1--1111--1-1----1---1----------  0011
     RHO  16  1-1---------1-------------1111-1-------111---------1---  0011
     RHO  17  ---------------11-1-1----1111-1----1---------------1----  0011
     RHO  41  -----------11--------1--1----111-11----------------1----  0011
     RHO  46  11---1------------1-----1----111-1---111--1-----------  0011
     CHO  13  --1----------1-------1---------1-111-1-1------1----------  0011
     CNI   8  ---------------111----11-1----1--1--------1-----------1--  0011
     PHA   4  --1---1-1-111-111--1-111-1111-111------1-----------1----  0100
     PHA  21  1111-1-1-1111-1--1--1---------11-111-1111-----1--------  0100
     RHO   3  1-11-1-1111--1---------11-111-111--11111------------11--  0100
     RHO   6  --11----1-1111111111111-1-111111-11-1-------------111---  0100
     RHO  21  1111-1111-1---1---1---------1--1-11--1111--1--1---------  0100
     RHO  53  -1-1-1--1-------------1---------1-11-------1-----------1---  0100
     PHA   1  --11-1--1--11111111111111111111111111-1-1-11--1---11----  0101
     PHA   3  1-11---------1-------------1-1-1---11---11-1--1-1---------  0101
     PHA  35  --1-------1---------------------------11-----------------1---  0101
     RHO   1  --11111-111111111-111-1-1-111111111-1-------1--1-11-1--  0101
     RHO  14  --1------11-1-11------1--11111111--1--111-1--11--------1-  0101
     RHO  18  ----------1-----------1----1------1-----------1---------  0101
F -  RHO  22  -----1---1-111-111---1-1---11-1111--1111---1-----11-11-  0101
     RHO  23  ------------1-1111-----111--111-111--1---1--11---11----  0101
     RHO  26  -111----1-1-1-------1---1---1--1111--1111--1-------11---  0101
     RHO  65  ---1-------1----------------------------111-------------1--  0101
     ART   1  ---1---11--1-11------1-1---1---111-1-1-11---1-1--11----  0101
     BRY   1  ---1----11-1-111--1111111-1-1111111-111----1-1--11----  0101
     CHO   2  ---------1-------------------11-1--1111--------1----------  0101
     CHO  20  1----1--1-1----------------------111------------1---1----  0101
     CHL   7  1--1-1-------1--------1--1---11---11-1-----------1--1-1---  0101
     ANG   5  --11-----------1---1-1--------1---111---1-----------1-1---  0101
     CNI   1  --------1-----------1-11----11----1--------------1--1-----  0101
     CNI   2  ---------11---------1--------11-----1------------------1----  0101
     CNI   9  --------------11--------1-------1---1--1---1--1----------  0101
     MOL   5  -----------1----11-------1---1---1--1-----------1---------  0101
     MOL  19  ---11-------------------------1--------11----1----------  0101
     PHA   9  1-11--11111111111111111111--11--1111-1111-1-111-111----  0110
     PHA  19  ------------1------------1----1--------1---------1---------  0110
     PHA  24  -----1----1------------------------1-------1-------1------  0110
     PHA  28  --11------1-------------------1--------------1----------  0110
     RHO  25  1-----11111111-----11---1--1--111---1-1-1--111---1----  0110
     RHO  29  ---1-1---1111--------11--1---1----11-1---------11--1-1--  0110
     RHO  35  ---1------11-1-111--11-1-------1---1----1-1-111---------  0110
     RHO  61  ---1--------1-1----------111-------1-1--1--------1--------1--  0110
     RHO  64  --11---1--11--11-----1----------1-----11----1-----11----  0110
     RHO  68  ---1-----1---1----------------------1--------------1---------  0110
E -  RHO  69  ---1----111---------------1----------1-------1----1---1----  0110
     RHO  93  -----------------1--------11-----------1---------1---------  0110
     CHO  18  ---------1------------1--1-----------1--------1-----------  0110
     CNI  13  ---1-------1--------------------------1------1---------1----  0110
     PHA  55  --1---1---1------------1-----------------------------1--------  0111
     RHO   4  --11--------1-1-1------------1--1----------------1---------  0111
     RHO  36  --11111-11111-1------1-1111--1----------11---11----1----  0111
     RHO  75  ---1--1111-1-------1-1--1-----------1----1------------1-1--  0111
     RHO  80  --11----11-1--1---------1--------------------1---11---------  0111
     RHO  96  ---1---------------------1------------------------1---------  0111
     ART   4  1----11--1-----11--1------1---------------------1--1---1--------  0111
     CHO  17  -1------1-1---11------1-1-----------------------------11----  0111
     CHO  24  ------1--11--1----1----11------------1-----------------1-----  0111
     MOL  33  -----------1----1--11-1-11-1-----------------------11--------  0111
     RHO  34  ----------------------------1--1-11--1------------1------  1000
     RHO  43  -----------------------------11------1-1---1------------  1000
     MOL   6  -------------------------1-1111-1-------1--11----------  1000
     PHA   6  ---------------1----------1--1-111--1------1-----1---------  1001
     PHA   7  --------------------------1-11--1---1-------------1--------  1001
     PHA  16  ---1------------------1----1-1---------1-1-1--1-1---------  1001
     PHA  25  1-----------------------------1-1-1----------------1-----  1001
D -  RHO   8  ---------1--------------------1--11--1--1----------1---------  1001
     RHO  37  -----------------1---------------1----1----1-------------1---  1001
     CHO   3  -----1---1---1--1------------11-11---1-1------1--1---------  1001
     CHL   1  ------------------------11--111-1111-----------1-----1-----  1001
     CHL   2  -----------111-1---------------111--11-1-1---11-1-1---------  1001
     CHL   4  --11---------11-11------------1111111111-1-1111-111---1----  1001
     CHL  11  --1----------1------------------------11-1--1-1------1----------  1001
     CNI   7  ----------------1---------------1--1-----1-1---------1----------  1001
     MOL   2  ----------1-------------------11----------------11---1----------  1001
     MOL   7  -------------------1----------1-1----1--11-1--1-----------  1001
     MOL  23  --11------1-------------------------1-1-1-11-11----1--11----  1001
```

APPENDIX II (cont'd)

OUTPUT OF TWINSPAN CLUSTER ANALYSIS

```
Species     Group       |     VI     |      V        |    IV    |  III |  II |   I    |
Assemblage  Site        |35333444455 |22333445556666 |     11122|422344| 1222| 1111124|
            number      |90029045717 |79567362580123 |1238934543|225389|72016|51678991|
    ┌  PHA   10  ----------1--1-------------1-11-----1111-1--1--1------  1010
    │  PHA   20  ---------------------------1-1-------1---------1-----  1010
    │  RHO   42  ----------------------------1-1--1----------------1--  1010
    │  CHO    1  --11-----1-11---1---------111-11111111--1-1-111---1-1--  1010
    │  CHO    5  ---1---------------------1---1-1-1---11-----1----11--  1010
    │  CHL    8  -------1---1--------------1-11---11-1---------11---1----  1010
    │  CHL    9  ---1-----1--1-------------1-11-1-1111--1----1-1--11---1  1010
    │  CHL   12  -----------1-------------------1-1-11---------11---------  1010
    │  MOL    1  ---------1---------------11111-1-----1---1-1-1----1----  1010
    │  MOL    4  -----------1----------------1111-1-1--1-1---1-1----1----  1010
    │  MOL   27  -------------------------------11-----1---------1----  1010
C  ─┤  ECH    3  ---1---------------------1-----1---------------1-----  1010
    │  PHA   17  -----------1---------------------1-------1---1------------  1011
    │  PHA   46  --------1-------------------------1----1---1-----------  1011
    │  RHO   32  -------------------------1----------1---------1-----  1011
    │  RHO   45  ----------------------1---1-------------1----------  1011
    │  RHO   51  --------1------------------------1--------1----1----------  1011
    │  CHL   14  -------------------------------1----1----1-----------  1011
    │  CNI   12  -------------1----------------------11----111--11---1-----  1011
    │  CNI   16  -----------1------------------------1-1--------1---------  1011
    │  MOL    9  ---------------------------1--1----------------1---------  1011
    │  MOL   13  ----------------------------1------1----------1---------  1011
    └  ECH    1  --------------------------1111---1------1---111-1--1----  1011
    ┌  RHO    7  --1--1---111-111--11-11111111111-1111111-11111---1111-  1100
    │  RHO   28  --11------1--11---1-----1--------11-111--1----11-11-1--  1100
    │  RHO   30  111-1----1-----------1--------1111--------1-1---1---1--1-  1100
    │  RHO   48  1-11-----1----1-------------------------11---11----1-11--  1101
    │  RHO   72  -1-----------1-------------------------------1---------1-----  1101
    │  RHO   76  --------1-1-------------------------------1-----1---1----  1101
    │  RHO   77  -----------1-----1--1----------------------------1-1--------  1101
B  ─┤  RHO   81  ---------11---------1-----------------------------1-1--------  1101
    │  CHO   15  --1------1--------------------------1-------1--------1----  1101
    │  ANG    6  ------1--------11111111--1-----------1-1--1------1-1111--1  1101
    │  ANG    7  ---------11---------------1--------------1--1----1--------1-  1101
    │  CNI   10  ---1----1--1-1111-1--1111----------11-1---1--1111-111----  1101
    │  MOL   10  ----------1-------1-----------------------------------1--1----  1101
    │  MOL   11  --1---------------------------------------------------1-------  1101
    │  MOL   18  1-------------1--11----11--------------1-1---1--111---1----  1101
    │  MOL   26  1----------------1-------------------------------------1--1--  1101
    │  MOL   32  ---1---------------------------------------------1---------  1101
    └  MOL   39  1-1----------1-------------------------------------1-------1-  1101
```

APPENDIX II (cont'd)

OUTPUT OF TWINSPAN CLUSTER ANALYSIS

```
              Group        VI           V            IV       III    II     I
Species       Site
Assemblage    number  35333444455 22333445556666      11122 422344  1222  1111124
                      90029045717 79567362580123 1238934543 225389 72016 51678981
    PHA   5   --1---------1-11-------1111-1--1111-1-1----111--111---   1110
    PHA  12   ---------1-----------------1---------11------1---1----   1110
    PHA  14   1--1-1---1---------------1---1111---1111-1----1-1-11--   1110
    PHA  15   11--------1-111----------1-------11-1--1-1-1111--1----   1110
    PHA  18   -------------------------------1---------1------------   1110
    PHA  23   ------1--------------------------1-------------1------   1110
    PHA  26   --------------1-----------------1------1-----1-1------   1110
    PHA  30   -------------------------------1-------------1--------   1110
    PHA  49   ----1----------------------------1----11--1--1--------   1110
    RHO  24   -----1------------1--------1------1---1----1----111---   1110
    RHO  31   ----------------------------1---1--------1---1--------   1110
    RHO  38   --1--------1-----------1----1----1----1----1-------1--   1110
    RHO  74   --1-------------------------------1--------------1----   1110
    RHO  79   -----------------1-------1-------1----1----1--------1-   1110
    RHO  92   --1---------------------------------1--------1--------   1110
    CHO   4   ------------1-------------1---1-1-----1---1--1-11111--   1110
    CHO   6   ---------------------1---1---1-1----------11-1--------   1110
    CHO   7   ---1-------1--------------1--1-1111-111--111--1-1111--   1110
    CHO   8   ---1-------11------1-----1-1--11-11-1------111---1-1--   1110
    CHO   9   ---1--------------1--------1-1--111---1---11111-111---   1110
    CHO  23   -----------------------1----------1----------------1--   1110
    CHO  25   ------------------------1-----------1--------------1--   1110
    CHL   5   --------------1------11--11-1--1--1--1-----111----1-1-   1110
A - ANG   1   --11------1-1--------------1--11-1--111--1111---11--1-   1110
    CNI   5   ------------------------1---1--1-------------1---1----   1110
    CNI  11   ------------------------------111---1-1---111---111-1-   1110
    MOL   8   1--1----1--11----11---1-11-11111111-111--111111111111-   1110
    MOL  12   ----------------------------1---------------1---------   1110
    MOL  29   -----------------------------------1--11--------1---1-   1110
    MOL  38   1-------------------------------------1------1--------   1110
    ECH   4   ---------------------------1---------------------1----   1110
    PHA  13   --------------1-------------1---1-1---1-11-1111111-1--   1111
    PHA  32   ----------------------------------1------1--1---11----   1111
    RHO  73   --1----------1----------1-------------1-1---1---1111--   1111
    CHO  10   -1---1---1----------------------1-----1--1----11-111--   1111
    CHO  11   --------------1---------------1-11----1---1--1111111--   1111
    CHO  12   -------------------------1----1-1-----1------111111---   1111
    CHO  16   --------1-------------------1--------------1----11----   1111
    CHL  10   -----------11------------1--1-1---------------1--1111-   1111
    CHL  13   ------------------------------1-11--------11-1--1111--   1111
    ANG   2   -------------1--------------11----11--1----1111111111-   1111
    ANG   3   ---------------------------------------11-----111-111-   1111
    ANG   4   ---------------------------------11-1-----11111111111-   1111
    CNI   4   ------------------------------------11----1-1111111-1-   1111
    CNI  19   -------------------1------------------------11------1-   1111
    MOL  14   ---------------------1-1--------1-------------1-11-1--   1111
    MOL  25   --------------------------------1---------------1--1--   1111
    MOL  30   ------------------------------------------------1-1-1-   1111

              00000000000000000000000000000000000000000111111111111
              000000000000000000000000011111111111111110000011111111
              0011111111111111111111111000000000001111
                000000000111111111111110000000000011
```

THE 1986 SURVEY OF MOLLUSC AND ECHINODERM ASSEMBLAGES ON INTERTIDAL BEACHROCK PLATFORMS IN THE PERTH METROPOLITAN AREA

F E Wells J K Keesing and R J Sellers
Western Australian Museum

Abstract

The molluscan fauna of three intertidal platforms (Waterman, Trigg Island and Cottesloe) along the Perth metropolitan coastline was surveyed in January 1986 with techniques used in the previous three summers. The basic patterns found in previous years occurred again in 1986. Molluscs on the inshore platform were diverse in terms of species number, with a high density but low biomass as most species were small (< 2 cm). Proceeding seaward on the platform diversity and density declined but biomass increased owing primarily to the presence of abalone and to a lesser extent chitons. There were a number of variations from the general pattern caused by natural phenomena but most fluctuations were within the ranges found in previous years. Reduced numbers of adult abalone at Trigg Island in 1986 were attributed to the effects of amateur fishermen.

Echinoderms were surveyed for the first time in 1986. Seven species were collected. They were almost absent from the bare zone at the seaward edge of the platforms. Echinoderms occurred widely over the remainder of the platforms where their distribution was related to bottom topography rather than macroalgal type as occurs in molluscs.

CONTENTS

APPENDICES

FIGURE

TABLES

1. INTRODUCTION

The coastline of the Perth metropolitan area of the lower west coast of Western Australia is composed of extensive sandy beaches interrupted by small, isolated beachrock platforms. The platforms vary in extent from a few metres to those at the west end of Rottnest Island which extend as much as 100 m seaward from the base of the shoreward cliff. Fairbridge (1950) and Marsh (1955) summarised the structure of the platforms; more recently Semeniuk and Johnson (1985) recognised four types of platforms based on the presence or absence of shoreward cliffs, and their structure if present. The platforms vary considerably, with some being broad and flat while others are highly dissected by channels and pools. They range from being just subtidal to about 1 m above datum, but most are intertidal at a level of about 0.3 m. A ridge on the seaward margin tends to trap water on the platform surface at low tide. Subtidally the platforms drop off either vertically or with an undercut notch into water 1.5 to 6 m deep with a bottom type of either sand or rock. The subtidal undercut notch represents a previous sea level; other supratidal notches occur at levels where the sea surface was previously higher.

Studies on the flora and fauna living on the platforms began with a series of descriptive reports published in the 1950's (Hodgkin 1959a; 1959b; Hodgkin, Marsh and Smith 1959; Marsh 1955; Marsh and Hodgkin 1962; Smith 1952). Subsequent work dealt primarily with the biology of individual species or groups of species. Much of this work was done at Rottnest Island 20 km west of Perth and has been summarised by Black and Johnson (1983). The fauna of the inshore platforms along the metropolitan coast is primarily temperate but a number of tropical species have been recorded at the western end of Rottnest Island (Hodgkin, Marsh and Smith 1959; Black and Johnson 1983). The Rottnest Island platforms were regarded as unique but there were no quantitative data comparing them with inshore platforms. The description by Cresswell and Golding (1980) of the south-flowing Leeuwin Current along the outer continental shelf of the west coast provided a mechanism for the delivery of planktonic larvae of tropical species to Rottnest Island but not to the inshore areas. To examine the relative importance of tropical species at Rottnest Island and inshore a comparison was made during the summer of 1981/82 of the molluscs, a dominant group on the platforms, at Cape Vlamingh and Radar Reef at Rottnest Island with the inshore platforms at Trigg Island and Cottesloe. The results showed that there are twice as many tropical species on the Rottnest Island platforms and they comprise a substantial portion of the density and biomass of molluscs compared to the inshore platforms (Wells 1985).

During the initial survey controversy was generated over the increased fishing of abalone (*Haliotis roei*) and other molluscs on metropolitan platforms by amateurs and the effects this was having on the professional fishery. Temporary bans on collecting these animals were put into place by the WA Fisheries Department in March 1982; the bans were subsequently modified and extended that October. In November 1982 the platform mollusc programme was substantially enlarged into a three year examination of mollusc populations, particularly abalone, on the platforms to provide information for use in managing the mollusc populations.

One major aspect of the study was an annual detailed survey in 1983, 1984 and 1985. Four platforms were selected based primarily on differences in fishing pressure for abalone: Waterman platform is part of the Waterman Marine Reserve where fishing pressure is minimal; Trigg Island has been fished in the past by professionals and more recently by amateurs; Cottesloe has been fished only by amateurs; and the southwestern corner of Garden Island is a professional fishery where amateur fishing is at a low level. Fishing pressure on other platform molluscs on these four platforms parallels that of abalone. The project for the Fisheries Department was completed in late 1985 and the final report submitted in February 1986 (Wells and Keesing 1986).

The summer mollusc survey on three of these platforms (Waterman, Trigg Island and Cottesloe) is of direct relevance to the management of the proposed Marmion Marine Park. The availability of data collected prior to the implementation of the park allows the monitoring of changes in the populations of molluscs on the platforms when the Park is implemented. For this reason the 1986 survey was undertaken. Molluscs are a dominant faunal group on the platforms and all previous surveys had been devoted entirely to them. During the 1986 survey the opportunity was taken also to examine echinoderms on the two groups.

2. MATERIALS AND METHODS

Each platform was divided into habitats based on the types of macroalgae present on different areas of the platforms; not all algal types were present on all platforms. Changes in mollusc populations were found to parallel changes in macroalgal composition. The general pattern found at both Waterman and Trigg Island was a seaward bare zone largely devoid of macroalgae which gave way on the centre of the platform to a zone dominated by *Sargassum*. An association of mixed macroalgae occurred on the inshore zone of the platform. There was no bare zone as such on the seaward margin at Cottesloe; only isolated bare patches of 1 m^2 or less in area. The *Sargassum* zone at Cottesloe was extensive and was divided into outer and inner *Sargassum* zones followed by the inshore platform zone. A separate *Ecklonia* zone also occurred in a deeper section of the platform at Cottesloe. Division of the platforms into algal zones allowed comparisons of the molluscs in different areas of a single platform, the same type of habitat on different platforms and annual changes in a particular zone during the various years of the study.

In each zone a transect of eight stations 5 or 10 m apart was sampled. At each station all molluscs and echinoderms 5 mm or more in greatest dimension in four quadrats (50 by 50 cm) were counted and as far as possible identified in the field; collecting was kept to a minimum to minimise effects on the populations. Representative specimens of each species were collected outside the quadrat areas for dry weight determinations in 1983 Spot checks of dry weight of selected species and those which appeared to have changed in size were conducted annually. To determine shell free, dry weight the shell of large specimens was cracked off and the animal placed in dilute hydrochloric acid; smaller animals were placed directly in acid. Additional acid was added daily until all reactions ceased. The animals were then washed thoroughly in fresh water dried to constant weight at 60^{o}C and weighed to the nearest milligram on a Sartorius electronic balance. The data were then converted to shell free dry weight biomass.

Feeding studies were undertaken on several species of platform molluscs: *Thais orbita* (Keesing 1982); *Haliotis roei* (Galloway 1983; Wells and Keesing 1986); and *Prothalotia pulcherrimus* (Herlihy 1984). Data on the feeding types of other species were determined using published information on the same species in other geographical areas or on related species using the following sources: Fretter and Graham (1962); Hyman (1967); Purchon (1968); Thompson (1976) and personal knowledge. Echinoderm feeding strategies were categorised using the papers by Baker (1982), Grice (1984), Rowe (1982), and Zeidler and Shepherd (1982). The feeding type was not known for all the species collected in this study; for these species the feeding type was assumed to be the same as reported for related species. This might have caused the incorrect classification of one or two species, but should not have affected the general trends.

Abalone density and size frequency characteristics were measured at six sites in 1983, 1984 and 1985; the sites were re-examined in 1986. Two sites were at Waterman: at the base of the steps leading to the beach from the marine laboratory (Waterman North) and on the platform south of the laboratory (Waterman South). The stations at Trigg Island were Trigg North, just north of Shag Rock; Trigg West, at the seaward edge of the platform west of Shag Rock; and Trigg Island just west of Trigg Island. The site at Cottesloe was at the seaward edge of the platform just south of the groyne. At each site all abalone in each of 20, 50 by 50 cm quadrats, were counted and mean density and standard error calculated. At least 200 animals were measured *in situ* with calipers.

3. RESULTS

Appendix 1 provides full data on the mollusc species present in each zone of each platform, their density and shell free, dry weight biomass. Appendix 2 summarises the pertinent information for each species of mollusc collected during the survey. Appendices 3 and 4 provide the same type of data for echinoderms as in Appendices 1 and 2 respectively.

3.1 MOLLUSCS

The general pattern for molluscs was for the inshore platform zones to have a high species diversity and a high density. While density was great the dominant species (mussels and trochids) were small and the total biomass was low. The *Sargassum* zone seaward of the inshore platform zone usually had a lower species diversity. Density was greater or less than on the inshore platform zone depending on the extent of mussel populations, if they were present; biomass was increased by the presence of small numbers of large abalone. Diversity was further reduced on the seaward bare zone. Here mussels were absent and total mollusc density was low but biomass was large primarily owing to the weight of adult abalone and, to a lesser extent, chitons.

On the Waterman platform in 1986 (Table 1) mollusc populations were depressed on the inshore platform zone. Only 14 species were found with a total density of 18/m^2 and a biomass of 1g/m^2. In 1984 the inshore platform was covered with sand in some quarters of the year and no molluscs were found. Considerable quantities of sand were present in 1986 and only species which live in sand (such as *Bulla quoyii*) or those such as *Ischnochiton virgatus* which are able to attach to the underlying rock surface occurred on the inshore platform zone. Mussel beds do not occur at Waterman. In 1986 in the *Sargassum* zone species diversity (20) and density (248/m^2) were at levels comparable with previous years, but biomass 36 (g/m^2) was low. All three parameters in the bare zone in 1986 were at levels similar to those recorded previously.

At Trigg Island in 1986 on the inshore platform zone the number of species (22) and density (3410/m^2) were within the range recorded in previous years, but biomass was substantially greater (420 g/m^2). The inshore platform near Shag Rock was covered by an extensive mussel bed which became less continuous towards Trigg Island. One species, *Brachidontes ustulatus*, alone had a density of 3197/m^2 and a biomass of 416 g/m^2, thus dominating these statistics. Two other mussels, *Xenostrobus pulex* and *Mytilus edulis*, were present in the bed but at low levels of density and biomass. The 1986 population of *B ustulatus* had a lower density than in 1985 (5272/m^2) but biomass increased over the 1985 figure of 95 g/m^2 probably as a result of growth of individuals in a single year class. In 1985 two mussels, *B ustulatus* and *X pulex*, had a combined density of 6941/m^2 and a biomass of 125 g/m^2 in the *Sargassum* zone. The populations of both species had declined sharply in 1986 and the total density in the zone was only 534/m^2 with a biomass of 74 g/m^2. The 1986 figures for the bare zone at Trigg Island were all comparable with previous years.

Table 1. Summary of quantitative surveys of molluscs on three inter-tidal platforms in the Perth metropolitan area in January 1986.

PLATFORM	NO OF SPECIES	DENSITY (No/m^2)	BIOMASS (g/m^2)	DOMINANT SPECIES* DENSITY, BIOMASS
WATERMAN				
Inshore platform zone	14	18	1	T t, T t
Sargassum zone	20	248	36	P p, H r
Bare zone	15	638	1090	P a, H r
TRIGG I				
Inshore platform zone	22	3410	420	B u, B u
Sargassum zone	19	534	74	B u, H r
Bare zone	15	597	353	P a, H r
COTTESLOE				
Inshore platform zone	35	448	10	B u, B u
Inner *Sargassum* zone	32	477	10	P p, B u
Outer *Sargassum* zone	23	540	54	B u, H r
Ecklonia zone	15	277	37	B u, H r

*Key to dominant species

H r	*Haliotis roei*
P a	*Patelloida alticostata*
P p	*Prothalotia pulcherrimus*
T t	*Turbo torquatus*
B u	*Brachidontes ustulatus*

At Cottesloe total density on the inshore platform was 1980/m^2 and biomass was 21g/m^2 during the first survey conducted in 1983. While diversity at Cottesloe had remained high (35 species in 1986) density and biomass declined in 1984 and further in 1985 as a result of the loss of mussel beds.

These had not re-established by 1986, causing density and biomass to remain low. Mussel populations (almost exclusively *B ustulatus)* peaked in the inner *Sargassum* zone in 1984 at a level of $8654/m^2$ and a biomass of $157g/m^2$, then declined in 1985. A further decline was recorded in 1986. Density and biomass in the outer *Sargassum* and *Ecklonia* zones at Cottesloe in 1986 were lower than in 1985, again primarily because of reductions in mussel populations.

Table 2 summarises the data for the feeding types of molluscs on all three platforms. Herbivores were dominant in all three zones on the platform at Waterman, constituting 71% of the total number of species and at least 88% of the density and biomass. Herbivores were also the dominant group in terms of the number of species at Trigg Island, but several species of filter feeders were present in all three zones. Dominance in terms of density and biomass was mixed. Filter feeders (mussels) comprised 95% or more of total mollusc density and biomass on the inshore platform zone. Mussels were less abundant in the *Sargassum* zone, but were still 75% of total molluscan density. Biomass, however, was largely composed of herbivores, almost all of these were abalone. Herbivores were also the dominant group in the bare zone, with limpets having the greatest density and abalone the greatest biomass. Herbivores were the most diverse, in terms of species numbers, in all zones at Cottesloe. Filter feeders, again primarily mussels, had the greatest density in all zones and the greatest biomass on the inshore platform zone and in the inner *Sargassum* zone. Fourteen carnivorous species were found in 1986. While they may play an important ecological role none was important in terms of density or biomass.

Table 2. Trophic categories of molluscs collected on three intertidal platforms in the Perth metropolitan area in January 1986.

FEEDING TYPE	NO OF SPECIES	DENSITY (No/m^2)	BIOMASS (g/m^2)
WATERMAN			
Inshore platform zone			
Herbivores	10	16	1
Carnivores	3	1	0
Filter feeders	-	-	-
Unknown	1	1	0
TOTALS	14	18	1
Sargassum zone			
Herbivores	10	220	34
Carnivores	3	2	2
Filter feeders	5	2	0
Unknown	2	24	0
TOTALS	20	248	36
Bare zone			
Herbivores	11	633	1086
Carnivores	1	3	4
Filter feeders	3	2	0
Unknown	-	-	-
TOTALS	15	638	1090

Table 2. Trophic categories of molluscs collected on three intertidal platforms in the Perth metropolitan area in January 1986 (cont'd).

FEEDING TYPE	NO OF SPECIES	DENSITY (No/m^2)	BIOMASS (g/m^2)
TRIGG ISLAND			
Inshore platform			
Herbivores	12	133	3
Carnivores	2	1	0
Filter feeders	5	3239	416
Unknown	3	36	1
TOTALS	22	3409	420
Sargassum zone			
Herbivores	9	114	62
Carnivores	1	3	5
Filter feeders	7	400	7
Unknown	2	17	0
TOTALS	19	534	74
Bare zone			
Herbivores	9	571	350
Carnivores	1	1	2
Filter feeders	5	25	1
Unknown	–	–	–
TOTALS	15	597	353
COTTESLOE			
Inshore platform			
Herbivores	13	46	1
Carnivores	10	6	1
Filter feeders	10	386	7
Unknown	2	10	0
TOTALS	35	448	9
Inner *Sargassum* zone			
Herbivores	15	207	2
Carnivores	5	3	3
Filter feeders	8	232	5
Unknown	4	35	0
TOTALS	32	477	10
Outer *Sargassum* zone			
Herbivores	11	128	27
Carnivores	3	9	16
Filter feeders	7	394	10
Unknown	2	9	0
TOTALS	23	540	53
Ecklonia zone			
Herbivores	8	26	28
Carnivores	1	2	4
Filter feeders	5	249	5
Unknown	1	0	0
TOTALS	15	277	37

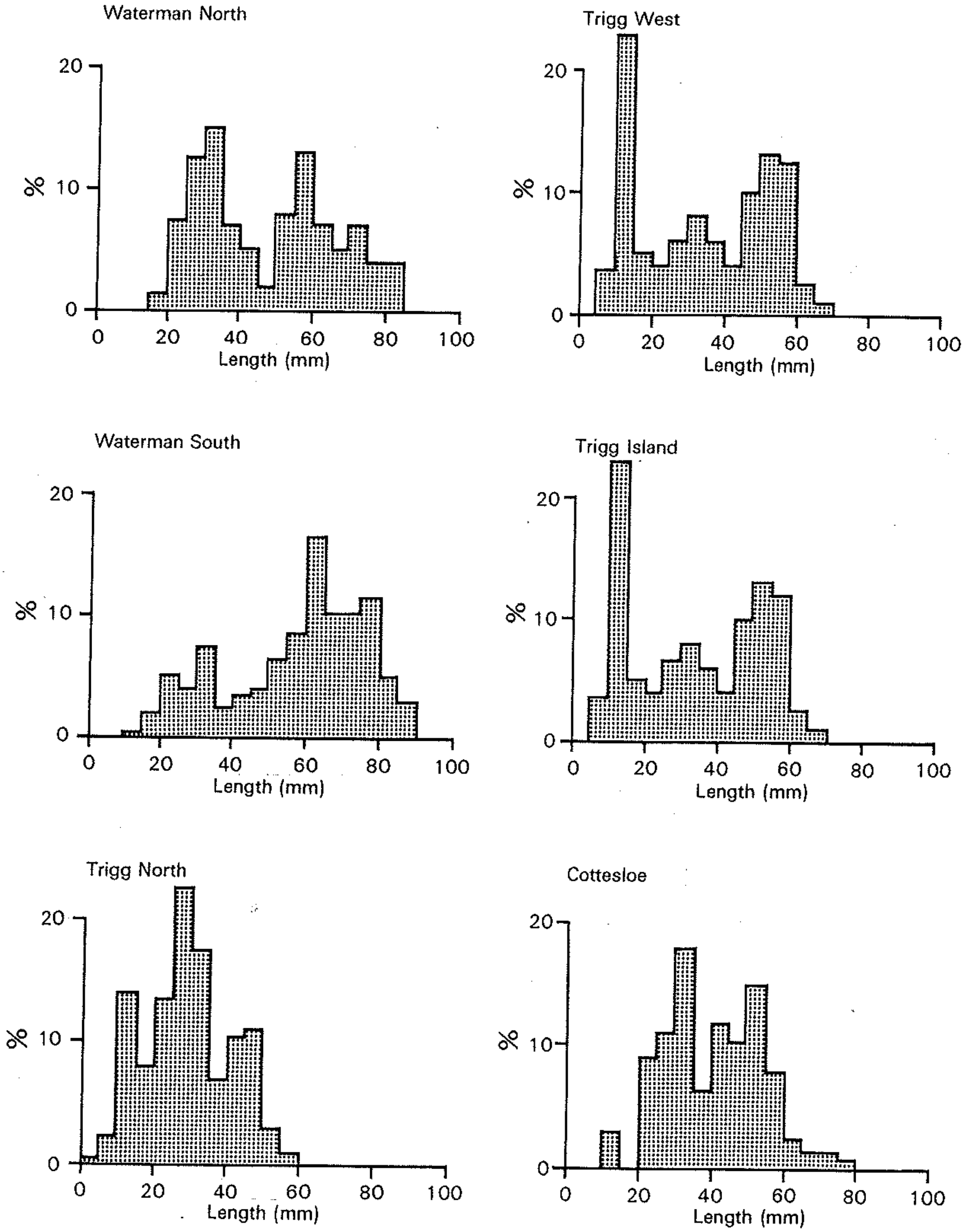

Figure 1. Size frequency characteristics of abalone *(Haliotis roei)* on intertidal platforms in the Perth metropolitan area in January 1986.

Densities of abalone were high at both of the Waterman sites, 136/m^2 at Waterman North and 97/m^2 at Waterman South (Table 3). The populations at Waterman were composed primarily of animals in the 2+ age group at Waterman South and about equal proportions of 0+ and 1+ and 2+ individuals at Waterman North (Figure 1). Few abalone were present at Cottesloe, where the mean density was 8/m^2. Densities at Trigg Island were lower than those recorded at Waterman, ranging from 21/m^2 at Trigg North to 52/m^2 at Trigg West. In contrast to Waterman all of the abalone at Trigg Island were 0+ or 1+ individuals; there were no 2+ animals. No abalone of legal size (>6 cm) were found at Trigg North and only 7% of the population at Trigg West and Trigg Island were legal sized. A substantial proportion, over 40%, of the populations on all three Trigg Island sites were recruits in the size range <20 mm, showing that recruitment was good despite the lack of reproducing adults on the platform. Densities of animals <20 mm varied between 8/m^2 and 21/m^2 at Trigg Island compared to 4/m^2 to 5/m^2 at the two Waterman sites.

Table 3. Density of the abalone *(Haliotis roei)* at the seaward margins of three intertidal platforms in the Perth metropolitan area in January 1986.

SAMPLE SITE	DENSITY (No/m^2) $\bar{x} \pm 1$ s e
Waterman North	136.0 ± 14.1
Waterman South	97.2 ± 7.8
Trigg North	21.4 ± 4.8
Trigg West	52.0 ± 6.8
Trigg Island	25.8 ± 2.5
Cottesloe	8.2 ± 1.5

3.2 ECHINODERMS

Compared with molluscs the echinoderm fauna of the platforms was impoverished, with only seven species being recorded during the 1986 survey. One asteroid, *Patiriella gunni*, and one holothurian, *Psolidium* sp aff *nigrescens*, dominated the echinoderm fauna.

There were no clear patterns in the distribution of echinoderms in the various algal zones (Table 4). Diversity tended to be greatest on the inshore platform zone and declined in the *Sargassum* and bare zones. The exception was at Waterman where the number of echinoderm species was low on the inshore platform zone owing to the presence of sand. Echinoderms in the *Ecklonia* zone at Cottesloe were diverse, with five species being recorded. Density and biomass were greatest in the *Sargassum* zone at Waterman, on the inshore platform at Trigg Island and in the inner *Sargassum* zone at Cottesloe. The only clear feature of echinoderm distributions was that diversity, density and biomass were all at minimal levels in the bare zone, with *P gunni* being the only species found in this habitat.

Table 4. Summary of quantitative surveys of the echinoderms on three intertidal platforms in the Perth metropolitan area in January 1986.

PLATFORM	NO OF SPECIES	DENSITY (No/m^2)	BIOMASS (g/m^2)	DOMINANT SPECIES* DENSITY, BIOMASS'
WATERMANS				
Inshore platform	2	1	1	H sp, H sp
Sargassum zone	4	144	90	P g, P g
Bare zone	1	> 0	> 0	P g, P g
TRIGG ISLAND				
Inshore platform	4	45	25	H sp, H sp
Sargassum zone	2	23	19	P g, P g
Bare zone	1	> 0	> 0	P g, P g
COTTESLOE				
Inshore platform	5	11	5	H sp, H sp
Inner *Sargassum* zone	4	23	17	P g, P g
Outer *Sarqassum* zone	1	> 0	> 0	H sp, H sp
Ecklonia zone	5	5	5	C c, H p

*Key to dominant species

P g	*Patiriella gunni*
C c	*Coscinasterias calamaria*
H p	*Holopneustes porosissiumus*
H sp	*Holothurian* sp

Except for the bare zone distribution of the dominant echinoderms was related to the platform topography rather than to algal zonation. *P gunni* occurred in crevices and channels in the rock rather than on the open surface. *P* sp aff *nigrescens* also occurred in these areas, usually buried under the sand, and was also found among *Sargassum* and *Ecklonia* holdfasts. The echinoids also occurred among the holdfasts.

Four separate feeding types were recognised among the seven echinoderm species collected on the platforms: the three echinoids were classified as herbivores; the holothurian and ophiuroid as detritivores; *P gunni* as omnivorous; and *Coscinasterias calamaria* as carnivorous. Omnivorous species and detritivores dominated the echinoderm fauna (Table 5). The inshore platform, with its high concentration of sand overlying the rock surface in crevices and holes, had about the same density and biomass of detritivores (almost exclusively the holothurian) and the omnivorous *P gunni*. The omnivorous *P gunni* dominated the *Sargassum* zone, where wave action was greater and detritus presumably was less abundant.

Table 5. Trophic categories of echinoderms collected on three intertidal platforms in the Perth metropolitan area in January 1986.

FEEDING TYPE	NO OF SPECIES	DENSITY (No/m^2)	BIOMASS (g/m^2)
WATERMAN			
Inshore platform			
Herbivores	–	–	–
Carnivores	–	–	–
Omnivores	1	> 0	> 0
Detrital feeders	1	< 1	<10
TOTALS	2	1	1
Sargassum zone			
Herbivores	2	1	< 1
Carnivores	–	–	–
Omnivores	1	87	73
Detrital feeders	1	56	16
TOTALS	4	144	90
Bare zone			
Herbivores	–	–	–
Carnivores	–	–	–
Omnivores	–	> 0	> 0
Detrital feeders	–	> –	
TOTALS	1	> 0	> 0
TRIGG ISLAND			
Inshore platform			
Herbivores	–	–	–
Carnivores	1	> 0	> 0
Omnivores	1	22	18
Detrital feeders	2	23	6
TOTALS	4	45	25
Sargassum zone			
Herbivores	–	–	–
Carnivores	1	> 0	> 0
Omnivores	1	23	19
Detrital feeders	–	–	–
TOTALS	2	23	19
Bare zone			
Herbivores	–	–	–
Carnivores	–	–	–
Omnivores	1	> 0	> 0
Detrital feeders	–	–	–
TOTALS	1	> 0	> 0

Table 5. Trophic categories of echinoderms collected on three intertidal platforms in the Perth metropolitan area in January 1986 (cont'd).

FEEDING TYPE	NO OF SPECIES	DENSITY (No/m^2)	BIOMASS (g/m^2)
COTTESLOE			
Inshore platform			
Herbivores	2	> 0	> 0
Carnivores	1	> 0	> 0
Omnivores	1	2	2
Detrital feeders	1	9	2
TOTALS	5	11	5
Inner *Sargassum* zone			
Herbivores	1	0	> 0
Carnivores	1	1	> 0
Omnivores	1	18	17
Detrital feeders	1	4	1
TOTALS	4	23	19
Outer *Sargassum* zone			
Herbivores	-	-	-
Carnivores	-	-	-
Omnivores	-	-	-
Detrital feeders	1	> 0	> 0
TOTALS	1	> 0	> 0
Ecklonia zone			
Herbivores	2	1	3
Carnivores	1	2	1
Omnivores	1	2	1
Detrital feeders	1	0	> 0
TOTALS	5	5	5

4. DISCUSSION

Analysis of the survey results for 1983 to 1985 (Wells and Keesing 1986) showed that there were different mollusc assemblages inhabiting the different algal zones on a single platform. Substantial variations were found in the same year between the assemblages of a particular zone on different platforms, and there were significant seasonal and annual variations in mollusc populations. The 1986 results continued to exhibit this natural variability, and in several cases the 1986 data exceeded the ranges found in the previous years.

One consistent feature of the various algal zones was the relative stability of the bare zone at the seaward edge of the platforms. Diversity was always low, as was total mollusc density. Biomass was great as a result of the weight of large abalone. The actual numbers were fairly stable from year to year, except at Trigg Island where fishing pressure had reduced the abalone populations. Compared to the bare zone the mollusc assemblages in the

Sargassum and inshore platform zones fluctuated much more erratically in diversity, total mollusc density and biomass. Some of these fluctuations could be directly attributed to specific causes such as the killing off of mollusc populations on the inshore platform zone at Waterman by sand covering the platform. The largest changes in density and biomass on the inshore platform and in the *Sargassum* zone were caused by fluctuations in the mussel beds, and these alone explain much of the total variation within these zones. Mussels were the dominant filter feeding molluscs on the platform; they perform the ecological role of converting microscopic material in the plankton into body tissue available to higher level benthic predators such as the whelk, *Thais orbita*, and the starfish, *Coscinasterias calamaria*. For these reasons a more detailed examination of the biology of mussels on the platforms is essential to an overall understanding of the biology of platform molluscs, and indeed the functioning of the platform community as a whole.

The above changes in mollusc populations found during the 1986 survey resulted from natural population variability. Changes in abalone populations at Trigg Island (Table 6) were caused by fishing pressure of amateur fishermen. In January 1983, after the bans were put into effect, abalone densities were low, but they had increased by January 1984. Densities declined at all three Trigg Island sites in January 1985, though the declines at Trigg North and Trigg Island were minimal. Further decreases in population density occurred at these two sites in 1986, to the lowest levels recorded in the four years surveyed. In addition to density decreases there were also consistent declines in the percentage of legal sized (>6 cm) animals in the population (Table 6). The small proportion of legal sized abalone at Trigg North indicates that the animals could have reached legal size on that part of the platform, but as fishing pressure was intense few individuals >5cm were found. The percentages of legal sized animals at Trigg West and Trigg Island in 1986 were both 7%, down from 24% and 34% respectively in the initial 1983 survey.

Table 6. Total abalone density and percentage of the population of legal size at three sites at Trigg from 1983 to 1986. The 1986 data are from the present survey; data for 1983, 1984 and 1985 are from Wells and Keesing (1986).

	SITE					
	TRIGG NORTH		TRIGG WEST		TRIGG ISLAND	
	DENSITY (No/m^2) ($\bar{x}$ ± 1 s e)	% LEGAL SIZE	DENSITY (No/m^2) ($\bar{x}$ ± 1 s e)	% LEGAL SIZE	DENSITY (No/m^2) ($\bar{x}$ ± 1 s e)	% LEGAL SIZE
1983	30.6±3.7	1	34.8±2.9	24	Not recorded	34
1984	43.4±6.3	3	60.6±6.6	14	46.0±6.8	14
1985	40.8±6.2	0	42.8±7.6	13	43.6±2.9	5
1986	21.4±4.8	0	52.0±6.8	7	25.8±2.5	7

There are no previous data available for comparison with the 1986 echinoderm data, but useful comparisons can be drawn with the molluscs. In all three categories examined (number of species, density and biomass) molluscs were more abundant than echinoderms in all of the algal zones on all three platforms. The molluscan component of the fauna clearly changed on the platform surface and could be related to changes in the dominant macroalgae. The echinoderms showed no such relationship to the type of algae present but instead their abundance was related to the number and type of crevices and holes in the rock surface. Molluscs on the platform were largely herbivores, or filter feeders where mussel beds were present. Echinoderms were mainly a mixture of omnivores and detritivores on the inshore platform zone, and omnivores in the *Sargassum* zone; they were absent from the bare zone.

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MOLLUSCS COLLECTED ON INTERTIDAL BEACHROCK PLATFORMS IN THE PERTH METROPOLITAN AREA

WATERMAN 1986

	INSHORE PLATFORM		*SARGASSUM*	
	DENSITY No/m^2 $\bar{x}$ ± 1 s e	BIOMASS g/m^2 $\bar{x}$ ± 1 s e	DENSITY No/m^2 $\bar{x}$ ± 1 s e	BIOMASS g/m^2 $\bar{x}$ ± 1 s e
CLASS POLYPLACOPHORA				
Ischnochiton virgatus	0.38±0.26	0.002±0.001	1.00± 0.63	0.004± 0.003
Ischnochiton sp	0.25±0.16	–		
Acanthochitona cf *johnstonii*	0.75±0.41	–		
Clavarizona hirtosa				
Onithochiton occidentalis				
CLASS GASTROPODA				
Haliotis roei			3.88± 1.90	30.225±14.801
Amblychilepas nigrita			2.75± 1.10	0.033± 0.013
Macroschisma producta	1.25±0.90	0.131±0.095	0.63± 0.37	0.066± 0.039
Patella peronii				
Collisella onychitis				
Patelloida alticostata			2.13± 1.22	0.258± 0.148
Patelloida nigrosulcata	0.13±0.12	0.018±0.017	0.75± 0.25	0.105± 0.035
Notogibbula preissiana	0.75±0.37	0.009±0.004	31.00± 8.77	0.372± 0.105
Prothalotia lehmanni			0.13± 0.12	0.001± 0.001
Prothalotia pulcherrimus	0.88±0.35	0.004±0.001	155.63±24.90	0.778± 0.125
Turbo torquatus	7.00±2.73	0.560±0.218	22.38± 2.87	1.790± 0.230
Epitonium jukesiana			0.63± 0.32	–
Epitonium perplexa	0.13±0.12	–		
Sabia conica			0.25± 0.25	0.003± 0.003
Bedeva paivae			0.25± 0.25	0.008± 0.008
Muricopsis planiliratus	0.13±0.12	0.004±0.004		
Thais orbita			1.25± 0.31	2.250± 0.558
Dentimitrella lincolnensis	0.50±0.27	0.004±0.002	23.13± 5.01	0.185± 0.040

MOLLUSCS COLLECTED ON INTERTIDAL BEACHROCK PLATFORMS IN THE PERTH METROPOLITAN AREA (cont'd)

WATERMAN 1986

	INSHORE PLATFORM		*SARGASSUM*	
	DENSITY No/m^2 $\bar{x} \pm 1$ s e	BIOMASS g/m^2 $\bar{x} \pm 1$ s e	DENSITY No/m^2 $\bar{x} \pm 1$ s e	BIOMASS g/m^2 $\bar{x} \pm 1$ s e
Pyrene bidentata			1.00± 0.53	0.029± 0.015
Vexillum marrowi	0.50±0.38	0.002±0.002		
Bulla quoyii	5.00±1.87	0.275±0.103		
Aplysia oculifera	0.13±0.12	0.122±0.113		
CLASS BIVALVIA				
Brachidontes ustulatus			0.25± 0.16	0.005± 0.003
Xenostrobus pulex				
Bivalve sp B			0.13± 0.12	-
Anomia sp			0.63± 0.32	-
Crassostrea sp			0.50± 0.19	-
TOTALS	17.78±6.15	1.131±0.395	248.30±39.30	36.112±14.619
Number of species	14		20	

MOLLUSCS COLLECTED ON INTERTIDAL BEACHROCK PLATFORMS IN THE PERTH METROPOLITAN AREA (cont'd)

WATERMAN 1986

	BARE ZONE	
	DENSITY (No/m^2) x ± 1 s e	BIOMASS (g/m^2) x ± 1 s e
CLASS POLYPLACOPHORA		
Ischnochiton virgatus	0.13±0.12	0.001± 0.001
Ischnochiton sp		
Acanthochitona cf *johnstoni*		
Clavarizona hirtosa	29.50±5.63	33.070± 6.311
Onithochiton occidentalis	5.75±1.60	6.302± 1.754
CLASS GASTROPODA		
Haliotis roei	127.00±21.99	989.330±171.302
Amblychilepas nigrita	0.13± 0.12	0.002± 0.001
Macroschisma producta		
Patella peronii	27.75± 5.30	1.249± 0.239
Collisella onychitis	6.50± 1.40	0.293± 0.063
Patelloida alticostata	306.75±56.72	37.117± 6.863
Patelloida nigrosulcata	129.38±22.71	18.113± 3.179
Notogibbula preissiana	0.13± 0.12	0.002± 0.001
Prothalotia lehmanni		
Prothalotia pulcherrimus		
Turbo torquatus	0.25± 0.25	0.020± 0.020
Epitonium jukesiana		
Epitonium perplexa		
Sabia conica	0.25± 0.25	0.003± 0.003
Bedeva paivae		
Muricopsis planiliratus		
Thais orbita	2.38± 0.53	4.284± 0.954
Dentimitrella lincolnensis		
Pyrene bidentata		
Vexillum marrowi		
Bulla quoyii		
Aplysia oculifera		
CLASS BIVALVIA		
Brachidontes ustulatus		
Xenostrobus pulex	1.13± 0.85	0.020± 0.015
Bivalve sp B		
Anomia sp		
Crassostrea sp	0.63± 0.32	–
TOTALS	637.66±23.17	1089.806±167.609
Number of Species	15	

MOLLUSCS COLLECTED ON INTERTIDAL BEACHROCK PLATFORMS IN THE PERTH METROPOLITAN AREA (cont'd)

TRIGG 1986

	INSHORE PLATFORM		*SARGASSUM*	
	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e
CLASS POLYPLACOPHORA				
Ischnochiton virgatus	20.38± 9.39	0.082±0.038		
Acanthochitona bednalli	0.25± 0.16	–		
Acanthochitona cf *johnstoni*	4.50± 2.40	–		
Acanthochitona cf *lachrymosus*	0.13± 0.12	–		
Clavarizona hirtosa				
Onithochiton occidentalis				
CLASS GASTROPODA				
Haliotis roei			7.63± 1.71	59.438±13.321
Amblychilepas nigrita	0.13± 0.12	0.002±0.001	0.25± 0.25	0.003± 0.003
Macroschisma producta	12.38± 7.96	1.300±0.836		
Patella peronii				
Collisella onychitis				
Patelloida alticostata			0.38± 0.26	0.046± 0.031
Patelloida nigrosulcata			4.13± 1.16	0.578± 0.162
Notogibbula preissiana	27.88± 2.83	0.335±0.034	26.75±15.74	0.321± 0.189
Prothalotia lehmanni	0.25± 0.16	0.001±0.001	0.13± 0.12	0.001± 0.001
Prothalotia pulcherrimus	53.63± 17.18	0.268±0.086	65.63±26.88	0.328± 0.134
Thalotia chlorostoma	0.13± 0.12	–		
Turbo torquatus	11.13± 3.98	0.890±0.318	9.13± 2.57	0.730± 0.206
Serpulorbis sipho			0.13± 0.12	–
Opalia granosa	1.25± 1.11	–		
Sabia conica			9.13± 3.73	0.091± 0.037
Cypraea caputserpentis			0.13± 0.12	0.094± 0.009

MOLLUSCS COLLECTED ON INTERTIDAL BEACHROCK PLATFORMS IN THE PERTH METROPOLITAN AREA (cont'd)

TRIGG 1986

	INSHORE PLATFORM		*SARGASSUM*	
	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e
Thais orbita			2.88± 0.69	5.184± 1.242
Dentimitrella linocolnensis	23.50± 3.99	0.188± 0.320	10.25± 5.91	0.082± 0.047
Dentimitrella menkeana	0.25± 0.16	0.002± 0.001		
Pyrene bidentata	12.13± 4.75	0.352± 0.138	6.75± 5.78	0.196± 0.168
Vexillum marrowi	0.13± 0.12	0.001± 0.000		
Bulla quoyii	2.57± 1.55	0.141± 0.850		
CLASS BIVALVIA				
Brachidontes ustulatus	3197.13±829.31	415.627±107.810	372.00±222.65	6.696± 4.008
Lithophaga sp				
Mytilus edulis	3.63± 2.32	0.189± 0.121	2.63± 1.05	0.137± 0.055
Xenostrobus pulex	32.75± 16.60	0.590± 0.299	13.50± 13.49	0.108± 0.108
Crassostrea sp	2.25± 1.47	-	2.88± 0.95	-
Venerupis galactites	3.38± 1.65	0.162± 0.079		
Hiatella australis			0.13± 0.12	-
TOTALS	3409.76±827.53	420.048±107.746	534.44±223.77	74.033±16.149
Number of species	22		19	

MOLLUSCS COLLECTED ON INTERTIDAL BEACHROCK PLATFORMS IN THE PERTH METROPOLITAN AREA (cont'd)

TRIGG ISLAND 1986

	BARE ZONE	
	DENSITY (No/m^2) x ± 1 s e	BIOMASS (g/m^2) x ± 1 s e
CLASS POLYPLACOPHORA		
Ischnochiton virgatus	2.63± 1.53	0.011± 0.006
Acanthochitona bednalli		
Acanthochitona cf *johnstoni*		
Acanthochitona cf *lachrymosus*		
Cavarizona hirtosa	12.63± 4.34	14.158± 4.865
Onithochiton occidentalis	16.63± 2.43	18.226± 2.663
CLASS GASTROPODA		
Haliotis roei	33.63± 5.36	261.978±41.754
Amblychilepas nigrita		
Macroschisma producta		
Patella peronii	17.88± 0.64	0.805± 0.029
Collisella onychitis	55.75± 2.66	2.509± 0.120
Patelloida alticostata	399.00±18.22	48.279± 2.205
Patelloida nigrosulcata	30.63± 4.94	4.288± 0.692
Notogibbula preissiana	2.00± 0.53	0.024± 0.006
Prothalotia lehmanni		
Prothalotia pulcherrimus		
Thalotia chlorostoma		
Turbo torquatus		
Serpulorbis sipho		
Opalia granosa		
Sabia conica	1.25± 0.84	0.013± 0.008
Cypraea caputserpentis		
Thais orbita	1.25± 0.45	2.250± 0.810
Dentimitrella lincolnensis		
Dentimitrella menkeana		
Pyrene bidentata		
Vexillum marrowi		
Bulla quoyii		
CLASS BIVALVIA		
Brachidontes ustulatus	9.00± 6.80	0.162± 0.122
Lithophaga sp	0.13± 0.12	–
Mytilus edulis	13.75± 8.21	0.715± 0.427
Xenostrobus pulex		
Crassostrea sp	0.63± 0.37	
Venerupis galactites		
Hiatella australis		
TOTALS	596.79±22.37	353.418±41.013
Number of species	15	

MOLLUSCS COLLECTED ON INTERTIDAL BEACHROCK PLATFORMS IN THE PERTH METROPOLITAN AREA (cont'd)

COTTESLOE 1986

	INSHORE PLATFORM		*SARGASSUM*	
	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e
CLASS POLYPLACOPHORA				
Ischnochiton lineolata	0.25± 0.25	-		
Ischnochiton torri				
Ischnochiton virgatus	9.75± 2.15	0.039±0.009	2.50± 1.68	0.010±0.007
Acanthochitona bednalli	0.88± 0.52	-		
Acanthochitona cf *johnstoni*	2.26± 1.00	-		
Acanthochitona cf *lachrymosus*				
Acanthochitona sp 1	0.88± 0.61	-	0.25± 0.25	-
Acanthochitona sp 2				
Clavarizona hirtosa				
Onithochiton occidentalis				
CLASS GASTROPODA				
Haliotis roei				
Amblychilepas nigrita	0.63± 0.42	0.008±0.005	3.00± 1.40	0.036±0.018
Macroschisma producta	6.25± 4.94	0.656±0.519	0.13± 0.12	0.014±0.013
Patella peronii				
Patelloida alticostata				
Patelloida nigrosulcata				
Notogibbula preissiana	5.75± 3.11	0.069±0.037	10.13± 3.61	0.122±0.043
Prothalotia pulcherrimus	14.13± 5.91	0.071±0.035	185.50± 91.80	0.928±0.459
Turbo torquatus	0.50± 0.27	0.040±0.022	2.63± 0.53	0.210±0.042
Serpulorbis sipho	0.38± 0.18	-		
Vermetid sp				
Triphorid sp			0.13± 0.12	-

MOLLUSCS COLLECTED ON INTERTIDAL BEACHROCK PLATFORMS IN THE PERTH METROPOLITAN AREA (cont'd)

COTTESLOE 1986

	INSHORE PLATFORM		*SARGASSUM*	
	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e
Epitonium godfreyi	0.13± 0.12	-		
Epitonium jukesiana			0.13± 0.12	-
Epitonium perplexa	2.13± 0.35	-		
Opalia granosa	0.50± 0.50	-	0.88± 0.52	-
Sabia conica	5.13± 3.02	0.051±0.030	18.00± 6.67	0.180±0.667
Proterato denticulata			0.13± 0.12	-
Charonia lampas rubicunda			0.13± 0.12	0.520±0.480
Bedeva paivae	1.63± 0.68	0.051±0.002		
Muricopsis planiliratus	0.13± 0.12	0.004±0.004		
Croonia avellana	0.25± 0.16	-		
Morula sp				
Thais orbita	0.38± 0.18	0.684±0.324	1.50± 0.63	2.700±1.134
Dentimitrella lincolnensis	9.00± 4.31	0.072±0.034	33.75± 9.67	0.270±0.774
Dentimitrella menkeana			0.25± 0.16	0.002±0.001
Pyrene bidentata	1.38± 0.46	0.040±0.013	1.00± 0.65	0.029±0.019
Cominella tasmanica	0.13± 0.12	-		
Microcolus dunkeri	0.13± 0.12	-		
Bulla quoyii	1.63± 0.62	0.090±0.034	0.25± 0.16	0.014±0.009
Pyramidellid sp	0.13± 0.12	-	0.38± 0.26	-
Aplysia oculifera			0.25± 0.25	0.235±0.235
Juliid sp			0.13± 0.12	-
Oxynoe viridis			0.25± 0.25	-
Cylindrobulla fischeri			1.63± 1.49	-
Elysia australis			0.13± 0.12	-
Elysia sp			0.13± 0.12	-
Siphonaria luzonica	3.50± 3.36	0.070±0.067		
CLASS BIVALVIA				
Brachidontes ustulatus	367.25±234.33	6.610±4.218	183.38±355.24	3.301±6.394

MOLLUSCS COLLECTED ON INTERTIDAL BEACHROCK PLATFORMS IN THE PERTH METROPOLITAN AREA (cont'd)

COTTESLOE 1986

	INSHORE PLATFORM		*SARGASSUM*	
	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e
Modiolus areolatus	0.25± 0.16	–		
Musculus cf *imus*			0.13± 0.12	–
Mytilus edulis	7.50± 3.79	0.390±0.197	26.88± 13.27	1.398±0.690
Xenostrobus pulex	2.50± 2.36	0.045±0.045	2.00± 1.59	0.016±0.013
Pinctada fucata	0.13± 0.12	–	0.13± 0.12	–
Anomia sp	0.25± 0.25	–	1.50± 0.71	–
Crassostrea sp				
Venerupis exotica			0.13± 0.12	0.006±0.006
Venerupis galactites	2.26± 1.11	0.108±0.053		
Irus crenata	0.13± 0.12	–		
TOTALS	448.10±233.59	9.098±4.590	477.34±137.64	9.991±2.726
Number of species	34		32	

MOLLUSCS COLLECTED ON INTERTIDAL BEACHROCK PLATFORMS IN THE PERTH METROPOLITAN AREA (cont'd)

	COTTESLOE 1986			
	OUTER *SARGASSUM*		*ECKLONIA*	
	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e
CLASS POLYPLACOPHORA				
Ischnochiton lineolata				
Ischnochiton torri	0.13± 0.12	–		
Ischnochiton virgatus				
Acanthochitona bednalli				
Acanthochitona cf *johnstoni*			0.13± 0.12	–
Acanthochitona cf *lachrymosus*	0.13± 0.12	–		
Acanthochitona sp 1				
Acanthochitona sp 2				
Clavarizona hirtosa	0.50± 0.50	0.560± 0.560		
Onithochiton occidentalis	0.13± 0.12	0.142± 0.131		
CLASS GASTROPODA				
Haliotis roei	3.25± 1.61	25.318±12.542	3.25± 1.26	25.318±9.815
Amblychilepas nigrata				
Macroschisma producta				
Patella peronii	0.13± 0.12	0.006± 0.005		
Patelloida alticostata	2.88± 2.20	0.348± 0.266	13.25±12.82	1.603±1.551
Patelloida nigrosulcata	1.88± 0.83	0.263± 0.116	2.25± 0.98	0.315±0.137
Notogibbula preissiana	0.88± 0.29	0.011± 0.003	0.63± 0.62	0.008±0.007
Prothalotia pulcherrimus	115.13±55.91	0.518± 0.280	6.13± 2.12	0.031±0.011
Turbo torquatus	3.25± 1.78	0.260± 0.142	0.25± 0.16	0.020±0.013
Serpulorbis sipho				
Vermetid sp	0.25± 0.16	–		
Triphorid sp				

MOLLUSCS COLLECTED ON INTERTIDAL BEACHROCK PLATFORMS IN THE PERTH METROPOLITAN AREA (cont'd)

	COTTESLOE 1986			
	OUTER *SARGASSUM*		*ECKLONIA*	
	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e
Epitonium godfreyi				
Epitonium jukesiana	0.13± 0.12	–		
Epitonium perplexa				
Opalia granosa				
Sabia conica	20.00± 7.25	0.200± 0.073	9.13± 2.84	0.091±0.028
Proterato denticulata				
Charonia lampas rubicunda				
Bedeva paivae				
Muricopsis planiliratus				
Cronia avellana				
Morula sp	0.13± 0.12	0.003± 0.003		
Thais orbita	9.13± 2.12	16.434± 3.816	2.38± 0.60	4.284±1.080
Dentimitrella lincolnensis	8.38± 2.29	0.067± 0.018	0.13± 0.12	0.001±0.001
Dentimitrella menkeana				
Pyrene bidentata	0.13± 0.12	0.004± 0.003		
Cominella tasmanica				
Microcolus dunkeri				
Bulla quoyii				
Pyramidellid sp				
Aplysia oculifera			0.13± 0.12	0.122±0.113
Juliid sp				
Oxynoe viridis				
Cyliindrobulla fischeri				
Elysia australis				
Elysia sp				
Siphonaria luzonica				

MOLLUSCS COLLECTED ON INTERTIDAL BEACHROCK PLATFORMS IN THE PERTH METROPOLITAN AREA (cont'd)

COTTESLOE 1986

	OUTER *SARGASSUM*		*ECKLONIA*	
	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e
CLASS BIVALVIA				
Brachidontes ustulatus	271.25±73.13	4.883± 1.316	225.13±88.28	4.052±1.589
Modiolus aerolatus	0.25± 0.25	–		
Musculus cf *imus*				
Mytilus edulis	89.63±30.36	4.661± 1.579	12.38± 9.07	0.644±0.472
Xenostrobus pulex	0.25± 0.25	0.005± 0.005		
Pinctada fucata				
Anomia sp				
Crassostrea sp	11.88± 2.57	–	1.63± 0.60	–
Venerupis exotica				
Venerupis galactites			0.38± 0.37	0.018±0.018
Irus crenata				
TOTALS	539.70±95.52	53.683±13.287	277.18±82.26	36.507±9.665
Number of species	23		15	

SUMMARY OF INFORMATION ON MOLLUSC SPECIES COLLECTED ON THREE INTERTIDAL PLATFORMS IN THE PERTH METROPOLITAN AREA IN JANUARY 1986

W Waterman; T Trigg I; C Cottesloe; TROP tropical; TEMP temperate; END endemic; HERB herbivorous; CARN carnivorous; FILT filter feeder; UNK unknown.

SPECIES	PLATFORM	MAX SIZE (cm)	DISTRIBUTION	FEEDING TYPE
CLASS POLYPLACOPHORA				
Family Ischnochitonidae:				
Ischnochiton lineolatus (Blainville, 1825)	C	4	TEMP	HERB
Ischnochiton torri Iredale and May, 1916	C	4	TEMP	HERB
Ischnochiton virgatus Reeve, 1847	W T C	1	TEMP	HERB
Ischnochiton sp	W	?	?	HERB
Family Acanthochitonidae:				
Acanthochitona bednalli (Pilsbury, 1894)	T C	1	TEMP	HERB
Acanthochitona cf *johnstoni* Ashby, 1923	W T C	1	TEMP	HERB
Acanthochitona cf *lachrymosus* (May & Torr, 1894)	T C	3	TEMP	HERB
Acanthochitona sp 1	C	?	?	HERB
Acanthochitona sp 2	C	?	?	HERB
Family Chitonidae:				
Clavarizona hirtosa (Blainville, 1825)	W T C	6	END	HERB
Onithochiton occidentalis (Gould, 1846)	W T C	5	TEMP	HERB
CLASS GASTROPODA				
SUBCLASS PROSOBRANCHIA				
Order Archeogastropoda				
Family Haliotidae:				
Haliotis roei Gray, 1827	W T C	12	TEMP	HERB
Family Fissurellidae:				
Amblychilepas nigrita (Sowerby, 1834)	W T C	2	TEMP	HERB
Macroschisma producta A Adams, 1850	W T C	2	TEMP	HERB
Family Patellidae:				
Patella peronii Blainville, 1825	W T C	3	TEMP	HERB
Family Acmaeidae:				
Collisella onychitis (Menke, 1843)	W T	2	TEMP	HERB
Patelloida alticostata (Angas, 1865)	W T C	5	TEMP	HERB
Patelloida nigrosulcata (Reeve, 1825)	W T C	3	END	HERB
Family Trochidae:				
Notogibbula preissiana (Risso, 1826)	W T C	1	TEMP	HERB
Prothalotia lehmanni (Menke, 1843)	W T	1	TEMP	HERB
Prothalotia pulcherrimus (Wood, 1828)	W T C	1	TEMP	HERB
Thalotia chlorostoma (Menke, 1843)	T	2	TEMP	HERB

SUMMARY OF INFORMATION ON MOLLUSC SPECIES COLLECTED ON THREE INTERTIDAL PLATFORMS IN THE PERTH METROPOLITAN AREA IN JANUARY 1986 (cont'd)

W Waterman; T Trigg I; C Cottesloe; TROP tropical; TEMP temperate; END endemic; HERB herbivorous; CARN carnivorous; FILT filter feeder; UNK unknown.

SPECIES	PLAT- FORM	MAX SIZE (cm)	DISTRIB- UTION	FEEDING TYPE
Family Turbinidae:				
Turbo torquatusu (Gmelin, 1790)	W T C	9	TEMP	HERB
Order Mesogastropoda				
Family Vermetidae:				
Serpulorbis sipho (Lamarck, 1818)	T C	15	TEMP	FILT
Vermetid sp	C	?	?	FILT
Family Triphoridae:				
Triphorid sp	C	?	?	HERB
Family Epitoniidae:				
Epitonium godfreyi Cotton, 1938	C	4	TEMP	CARN
Epitonium jukesiana Forbes, 1852	W C	3	TEMP	CARN
Epitonium perplexa Pease, 1860	W C	4	TROP	CARN
Opalia granosa (Quoy and Gaimard, 1834)	T	3	TEMP	CARN
Family Hipponicidae:				
Sabia conica (Schumacher, 1817)	W T C	2	TROP	FILT
Family Eratoidae:				
Proterato denticulata (Pritchard and Gatliff 1900)	C	1	TEMP	HERB
Family Cypraeidae:				
Cypraea caputserpentis Linnaeus, 1758	T	4	TROP	HERB
Family Cymatiidae:				
Charonia lampas rubicunda Perry, 1811	C	15	TEMP	CARN
Order Neogastropoda				
Family Muricidae:				
Bedeva paivae (Crosse, 1864)	W C	3	TEMP	CARN
Muricopsis planiliratus (Reeve, 1845)	W C	2	TEMP	CARN
Family Thaididae:				
Cronia avellana (Reeve, 1846)	C	4	END	CARN
Morula sp	C		?	CARN
Thais orbita (Gmelin, 1791)	W T C	8	TEMP	CARN

APPENDIX 2

SUMMARY OF INFORMATION ON MOLLUSC SPECIES COLLECTED ON THREE INTERTIDAL PLATFORMS IN THE PERTH METROPOLITAN AREA IN JANUARY 1986 (cont'd)

W Waterman; T Trigg I; C Cottesloe; TROP tropical; TEMP temperate; END endemic; HERB herbivorous; CARN carnivorous; FILT filter feeder; UNK unknown.

SPECIES	PLATFORM	MAX SIZE (cm)	DISTRIBUTION	FEEDING TYPE
Family Columbellidae:				
Dentimitrella lincolnensis (Reeve, 1859)	W T C	1	TEMP	UNK
Dentimitrella menkeana (Reeve, 1859)	T C	1	TEMP	UNK
Pyrene bidentata (Menke 1843)	W T C	1	END	UNK
Family Buccinidae:				
Cominela tasmanica Tenison-Woods, 1876	C	3	TEMP	CARN
Family Fasciolariidae:				
Microcolus dunkeri (Jonas, 1846)	C	1	TEMP	CARN
Family Costellariidae:				
Vexillum marrowi (Cernohorsky, 1973)	W T	1	END	CARN
SUBCLASS OPISTHOBRANCHIA				
Family Bullidae:				
Bulla quoyii Gray, 1863	W T C	5	TEMP	HERB
Family Pyramidellidae:				
Pyramidellid sp	C	?	?	CARN
Family Aplysiidae:				
Aplysia oculifera Adams and Reeve, 1850	W C	12	TROP	HERB
Family Juliidae:				
Juliid sp	C	1	?	UNK
Family Oxynoeidae:				
Oxynoe viridis Pease, 1861	C	1	TEMP	HERB
Family Cylindrobullidae:				
Cylindrobulla fischeri A Adams and Angas, 1864	C	1	TEMP	HERB
Family Elysiidae:				
Elysia australis (Quoy and Gaimard, 1833)	C	1	TEMP	HERB
Elysia sp	C	5	END	HERB
SUBCLASS PULMONATA				
Family Siphonariidae:				
Siphonaria luzonica Reeve, 1856	C	2	TEMP	HERB

SUMMARY OF INFORMATION ON MOLLUSC SPECIES COLLECTED ON THREE INTERTIDAL PLATFORMS IN THE PERTH METROPOLITAN AREA IN JANUARY 1986 (cont'd)

W Waterman; T Trigg I; C Cottesloe; TROP tropical; TEMP temperate; END endemic; HERB herbivorous; CARN carnivorous; FILT filter feeder; UNK unknown.

SPECIES	PLATFORM	MAX SIZE (cm)	DISTRIBUTION	FEEDING TYPE
CLASS BIVALVIA				
Family Mytilidae:				
Brachidontes ustulatus (Lamarck, 1819)	W T C	4	TEMP	FILT
Lithophaga sp	T	?	?	FILT
Modiolus areolatus Gould, 1850	C	5	TEMP	FILT
Musculus cf *imus* Bartsch, 1915	C	?	?	FILT
Mytilus edulis Linnaeus, 1758	T C	11	TEMP	FILT
Xenostrobus pulex Lamarck, 1819	W T C	3	TEMP	FILT
Family Pteriidae:				
Pinctada fucata (Gould, 1851)	C	2	TROP	FILT
Family Anomiidae:				
Anomia sp	W C	?	?	FILT
Family Ostreidae:				
Crassostrea sp	W T C	?	?	FILT
Family Veneridae:				
Irus crenata (Lamarck, 1818)	C	4	TEMP	FILT
Venerupis exotica Lamarck, 1818	C	2	TEMP	FILT
Venerupis galactites (Lamarck, 1818)	T C	2	TEMP	FILT
Family Hiatellidae:				
Hiatella australis (Lamarck, 1818)	T	5	TEMP	FILT

APPENDIX 3

ECHINODERMS COLLECTED ON INTERTIDAL BEACHROCK PLATFORMS IN THE PERTH METROPOLITAN AREA

WATERMAN 1986

	INSHORE PLATFORM		*SARGASSUM ZONE*	
	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e
CLASS ASTEROIDEA				
Patiriella gunni	0.88±0.48	0.743±0.405	86.88±11.62	73.327± 9.807
CLASS ECHINOIDEA				
Holopneustes porosissimus			0.25± 0.16	0.507± 0.324
Heliocidaris erythrogramma			1.00± 0.46	0.089± 0.041
CLASS HOLOTHUROIDEA				
Psolidium sp aff *nigrescens*	0.38±0.26	0.107±0.073	55.88±12.04	15.758± 3.395
TOTALS	1.26±0.67	0.085±0.454	144.01±15.95	89.681±10.163
Number of species	2		4	

	BARE ZONE	
	DENSITY (No/m^2) x ± 1 s e	BIOMASS (g/m^2) x ± 1 s e
CLASS ASTEROIDEA		
Patiriella gunni	0.25±0.25	0.211±0.211
CLASS ECHINOIDEA		
Holopneustes porosissimus		
Heliocidaris erythrogramma		
CLASS HOLOTHUROIDEA		
Psolidium sp aff *nigrescens*		
TOTALS	0.25±0.25	0.211±0.211
Number of species	1	

ECHINODERMS COLLECTED ON INTERTIDAL BEACHROCK PLATFORMS IN THE PERTH METROPOLITAN AREA (cont'd)

TRIGG 1986

	INSHORE PLATFORM		*SARGASSUM ZONE*	
	DENSITY (No/m^2) x ± 1 s e	BIOMASS (g/m^2) x ± 1 s e	DENSITY (No/m^2) x ± 1 s e	BIOMASS (g/m^2) x ± 1 s e
CLASS ASTEROIDEA				
Patiriella gunni	21.88±14.70	18.467±12.407	22.87±7.94	19.302±6.702
Coscinasterias calamaria	0.25± 0.16	0.113± 0.072	0.13±0.12	0.059±0.05
CLASS OPHIUROIDEA				
sp 1	0.13± 0.12	-		
CLASS HOLOTHUROIDEA				
Psolidium sp aff *nigrescens*	22.75±15.67	6.416± 4.419		
TOTALS	45.01±30.06	24.996±16.688	23.00±7.93	19.361±6.695
Number of species	4		2	

	BARE ZONE	
	DENSITY (No/m^2) x ± 1 s e	BIOMASS (g/m^2) x ± 1 s e
CLASS ASTEROIDEA		
Patiriella gunni	0.13±0.12	0.110±0.105
Coscinasterias calamaria		
CLASS OPHIUROIDEA		
sp 1		
CLASS HOLOTHUROIDEA		
Psolidium sp aff *nigrescens*		
TOTALS	0.13±0.12	0.110±0.108
Number of species	1	

APPENDIX 3

ECHINODERMS COLLECTED ON INTERTIDAL BEACHROCK PLATFORMS IN THE PERTH METROPOLITAN AREA (cont'd)

COTTESLOE 1986

	INSHORE PLATFORM		*INNER SARGASSUM*	
	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e
CLASS ASTEROIDEA				
Patiriella gunni	2.00±0.91	1.688±0.768	17.75±4.19	14.981±3.958
Coscinasterias calamaria	0.50±0.19	0.226±0.086	1.00±0.27	0.452±0.122
CLASS ECHINOIDEA				
Holopneustes porosissimus	0.13±0.12	0.263±0.243	0.25±0.16	0.507±0.324
Nudechinus scotiopremnus	0.13±0.12	0.012±0.011		
Heliocidaris erythrogramma				
CLASS HOLOTHUROIDEA				
Psolidium sp aff *nigrescens*	8.63±5.27	2.434±1.486	4.13±2.11	1.165±0.595
TOTALS	11.39±5.36	4.623±1.798	23.13±5.50	17.105±4.157
Number of species	5		4	

	OUTER *SARGASSUM*		*ECKLONIA*	
	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e	DENSITY No/m^2 x ± 1 s e	BIOMASS g/m^2 x ± 1 s e
CLASS ASTEROIDEA				
Patiriella gunni			1.63±0.50	1.376±0.422
Coscinasterias calameria			2.00±0.71	0.904±0.321
CLASS ECHINOIDEA				
Holopneustes porosissimus			1.25±0.62	2.533±1.256
Nudechinus scotiopremnus				
Heliocidaris erythrogranma			0.13±0.12	0.012±0.011
CLASS HOLOTHUROIDEA				
Psolidium sp aff *nigrescens*	0.25±0.25	0.07 ±0.071	0.13±0.12	0.037±0.034
TOTALS	0.25±0.25	0.071±0.071	5.14±1.23	4.862±1.410
Number of species	1		5	

SUMMARY OF INFORMATION ON ECHINODERM SPECIES COLLECTED ON THREE INTERTIDAL PLATFORMS IN THE PERTH METROPOLITAN AREA IN JANUARY 1986

W Waterman; T Trigg I; C Cottesloe; TROP tropical; TEMP temperate; END endemic; HERB herbivorous; CARN carnivorous; OMN Omnivorous; DET detrital feeder; UNK unknown.

SPECIES	REEF	MAX SIZE (CM)	DISTRIB-UTION	FEEDING TYPE
CLASS ASTEROIDEA				
Order Spinulosa				
Family Asterinidae				
Patiriella gunni (Gray, 1840)	W T C	8	TEMP	OMN
Order Forcipulata				
Family Asteriidae				
Coscinasterias calamaria (Gray, 1840)	T C	8	TEMP	CARN
CLASS OPHIUROIDEA				
sp 1	T	2	?	DET
CLASS ECHINOIDEA				
Order Centrechinoidea				
Family Temnopleuridae				
Holopneustes porosissimus Agassiz and Desor, 1846	W C	5	TEMP	HERB
Family Echinidae				
Nudechinus scotiopremnus H L Clark, 1912	C	3	TROP	HERB
Family Strongylocentrotidae				
Heliocidaris erythrogramma (Valenciennes, 1846)	W C	4	TEMP	HERB
CLASS HOLOTHUROIDEA				
Psolidium sp aff *nigrescens* 5	W T C	6	?	DET

POPULATION CHANGES, DEDUCED FROM ANECDOTAL INFORMATION, OF CERTAIN MOLLUSCS, CRUSTACEANS AND FISH IN THE MARMION MARINE PARK

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Abstract

Trends from the 1930's to the present are presented and discussed for certain animal populations in the area now proclaimed as the Marmion Marine Park. This report is based on anecdotal information as fisheries data for the specific area are mostly quite recent.

Twenty-one amateur anglers, 16 amateur divers, two professional fishermen and two professional divers were interviewed in 1985. Based on their recollections, and some detailed notes, it appears that catch rates and mean sizes of abalone, cowries, rock lobsters, dhufish, blue groper, baldchin groper, some other reef fish, and some demersal fish have declined in the area since the 1950's. The period of most rapid decline seems to have been about 1966-1985, which coincides with the period of rapid development of the coastal suburbs north of Perth and also markedly improved access to the coast and waters of the proposed park area. Decline in mean size of animals seen in a natural, effectively unfished population is an expected consequence of fishing activity. Whether decreased catch rates indicate decreased population size is much more difficult to determine in the absence of scientific fisheries data on total annual catch from the entire stock. For example, within the Marmion Marine Park, even with stable local stocks, decreased catch rates of some species may be a simple consequence of the greatly increased numbers of people fishing in the area over the past several decades.

A brief history is given of population increases and coastal developments in the metropolitan area northwest of Perth. This is discussed in the context of probable changes in fishing pressures on the area of the Marmion Marine Park in the period 1900-2000.

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APPENDIX

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1. INTRODUCTION

While there can be exceptions, a normally-expected consequence of fishing is that, following the initiation of fishing pressure, there is a decrease in the mean size of adult or legal-sized animals in the fished population. Properly managed fishing pressure, however, increases the maximum sustainable yield of the population, as large, old individuals, consuming food resources with little consequent increase in body weight, are replaced with smaller, faster-growing, and often more numerous, young individuals. The main objective of fisheries resource management is to ensure that any particular stock is not over-fished, to the extent that the caught fish are not being replaced by recruitment and immigration from other stocks of the population. Clearly, however, that requires assessment of the stocks concerned and of the fishing pressures on them.

One aim of this investigation was to examine the changes in fishing pressures that have occurred in the area which has now been proclaimed as the Marmion Marine Park. The other aim was to consider the nature of changes in local stocks of selected, commonly-fished or commonly-collected animal species within the area. Decisions could then be made by the park's managers knowing that these species were being fished at probably either acceptable, sustainable levels, or unacceptable, unsustainable levels. It was clear from the onset of the study, however, that scientific fisheries data for the Marmion Marine Park area were either quite recent, dating from about 1965, or included the Marmion Marine Park in much greater areas which precluded specific interpretation for our purposes. Hence, it was necessary to resort to anecdotal information gathered from people who had fished or collected in the area.

2. METHODS

2.1 INTERVIEWING TECHNIQUE

INDIVIDUAL ANGLERS AND DIVERS

Twenty-one amateur anglers, 16 amateur divers, two professional fishermen and two professional divers were interviewed in 1985. All of these had been active in the area of the now proclaimed marine park for at least about 20 years. Some of the anglers had been fishing for much longer, up to 50 years (since about 1935). These interviewees were found by approaching local fishing tackle shops, diving shops, angling clubs and diving clubs. Most interviews were done in person or, if this was not convenient for the interviewee, by telephone.

The following questions were posed:

1. How long have you been angling/skindiving/collecting in the general area of the (proposed) Marmion Marine Park? (Only those active for at least about 20 years were interviewed.)

2. Where did you fish, skindive or collect? (A map was presented to those interviewed in person, to avoid location discrepancies.)

3. How often did you fish, skindive or collect? (Only information from those who fished regularly, ranging from three times per week to several times per year, was used in this report.)

4. What method did you use to catch or collect?

5. Which species did you catch or collect? (All interviewees used common names to identify the species caught or collected. If there were any identification problems with fish, Hutchins & Thompson (1983) was consulted.)

6. What was the average number of each species caught or collected per trip? (Although skindivers were asked for the average number of each species caught, sometimes they also referred to the average number of animals seen. This is mentioned where appropriate.)

7. What was the average and maximum sizes of each species (as weights)?

8. Have you noticed any trends in the numbers of fish caught, or of the average sizes of the species; if so, when did the changes occur?

9. What do you know about past vehicle and boat access to the area of the proposed park, and of the old 'beach shack' developments in the area?

DIVING CLUBS

The Presidents of three metropolitan diving groups, the Pirates Club, the Australia Underwater Federation (AUF) and the Underwater Skindivers and Fishermens Association (USFA), were interviewed regarding the activities of the clubs, and where members dived in the proposed park area.

2.2 INFORMATION RECORDED

All relevant information, from the interviewees, was recorded. If the answer to the question was not consistent with the set format (ie length of fish given instead of weight for determining fish size), the reply was still recorded. Information collected from each interviewee is archived on Environmental Protection Authority files.

A brief history of the Marmion Marine Park area was compiled using information gathered from the anglers and skindivers interviewed, and from Newell & Weller (1980).

3. RESULTS

3.1 HISTORY OF THE BEACH SHACKS

Between the early 1900's and the 1960's, beach shacks and boat sheds were built on the foreshores at Trigg, Waterman, Marmion, Hillarys, Mullaloo Point and Whitford beaches (Figures 1-3). Most of the shacks were timber-framed, covered in asbestos sheets or weatherboard, with iron doors, iron shutters, and corrugated iron roofs. They were usually used as holiday shacks, although some were owned by professional fishermen who lived there during the fishing seasons. Most shack-owners also had small boats, which at that time were clinker-construction. Before the Second World War, most boats were rowed, although some had inboard motors. After this, outboard motors became increasingly common. People built their own shacks and paid a nominal yearly rent to the Government; for example, in 1946, the rent was two pounds per year for a shack at Marmion. They were squatters, however, and as they did not own the land the shacks could be removed at any time.

Trigg Beach: six boat sheds/shacks were built on Trigg Beach around the turn of the century. Four of the shacks were removed in 1967 and the last two shacks in 1969.

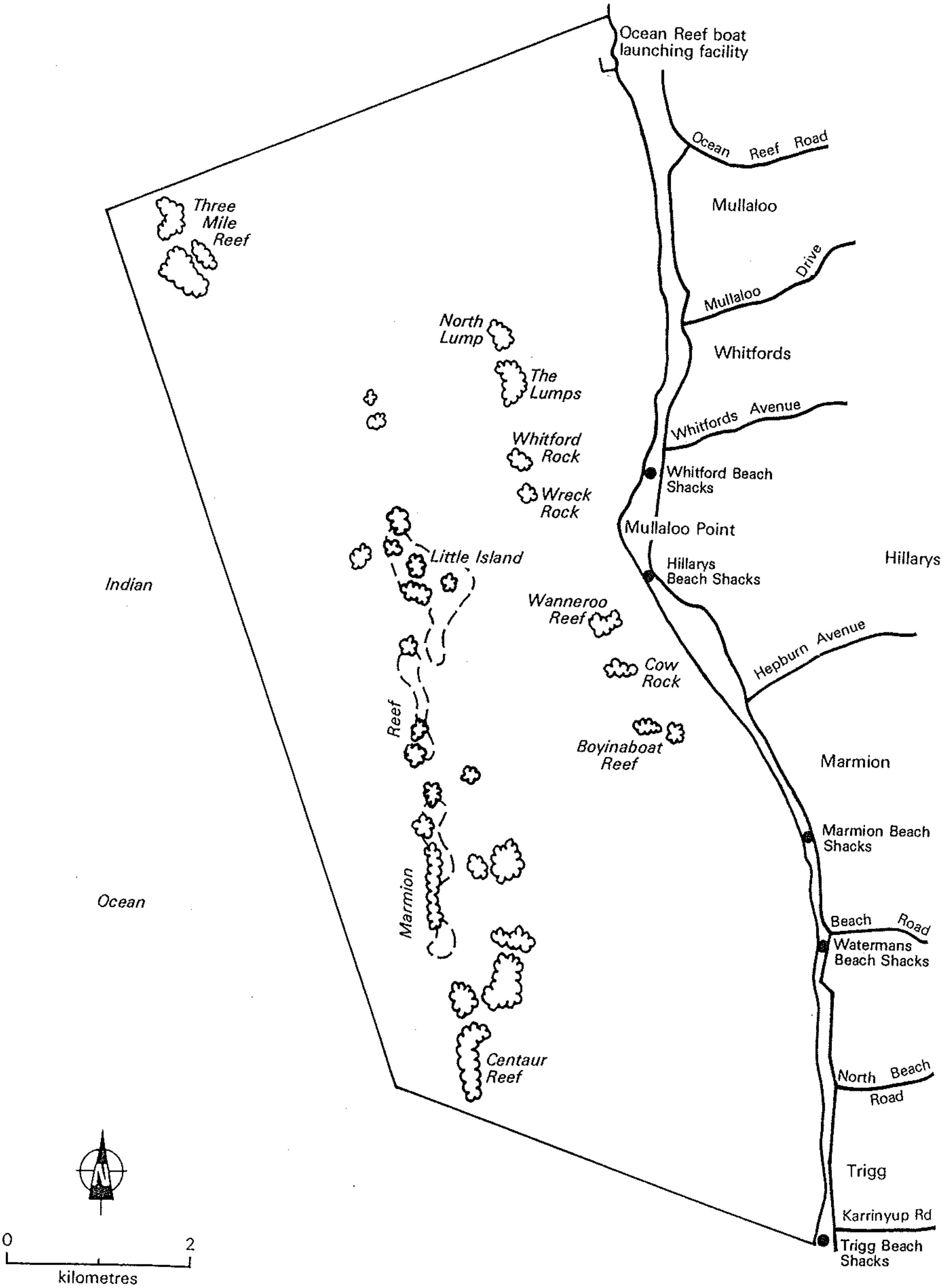

Figure 1. Location of beach shacks and boat sheds at Trigg, Waterman, Marmion, Hillarys, Mullaloo Point (= Pinnaroo Point) and Whitford beaches. Boundary of the Marmion Marine Park is shown as in the System Six report (Environmental Protection Authority 1983).

Figure 2. Beach shacks and boat sheds at Marmion Beach, 1953. (Photograph: courtesy Marmion Angling and Aquatic Club.)

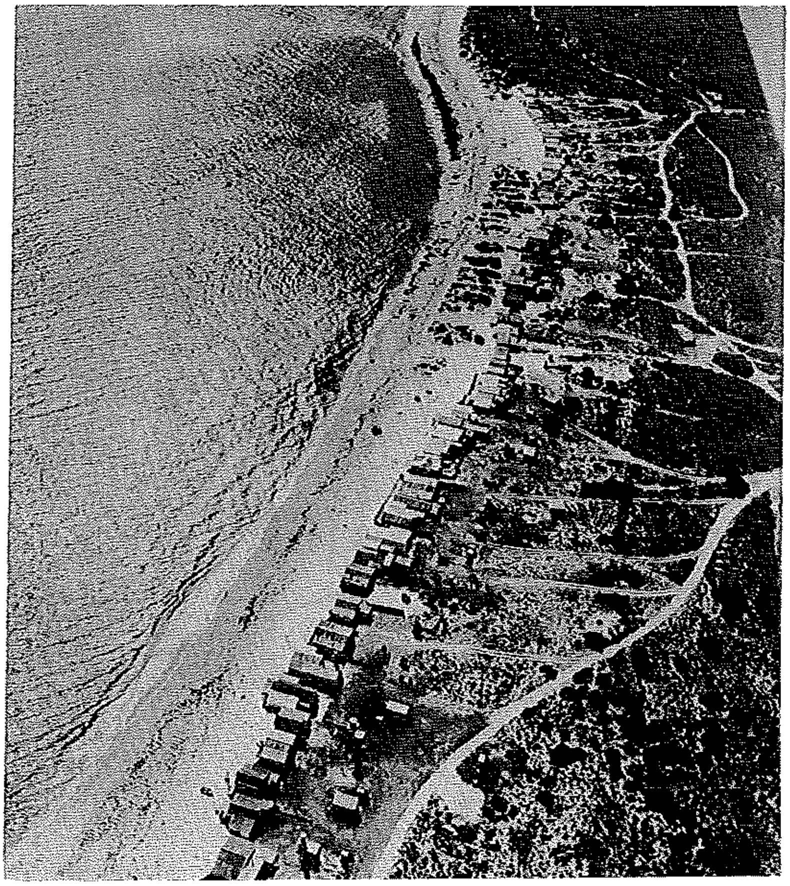

Figure 3. Aerial photograph of beach shacks on Whitford Beach in the late 1950's. (Photograph: courtesy "The West Australian" newspaper.)

Waterman Beach: seven boat sheds were erected in the early 1900's and removed in 1956.

Marmion Beach: the first shack at Marmion was built of stone in the early 1900's; most, however, were constructed of timber, asbestos and iron sheeting (Figure 2). There were 82 shacks in total, about 6 x 5 m in size, built on both the sandy and rocky foreshore. They were removed in 1954 for the construction of the Marmion Angling and Aquatic Club (MAAC).

Hillarys Beach: twenty shacks were built on Hillarys Beach from the early 1900's to about the 1950's. A storm on 8 July, 1964, washed away the shacks.

South of Mullaloo Point: the shacks here were called the Pinnaroo Point beach shacks. Following the storm that washed away the Hillarys beach shacks, in 1964, 20 shacks were erected here. They were demolished in 1975.

Whitford Beach: the first shack at Whitford Beach was erected in the early 1920's. By July 1972, when they were demolished, there were 72 shacks which extended south along Mullaloo Beach to Mullaloo Point. A syndicate of shack owners bought the land behind the shacks, which allowed private access for all shack owners.

3.2 HISTORY OF BEACH ACCESS

In the 1940's, a bitumen coastal road extended from Fremantle to North Beach. In the 1950's this coast road extended north to Sorrento. To drive to the coast north of Sorrento, one had to travel either along a track inland from Sorrento, requiring a four-wheeled drive vehicle, or inland along Wanneroo road and then follow sand or gravel tracks (many of them through pastoral land) which led to the beaches.

Prior to the 1970's, there were no concrete or bitumen boat ramps, except for one at Marmion built in the late 1950's for the Marmion Angling and Aquatic Club. Anglers and skindivers launched their dinghies, sometimes using rubber rollers, wherever the access roads met the beach. By the early 1970's, the West Coast Highway had extended to Mullaloo and a launching ramp at Mullaloo Point had been constructed of compressed sandstone rubble. In 1978, the Ocean Reef boat launching facility was constructed, as an extension of the original groynes flanking the Beenyup Sewage Treatment Plant wastewater outfall pipe (Smith 1986), providing all-weather shelter for small vessels and eight, concrete, small-boat launching ramps. Hillarys Boat Harbour was constructed in 1986, providing potential permanent mooring facilities for 1 000 vessels up to 25 m in length, and four (eventually six) concrete launching ramps for trailer-mounted small boats.

Section 3.5 gives further details of the development of the West Coast Highway, and of major roads connecting to it.

3.3 SUMMARY OF ANGLERS' AND DIVERS' CATCHES

Jones (1986) noted that amateur anglers catch up to about 40 species of fish in the marine park area. Garfish, western school whiting, tailor and Australian herring form a large part of amateur angler catches, and he lists 14 other species which are also commonly taken. This summary, however, only covers the species discussed by the interviewees.

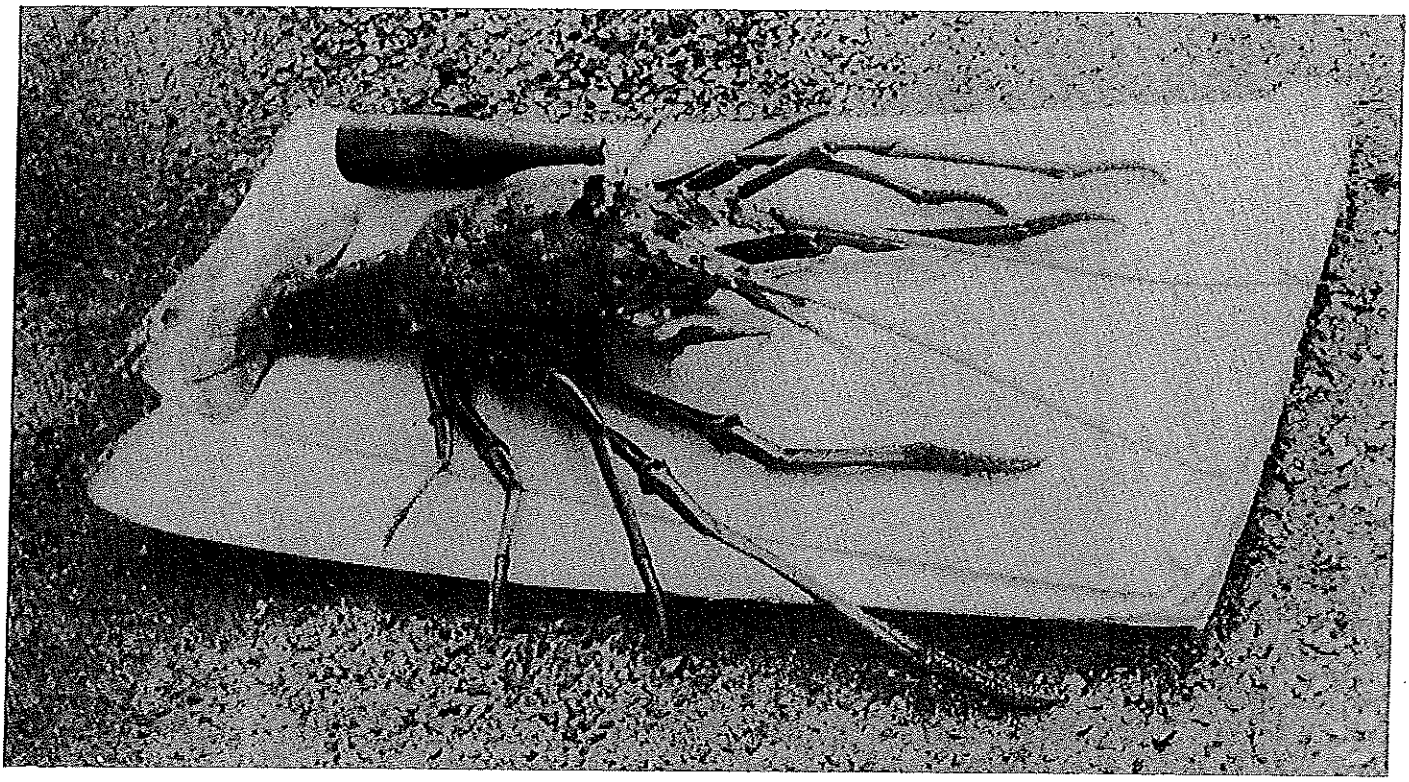

Figure 4. A 5.1 kg western rock lobster speared 15-20 m from the beach at Grannies Pool, Trigg, in the early 1950's. Note the standard beer bottle, next to the rock lobster, as an indication of size. (Photograph: courtesy W Sharpe-Smith.)

Anecdotal information was gathered on 33 species: six molluscs, one crustacean, ten reef fish, seven demersal fish and nine pelagic fish. A list of all species caught or collected by interviewees is given in Appendix 1, and some of the catches from the 1950's are shown in Figures 4 to 9.

The 14 species most commonly caught or collected, by five or more anglers and divers interviewed, have been discussed in more detail, with the trends in abundance summarised in Table 1. The location of catches has been separated into onshore, nearshore and offshore zones. The onshore zone included the intertidal reef platforms and areas generally accessible to collectors and anglers not using a boat. The nearshore zone was made up of the line of submerged reefs, about 1 km offshore, extending from North Lump to Boyinaboat Reef and surrounding waters. The offshore zone covered the chain of reefs, about 4 km offshore, from Three Mile Reef to Centaur Reef and adjacent waters.

The average number of each species caught or collected, per diving or fishing trip by each individual, was recorded for four time periods; pre-1955, 1956-65, 1966-75 and 1976-85. The numbers were ranked into categories 'abundant', 'common', 'few' and 'none'. The definition of each of these categories varied from one species to another, depending on the population characteristics of the species; for example 'abundant' for abalone meant that a collector could visit an area, collect a bag limit (20 specimens), and see hundreds in the surrounding area. On the other hand, 'abundant' for the cowrie, *Cypraea friendii friendii*, was defined as a catch of eight to ten specimens collected per dive.

Figure 5. Western rock lobsters caught on the onshore reefs at Trigg only a few metres from the shore, about 1956. Sizes ranged from 0.5-3 kg. (Photograph: courtesy J Sue.)

Three species of molluscs reportedly declined in abundance, with the decline being most apparent since the 1960's. Recreational collectors regarded Roe's abalone as generally 'abundant' on the onshore reefs until 1965, 'common' in 1966-1975, and 'few' in 1976-1985. (Nevertheless, a successful prosecution in 1986 indicated that some people could still collect, illegally, hundreds of abalone at one time: see Section 4.2.) The cowrie *Cypraea friendii* was regarded as 'abundant' on nearshore reefs in 1956-1965, and another cowrie *C venusta*, as 'common' (Table 1); by 1976-1985 these were regarded as 'common' or 'few', respectively. Conch and baler sightings have always been infrequent, but there was a suggestion these molluscs had also become rarer in recent years.

Catch rates per individual of the western rock lobster indicated it was considered 'abundant' (= large numbers readily found and taken) until about 1965; by the 1976-1985 period it was considered 'common' on the nearshore and offshore reefs and 'few' on the reefs directly accessible from the shore.

Table 1. Reported changes in catches per individual of the 14 most commonly collected or caught molluscan, crustacean and fish species, pre-1955 to 1985. (Derived from anecdotal information: see text for definitions of 'abundant', 'common' and 'few' for each species.) 'On', 'near' and 'off' refers to onshore, nearshore and offshore reefs.

SPECIES		TIME PERIOD											
		PRE 1955			1956-1965			1966-1975			1976-1985		
		LOCATION											
		ON	NEAR	OFF	ON	NEAR	OFF	ON	NEAR	OFF	ON	NEAR	OFF
Molluscs/crustaceans													
Roe's abalone	w	▓	n	n	▓	░	☐	▒	░	☐	░	░	☐
Cowrie *(C friendii)*	d	n	n	n	n	▓	n	n	▒	░	n	▒	░
Cowrie *(C venusta)*	d	n	n	n	n	░	n	n	▒	▒	n	░	░
Western rock lobster	d	▓	▓	▓	▓	▓	▓	░	▓	▓	░	▒	▒
Reef fish													
West Australian dhufish	d	░	n	▒	░	▒	▒	☐	n	▒	☐	n	░
West Australian dhufish	a	░	n	▒	☐	n	▒	n	n	▒	n	n	░
Banded sweep	d	n	▓	▓	n	▓	▓	n	▓	▓	n	▒	▒
Blue groper	d	▒	▒	▒	▒	n	▒	n	n	▒	☐	░	░
Baldchin groper	d	▒	▒	▒	▒	n	▒	☐	n	▒	n	░	░
Demersal fish													
Gummy shark	a	▒	n	▒	▒	n	▒	☐	n	▒	☐	n	░
Western school whiting	a	n	▓	▓	n	▓	▓	n	▓	▓	n	▓	▓
Pelagic fish													
Southern sea garfish	a	n	▓	▓	n	▓	▓	n	▓	▓	n	▓	▓
Tailor	a	▒	n	▒	▒	▒	▒	▒	▒	▒	░	▒	▒
Skipjack trevally	a	▓	▒	▓	▓	▒	▓	▒	▒	▓	▒	▒	▓
Australian herring	a	░	▓	▓	░	▓	▓	░	▓	▓	░	▓	▓

KEY

▓	'abundant'	☐	'none'	w	- reef walkers
▒	'common'	n	'no information'	d	- divers
░	'few'			a	- anglers/netters

Figure 6. A 34 kg blue groper speared in 1957, approximately 2 km off Whitford Beach. It won the Marlin Trophy (1957) for the biggest fish caught in Australia that year. (Photograph: courtesy W Sharpe-Smith.)

The most marked changes in individual catch rates appears to have occurred in the reef dwelling fish: all ten species discussed by the anglers or divers (Appendix 1) were reported to be scarcer. Three of the four most commonly caught species, West Australian dhufish, blue groper and baldchin groper, categorised as 'abundant' or 'common' on the offshore reefs before 1955, were listed as 'few' by the 1976-1985 period. The other very common reef fish banded sweep, was 'abundant' pre-1955 on nearshore and offshore reefs, and had reportedly declined to 'common' by the 1976-1985 period (Table 1).

Demersal fish also indicated some decline in catch rate per individual for four of the seven listed species (Appendix 1). Most information was collected on the gummy shark which had declined from 'common' pre-1975 to 'few' in 1976-1985 and whiting, which seems to have had a steady catch rate over the years examined and was regarded as consistently abundant (Table 1). Two professional fishermen, who netted yelloweye mullet and sea mullet, noted a decline in their catch rates since the 1970's.

Figure 7. A boat full of mullet (estimated at 500 kg) netted by Dick Leonard and Ernie Shadbolt, between Scarborough and Trigg, in the early 1950's. (Photograph: courtesy M Shadbolt.)

Of the nine pelagic fish species listed (Table 1; Appendix 1), three species showed some decline in catch rates in the 1976-85 period. Reduced catch rates were apparent for bronze whaler shark, tailor and narrow-barred spanish mackerel, and more so in the onshore and nearshore zones than offshore. Of the most commonly caught pelagic fishes, Australian herring, southern sea garfish and skipjack trevally, there was no reported change in catch rates, and they were still considered 'abundant' or 'common' in 1985.

3.3.1 MOLLUSCS AND CRUSTACEANS

3.3.1.1 Roe's abalone *(Haliotis roei)*

(Information from eight divers summarised in Table 1.)

Definitions:

'abundant' - could collect 20 (the 1985 bag limit) in a small area, and could easily see hundreds in the surrounding area.
'common' - needed to go to a few areas to collect 20, but with some searching could find hundreds.
'few' - difficult to collect 20 in one trip.

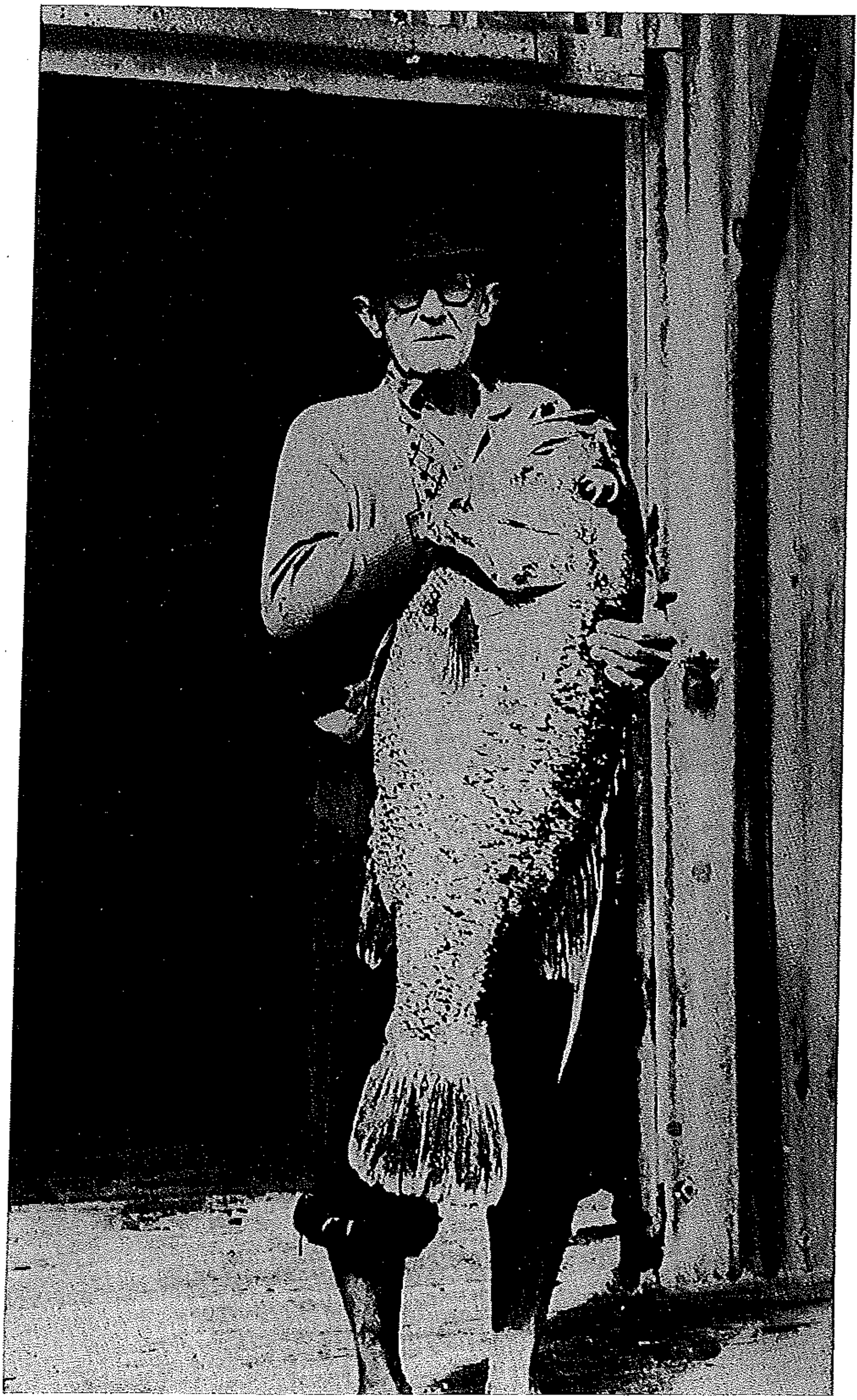

Figure 8. 18 kg dhufish caught by George Kirk near the western boundary of the now proclaimed Marmion Marine Park, in 1953. (Photograph: courtesy of Marmion Angling and Aquatic Club.)

Figure 9. Samson fish caught by Albert Hull in the 1950's. (Photograph: courtesy of Marmion Angling and Aquatic Club.)

The information on abalone was supplied by eight amateur collectors who concentrated their activities on the easily accessible onshore intertidal reef platforms. The abalone that occur on these reefs represent only a small proportion of the total stock in the park (J Penn, personal communication).

Onshore Reefs

Pre-1965: abalone on all onshore platform reefs were considered 'abundant' prior to 1965. Sizes ranged from 20 mm to 100 mm. The most dense abalone concentrations in the study area appeared to be between Trigg Island and Mettams Pool, where they were said to form, at any time, "a carpet" over the reef tops.

1966-1975: it became more difficult for the collectors to find abalone on the onshore reef platforms, but the abalone were still considered 'common'. Collectors could still easily find 20, but had to go to a few locations on one or perhaps two reefs.

1976-1985: the collectors felt that abalone were becoming increasingly scarce, particularly towards the end of 'open seasons', because of the rapidly increasing numbers of amateur collectors involved, and the reportedly excessive (and illegal) numbers of abalone taken by certain putatively amateur collectors. By 1984/85, amateur collectors generally had to visit a few reefs to find 20 abalone.

Decline in abundance was reportedly most obvious between the start and finish of each 'open season'. Amateurs collected mostly from the intertidal parts of the onshore reefs, and professional divers collected mostly from the deeper parts (about 3.5 m depth) of the onshore reefs. While some collectors believed there had been a general, overall decline in the available abalone stock, during 1976-1985, it was acknowledged that natural recruitment seemed to return local depletions of abalone numbers to 'common' levels within a few years.

According to three collectors, the reefs at Trigg were among the most affected, owing to easy access, which had led to considerable and increasing pressure from year-to-year.

Nearshore Reefs

Although abalone could be found on nearshore reefs, the reefs have not been considered worthwhile collection areas because of their small surface area and generally few abalone (information from three divers/collectors).

Offshore Reefs

The divers/collectors interviewed had never found abalone on the offshore reefs.

3.3.1.2 Cowrie *(Cypraea friendii)*

(Information from five divers summarised in Table 1.)

Definitions:

'abundant'- six to 10 per dive.
'common' - one to two per dive.
'few' - one per 10 dives.

There were two viewpoints: two divers suggested that *Cypraea friendii* had always been rare (one per 10 dives) in the area; alternatively, three divers suggested that it had been abundant pre-1965, at a depth of 10 m just west of Whitford Rock, The Lumps and North Lump, that its numbers have declined since 1975, and that by 1985 the species was only 'common'.

3.3.1.3 Cowrie *(Cypraea venusta)*

(Information from five divers summarised in Table 1.)

Definitions:

'abundant'- 35 per dive.
'common' - seven to 12 per dive.
'few' - one to two per dive.

Pre-1975: all four divers during this period collected *Cypraea venusta* from around the nearshore reefs. One diver collected 35 per dive, two days in succession, another two divers collected 12 to seven per dive ('common') and one diver collected only two per dive ('few'). The nearshore reefs (Boyinaboat, Cow Rocks and Wanneroo reef) had the greatest abundance. Divers operating on these nearshore reefs, in the 1956-1965 period, had similar catches.

1976-85: a distinct decline in catch rates of *Cypraea venusta* apparently occurred during this period. There was a decline, from 'abundant' or 'common' to 'few', reported by three divers. A new diver also collected only one to two per dive on the nearshore reefs ('few').

3.3.1.4 Western rock lobster *(Panulirus longipes cygnus)*

(Information from 11 amateur divers summarised in Table 1.)

Definitions:

'abundant' - needed to visit only one ledge to find the 1985 bag limit of eight legal-sized lobsters (carapace length exceeding 76 mm).
'common' - needed to visit many ledges to find the 1985 bag limit of eight.
'few' - difficult to find a lobster: one or two found with considerable searching.

Pre-1965: lobsters were considered 'abundant' around the onshore, nearshore and offshore reefs. The divers' recollections may be best illustrated by quoting some comments (imperial units have been converted to metric):

"Lobsters walked on the onshore reefs at Trigg at night."
"Two metres from the shoreline, I caught a 2 kg lobster."
"Only 2 to 6 m from the shoreline, lobster numbers ranged from two to 20 depending on the ledge size."
"Lobster antennae were interlocked along a 100 m ledge off Mullaloo Beach."
"Under a ledge there was usually a bull (jumbo) and 15 to 20 normal-sized (legal) lobsters."
"I had no trouble in catching 34 lobsters (reds) in a dive."
"I caught a sugar bag full every dive."
"The ledges were so crowded that lobsters were found on the ceiling and the floor."

Before 1965, eight lobsters (1985 bag limit) were obtained with apparently minimum searching effort from all reefs: the bag limit was likely to have been secured from under one ledge. The most popular locations along the onshore reefs were, Trigg, Mettams Pool, North Beach, Waterman and Mullaloo beaches, where 'whites' (year 1 of legal size: migratory phase of large juveniles), 'reds' (years 2-5 of legal size: juveniles and non-migratory adults) and 'jumbos' (year 6 and older: large adults, generally with carapace length exceeding 120 mm) were all 'abundant'. Although 'jumbos' were also found on the offshore reefs, they were less commonly seen there.

1966-75: amateur divers noticed a decline in lobster catches along the more accessible onshore and nearshore reefs between 1966-75. Lobster bag limits were still attainable, however, with considerable effort. Usually several ledges needed to be searched to find the bag limit of eight legal-sized animals. Increased human pressure, through improved shoreline accessibility, was suggested as a possible explanation. The divers noticed no decline in lobster numbers on the offshore reefs.

1976-85: the beginning of this period showed the main decline in catch rates. Only undersize lobsters could be found on the onshore reefs and there were few of these. Lobster numbers had reportedly declined from 'abundant' to 'common' from around the nearshore and offshore reefs. Considerable effort was required to obtain the bag limit of eight legal-sized lobsters and many ledges had to be searched.

Although most interviewees commented that there had been a notable reduction in numbers and average sizes over the last 30 years, some 1985 divers commented that, at the start of every lobster season the numbers in 1976-85 were still as great as in previous years; however, owing to increased human activity their numbers were depleted very quickly once the open season started.

Divers generally agreed that the larger lobsters, especially 'jumbos', were uncommon by 1985: most rock lobsters caught were either 'whites' or 'reds' just above legal size.

3.3.2 REEF FISH

3.3.2.1 West Australian dhufish *(Glaucosoma hebraicum)*

(Information from 11 divers summarised in Table 1.)

Definitions:

'abundant' - more than two per dive.
'common' - between two per dive and one per two dives.
'few' - between one per three dives and one per 20 dives.

Pre-1955: three divers interviewed spearfished the onshore reefs in the period 1945-1955. At that time, dhufish were considered 'common' to 'few'. One diver saw one to two dhufish per dive ('common') at Trigg and Mullaloo Beach. The other two divers speared one per four to six dives ('few') between Trigg and Mullaloo Point. The average dhufish was 4-5 kg with a maximum weight of about 11 kg.

Only one diver spearfished around the nearshore reefs, averaging one dhufish every two dives ('common').

Around the offshore reefs dhufish numbers ranged from 'abundant' to 'common'. One diver speared three to four dhufish per dive ('abundant') in the summer months between 1950-51, around Three Mile Reef. Outside summer months he could spear only one to two per dive ('common'). He observed a decline in numbers by 1952. The number of dhufish speared by the other three divers, on the offshore reefs, ranged from one per dive to one per three dives ('common'). Dhufish from the offshore reefs averaged 4- 8 kg with a maximum of about 13 kg.

1956-65: the pre-1955 divers, who continued to dive during this period, observed no change in dhufish numbers speared. Two new divers who dived around the offshore reefs speared about one dhufish per dive, with an average weight of 7-12 kg and a maximum of 20 kg.

Before the late 1960's, three divers said it was not unusual to see schools of 5-20 dhufish, between October and March.

1966-75: with the exception of one diver, all the pre-1966 divers either stopped diving in the proposed park area (some in search of better diving areas elsewhere) or noticed a decline in dhufish numbers. During this period, three of the divers interviewed were new to the area. One dived on the onshore reefs and observed no dhufish; the other two dived on the offshore reefs and speared one dhufish per dive each ('common').

1976-85: only one diver, of those interviewed, spearfished around the onshore reefs. He did not see any dhufish. The number of dhufish speared by divers who had been diving around the offshore reefs, prior to 1976, declined to 'few' (one per three to 20 dives) or none. A new diver, to the area of the offshore reefs, also speared only 'few' dhufish (one per 20 dives) around the offshore reefs. One underwater photographer saw one to two dhufish per dive ('common') immediately west of Little Island.

3.3.2.2 West Australian dhufish *(Glaucosoma hebraicum)*

(Information from 7 anglers summarised in Table 1.)

Definitions:

'abundant' - more than two per trip.
'common' - one to two per trip.
'few' - less than one per trip.

Pre-1955: one angler commented that, from the 1930's to the mid 1950's, dhufish were 'few', but caught regularly by anglers off Trigg Island reef and at most areas along the coast of the proposed Marmion Marine Park.

Two boat anglers interviewed, who fished around Three Mile Reef, caught between one to three per trip ('common' to 'abundant'). Another angler usually caught one dhufish each trip, in 2 m of water west of Little Island.

1956-65: the three pre-1955 boat anglers continued to get similar catch rates ('common' to 'abundant') and another boat angler in the area also caught two to three dhufish per trip. The dhufish caught around the offshore reef ranged from 5-15 kg. One boat angler caught dhufish regularly from around the nearshore reefs and remembers two 15 kg dhufish caught from Wreck Rock.

1966-75: there was no change in catch rates by the pre-1966 boat anglers. Another boat angler who fished at 'The Corals' (inner Marmion Reef) caught one to two dhufish per trip (common).

1976-85: three boat anglers who fished the offshore reef noticed a decline in catch size from 'abundant' or 'common' to 'few' or 'none', and two of these anglers observed a decline in dhufish size, to an average of about 5 kg. One professional fisherman interviewed still (1985) set droplines, 4 to 6 km off Whitford Beach, in 32 metres when the dhufish were schooling. He pulled the droplines 20 times per night, and his best catch over two nights was 36 fish averaging 6 kg in weight (maximum of 11 kg). He did not consider these catches financially worthwhile.

3.3.2.3 Banded sweep *(Scorpis georgianus)*

(Information from 7 divers summarised in Table 1.)

Definitions:

'abundant' - saw more than 15 per dive.
'common' - saw five to 10 per dive.

Prior to the mid 1970's banded sweep were 'abundant' around most reefs in the area. One diver commented that eight to nine banded sweep might be observed around every reef. Another diver commented that they were an edible fish that divers speared to "fill their catch bag." All divers interviewed had noticed a decline in the number of banded sweep since the late 1970's.

3.3.2.4 Blue groper *(Achoerodus gouldii)*

(Information from 10 divers summarised in Table 1.)

Definitions:

'abundant' - more than two per dive.
'common' - one per two to three dives.
'few' - one per 10 to 30 dives.

Pre-1955: sightings of blue groper were frequent around the onshore reefs at Blue Hole (Trigg), Mullaloo Beach, and between North Beach jetty and Waterman Beach. One diver saw five to six blue groper every dive (average weight 2 - 4 kg), and another diver speared one about every second dive (average 6 - 7 kg).

There were many popular spearfishing locations along the offshore reefs, and four divers speared one groper every two to three dives ('common'), with an average weight of 7 - 15 kg: (maximum 35 kg).

1956-1965: the six pre-1955 divers continued to see or spear similar numbers of blue groper. Another two divers supplied confirmatory recollections.

1966-1973: the divers who had previously been diving on the onshore reefs ceased activities there, mainly because they had bought boats and now operated further offshore. A new diver to the area observed no blue groper on the onshore reefs.

Catches from five divers on the offshore reefs ranged from 'few' (one per 10 dives) to 'common' (one per dive).

1973-1979: there was a ban on spearing blue groper during this period, from Cape Leeuwin northwards. One diver commented blue groper were very rare before the ban, but saw an increase in numbers, in the proposed park area, during the period. After 1979, spearing was again allowed, but with a catch limit of one per person per day.

1979-1985: reportedly there was a consistent decline in the number of blue groper speared during this period. Two divers saw no blue groper on the onshore reefs and only a few (1/10 - 1/30 dives) were speared from around the nearshore and offshore reefs (four divers).

3.3.2.5 Baldchin groper *(Choerodon rubescens)*

(Information from 10 divers summarised in Table 1.)

Definitions:

'abundant' - more than two per dive.
'common' - one per two to six dives.
'few' - one per 20 to 50 dives.

Pre-1955: the onshore reef sites, popular for spearfishing baldchin groper, were similar to those for blue groper (ie between Trigg and Mullaloo Point). One diver saw four to five baldchin groper every dive (maximum weight 3 kg), and another diver speared one every six dives (average 2 - 2.5 kg). A third diver, however, did not see any baldchin groper around the onshore reefs.

Around the offshore reefs baldchin groper catches ranged from one every four dives (two divers) to two every dive (one diver), with an average weight of 3 - 4 kg (maximum 7 kg).

1956-65: although one diver continued to see four to five baldchin groper each dive at Trigg, another two divers observed no baldchin groper around the onshore reefs.

Around the offshore reefs, baldchin groper catches ranged from one every two dives to one every four dives (three divers), with an average of 3 - 5 kg.

1966-75: only one of the pre-1966 divers continued to spearfish around the onshore reefs, and no baldchin groper were seen.

Baldchin groper catches around the offshore reefs ranged from one every two to three dives ('common'; maximum 4 kg), to one every six dives (average 3 kg), to one every 30 dives ('few'/'none'; three divers).

1976-1985: none of the interviewed divers continued to dive on onshore reefs during this period. Reasons given were either purchase of a boat or because sedentary fish numbers had declined to the extent that diving there "was not worthwhile".

The number of baldchin groper speared, by five divers from around the offshore reefs, ranged from 'few' (one every 20 to 50 dives) to 'none'.

3.3.3 DEMERSAL FISH

3.3.3.1 Gummy shark *(Mustelus antarcticus)*

(Information from 10 anglers summarised in Table 1.)

'abundant'- one to three per trip
'common' - one per two to three trips
'few' - one per four to ten trips

Pre-1965: one angler caught one to two gummy sharks per trip ('abundant') inside the Marmion Reef. Another angler only caught one every six to ten trips ('few') at 'The Patches' (about mid-way between Centaur Reef and Boyinaboat Reef -see Figure 1). One angler set a long-line 60 m off Mullaloo Point and often caught 1-3 gummy sharks each time. Beach-fishing at Scarborough, another angler caught one every three trips.

1966-75: an angler at Marmion Reef caught two to three gummy sharks per trip ('abundant'). One angler who previously caught one gummy shark every three trips prior to 1966 said that, inside Marmion Reef, they were scarce by the late 1960's ('few'). None of the anglers caught any from the onshore reefs.

1976-85: although one angler continued to catch one gummy shark every six to ten trips ('few') on the Marmion Reef, the catch size of two other anglers who fished at "The Corals" (also between Centaur Reef and Boyinaboat Reef) and at Scarborough beach declined to 'none', despite effort to catch this species.

3.3.3.2 Whiting *(Sillago spp)*

(Information from seven anglers summarised in Table 1.)

Definition:

'abundant' - more than 15 per trip.

Of seven anglers interviewed, five had been fishing since the 1930's and 1940's, and had been catching between 12-72 whiting per trip. The anglers felt that whiting were abundant in the proposed Marmion Marine Park and that there had been no change in numbers in the past 50 years.

Although whiting seem to have been caught in many places in the study area, the most popular locations were just inside Marmion Reef (including 'The Patches'), and around the nearshore reefs.

3.3.4 PELAGIC FISH

3.3.4.1 Southern sea garfish *(Hyporhamphus melanochir)*

(Information from 10 anglers and one net fisherman summarised in Table 1.)

Definition:

'abundant' - more than 15 per trip.

Pre-1955: garfish were 'abundant' in the area with five boat anglers catching between 30 and 60 per trip at many places between the nearshore and offshore reefs. One beach angler caught approximately 30 per trip between North Beach and Ocean Reef.

1956-65: the pre-1955 anglers continued catching similar numbers, at the same places, during this period and another three boat anglers also had catches between 15 and 60 per trip. A professional rock lobster fisherman, who netted for fish when the rock lobster season was poor, averaged 100 kg of garfish per haul in the area between the nearshore and offshore reefs.

1966-85: the above anglers continued fishing until 1985 and were still catching between 15 and 60 per trip. Three anglers commented that there were more garfish in 1985 than in previous years.

3.3.4.2 Tailor *(Pomatomus saltator)*

(Information from 10 anglers summarised in Table 1.)

Definitions:

'abundant' - more than 15 per trip.
'common' - between five and 15 per trip.
'few' - less than four per trip.

Pre-1955: two beach anglers caught between 10 to 40 tailor per trip at Trigg, North Beach, Mullaloo Beach and Ocean Reef. From boats, tailor catches ranged from three to about 24 per trip, between Boyinaboat and Marmion reefs (five anglers). Tailor size ranged from 0.5 to 4 kg. One angler had observed (from the shore using binoculars) large schools of tailor off Trigg, where they used to "lay-up" (school and feed).

1956-65: the pre-1955 anglers continued to catch similar numbers. Another two (beach) anglers at Trigg averaged two to three per trip and six to eight per trip. A beach angler at Mullaloo and Sorrento beaches averaged 10 to 12 tailor per trip.

1966-75: two boat anglers at Trigg and Little Island averaged 12 tailor per trip. During this period, most anglers had similar catches to previous years; two anglers, however, noted a decline in catches at Trigg.

1976-85: a decline in catch rates of tailor was observed by five beach anglers at Trigg, North Beach, Mullaloo and Ocean Reef. One angler who caught 24-36 tailor in 1966-75, only caught one to two per trip in 1976-85. Only one of the beach anglers interviewed continued to catch 10-12 per trip as before. A decline in tailor size (any over 1 kg were rare) was also observed by two anglers.

Tailor catch sizes of boat anglers varied, with three anglers continuing to get similar catch sizes and two anglers observing some decline in catch size (since the early 1980's).

3.3.4.3 Skipjack trevally *(Pseudocaranx dentex)*

(Information from nine anglers summarised in Table 1.)

Definition:

'abundant' - more than 12 per trip.
'common' - between five and 12 per trip.
'few' - less than five per trip.

The catches of skipjack trevally appear to have remained fairly constant since pre-1955 until the present (1985). Most angling was done by boat inside the Marmion Reef and around Little Island, Boyinaboat Reef and the Trigg reefs. Catch sizes ranged from five to 15 per trip, and individual fish weighed about 0.25 - 1.2 kg.

One angler observed a decline in abundance in the early 1970's. Another angler observed a major localised decrease in abundance around 1960 at Mettams Pool.

3.3.4.4 Australian herring *(Arripis georgianus)*

(Information from 16 anglers summarised in Table 1.)

Definition:

'abundant' - more than 24 per trip.

Information suggests that herring have been the most abundant and consistent catches throughout the proposed park area. Nine anglers had been catching 20 to 60 herring per trip since the 1950's and continue to do so. Another seven anglers fished in the area at different, shorter periods over the past 30 years, but also caught similar, consistent numbers of herring. Four of the beach anglers suggested that herring were more plentiful in the 1980's than previously; hence it took them less time to acquire their expected, usual catches.

Beach anglers had slightly smaller catches than boat anglers.

3.4 METROPOLITAN DIVING CLUBS

Members of metropolitan diving clubs reported that in recent years they did not usually spearfish in the proposed Marmion Marine Park area, because fish numbers there were small. Organised club dives between Trigg and Burns Beach were usually outside the western boundary of the proposed park, where fish appeared to be more abundant. The trend in these clubs is away from spearfishing and towards activities such as underwater hockey, photography and SCUBA diving courses, reportedly because of the decline in number and size of suitable fish along the metropolitan coast.

Jones (1986) noted that the major species sought by people spearfishing in the area, were blue groper, dhufish, sea kingfish, pink snapper and queen snapper, and were still "present in reasonable numbers" in 1985. This conclusion appears to contradict the opinions of most spearfishermen we interviewed.

3.5 GENERAL HISTORY OF THE PROPOSED MARMION MARINE PARK AREA

1810 - American whalers hunted whales off 'metropolitan' coast for about 20 years prior to establishment of Swan River Colony.

1829 - establishment of Swan River Colony.

1849 - Patrick Marmion established and operated a whaling station at Sorrento (Marmion's Chimney).

1852 - Operation of whaling station ceased.

1865 (?) - Edward Hamersley built a limestone cottage at North Beach, as a holiday home for the family, about 1860-1865. This cottage was named "The Castle".

1869 - Cowles carried out coastal survey (it has been suggested he may have named Star Swamp).

1872 - the brigantine 'Nightingale' brushed over what was to become Centaur Reef, with serious damage.

1874 - (December) - the iron brig 'Centaur', captained by F Brabham struck the southernmost section of Marmion Reef and was wrecked.

1900 - James Gibson purchased 'The Castle', renovated and extended the then dilapidated North Beach cottage, and converted it to 'The Castle Hotel'. Gibson became the hotel's first licensee.
- the first stone shack, at Marmion, was built.

1900-1910 - about 12-14 shacks were erected at Marmion beach.
- North Beach jetty was erected by Perth Road Board, about 1905-1908.
- 7 boat sheds were erected at Waterman beach.
- 5 boat sheds were erected at Trigg Island.

1911 - Perth Road Board visited North Beach to inspect a sand drift problem, which had been checked by Marram grass previously planted.

1918 - public auctions were held of land at Trigg, Sorrento and North Beach.

1920-1922 - first shack was erected at Whitford beach.

1922 - Willoughby Lance started bus service known as Golden Motor Coach, running from Bayswater to Perth (via Guildford Road) and on weekends to City Beach and North Beach.

1923 - North Beach Jetty extensions by Perth Road Board.
- Hamersley school opened June 11 as assisted school.

1931 - North Beach Surf Life Saving Club was officially opened.

1930 - first shack at Hillarys erected by Mr Hillary, who earned his living fishing.

1938 - about 30 families lived permanently at North Beach.

1940 - West Coast Highway was constructed to North Beach.

1940-1945 - US Army used Little Island as a training field and bomb target.

1945 - 25 shacks built by then on the Whitford beach.

1946 - 40 shacks built by then on the Marmion beach.

1954 - 82 shacks were removed from Marmion beach. Arthur Stewart organised a Commonwealth grant to build Marmion Angling and Aquatic Club (MAAC).

1955 - work began on Marmion Angling and Aquatic Club clubhouse at Marmion.

1956 - Marmion Angling and Aquatic Club opened.
- the 7 Waterman beach boat sheds removed.
- Marmion Primary School opened with 54 pupils.

1962 (?) - a public launching ramp was constructed, of limestone rubble, at Quinns Rock beach.

1964 - a storm on 8 July 1964 washed away the Hillarys beach shacks. At one stage there were 20 shacks.
- owners of the Hillarys beach shacks, which were washed away, began constructing beach shacks just north of Mullaloo Point (which was also known as the Pinnaroo Point settlement).

1965-1966 - the original North Beach jetty was demolished following damage by winter storms.

1966 - West Coast Highway extended from North Beach Road to Sorrento.

1967 - four beach shacks removed from Trigg Beach.

1968 - WA Marine Research Laboratories opened at Waterman.

1969 (?) - final two beach shacks removed from Trigg beach.

1972 - 72 shacks, on Whitford beach, were demolished.
- West Coast Highway extended from Sorrento to Whitfords.

1972-1976 - West Coast Highway extended from Whitfords to Corella Street, Mullaloo.

1973 - Whitfords Sea Sports Club founded.

1975 - the 20 shacks just south of Mullaloo Point (Pinnaroo Point settlement) were demolished.

1976 - CSIRO Marine Laboratories, of Division of Fisheries and Oceanography, opened at Marmion.

1977 - North Beach jetty rebuilt.

1977-1978 - submarine outfall for the Beenyup Wastewater Treatment Plant built and commissioned (May 1978), subsequently discharging 30 megalitres/day (1987 figure) of secondary-treated domestic wastewater 1.6 km west of the coast at Ocean Reef.

1978 - Ocean Reef boat launching facility constructed, providing 8 concrete launching ramps for trailer-mounted boats, and temporary all-weather shelter for small vessels.

- Beach Road construction completed, providing a direct northern route from Wanneroo Road to West Coast Highway.

1980 - Whitfords Sea Sports Club clubhouse built at Ocean Reef boat launching facility.

1982 - West Coast Highway extended from Mullaloo to Ocean Reef Road.

1984 - Hepburn Avenue sealed to West Coast Highway.

1986 - Hillarys Boat Harbour constructed, providing 4 (eventually 6) concrete launching ramps and, potentially, permanent mooring facilities for up to 1 000 vessels < 25 m length.

1987 - Marmion Marine Park proclaimed.

1988 - construction scheduled for Mindarie Keys marina, 1 km south of Quinns Rock. This private facility is expected to provide mooring sites for 250-350 vessels, and a 6-lane public boat ramp.

4. DISCUSSION

4.1 GENERAL

Most scientific information on populations or communities of marine species, in the area of the Marmion Marine Park, is quite recent (Jones 1986; Ottaway & Simpson 1986; Simpson & Ottaway 1987; Wells, Keesing & Sellers 1987; see also bibliography by Robinson & Cary 1987), with very little data available prior to about 1965. In the absence of scientific data, anecdotal recollections may be the only other source of information regarding population or community changes; for example, anecdotal accounts have been used as a major source of information for studies on squid (Voss & Brakoniecki 1985), fish (Johannes 1978; Peterman & Wong 1984), swans (Norman 1977) and whales (Whitehead & Glass 1985). In the present study, there was a high degree of consistency of information provided by independent sources (a minimum of five anglers or divers for each of the species listed in the summary of Table 1), further supported in some instances by photographs taken decades ago. While any anecdotal information must be interpreted with caution, the recollections of past catches in the area do give a credible indication of changes in usual catch rates per individual, and of changes in the average sizes of particular species taken over the past few decades. There is great difficulty, however, extrapolating these recollections to conclusions about changes in the total annual catch of any particular species from the area, because of a lack of information on other factors, which also influence an individual's catch rate, such as the total number of people fishing the stock.

Three most significant changed factors, since the turn of the century, are the numbers of people fishing, the species sought, and the efficiency of fishing techniques. At the turn of the century, fishing pressure on finfish, molluscs or rock lobster in the area probably had negligible impact on the target species. Extrapolating from the urban growth of the Perth metropolitan region, the numbers of people living in the hinterland to the area now occupied by the Marmion Marine Park, and the number of beach shacks and boat sheds on that part of the metropolitan coast, a first estimate can be made of numbers of people who fished the area. In 1900, there were probably less than 30 people occasionally fishing the area. By 1940, several hundred people (mostly recreational anglers) probably fished the area. By 1985, probably well in excess of 10 000 recreational anglers fished the area each year: two angling clubs at Marmion and Ocean Reef had a combined membership of about 2 000 (Farrell 1986), an estimated 3 300 small boats were owned by people living in Perth's northwest corridor (Table 2), and about 500-600 small boats were occasionally launched from Ocean Reef boat launching facility in a single day (Hicks 1986). Hence, it seems likely that numbers of people fishing the area increased by a factor of at least 10

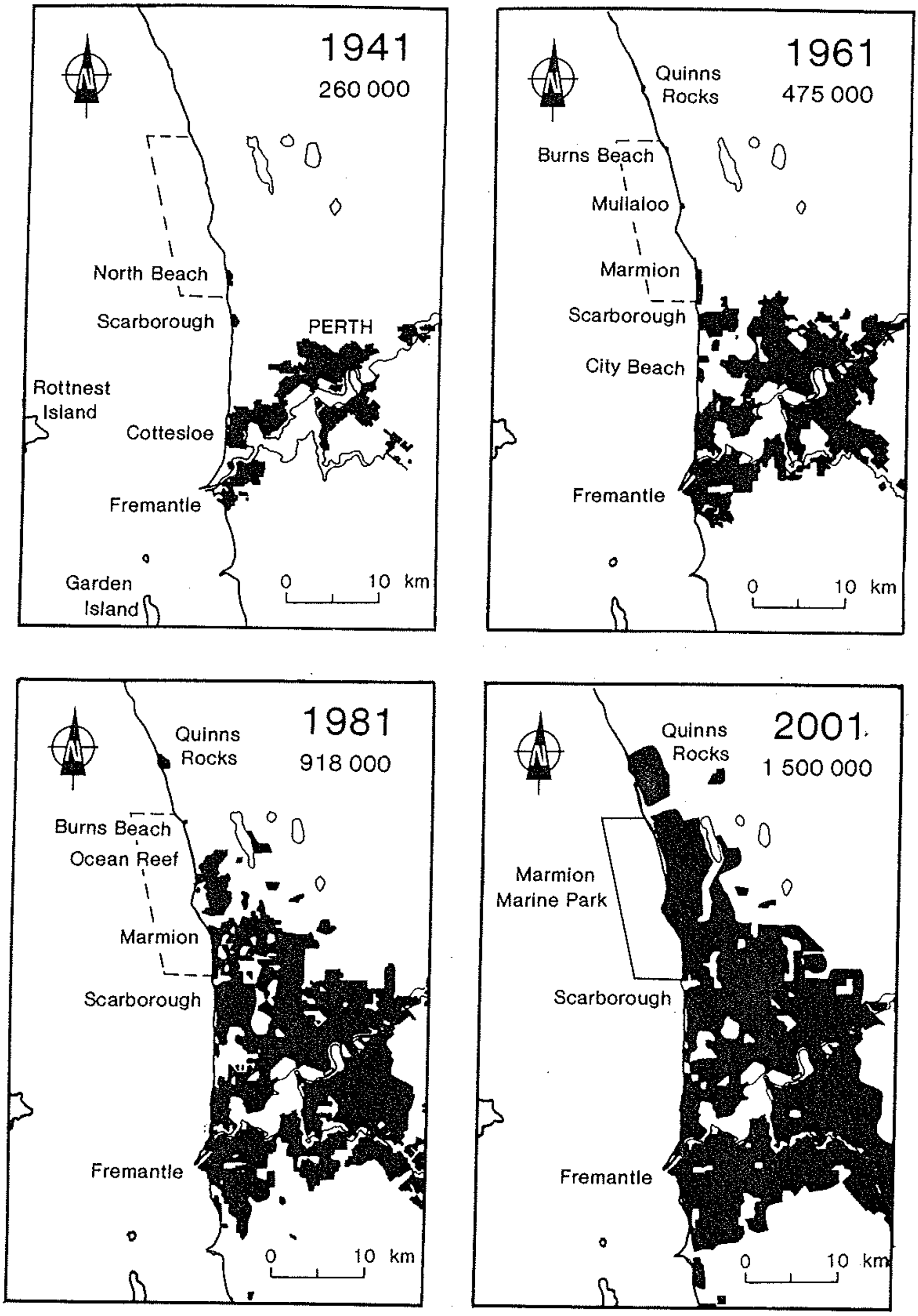

Figure 10. Urban growth of the Perth metropolitan region, 1941-2001. (Figure adapted from Carr 1983, with permission of the Western Australian State Planning Commission.)

Dark areas indicate the spread of city or suburban development, with population figures given for the years shown (projected figure for 2001). The position of the Marmion Marine Park is also indicated, with boundaries as gazetted by the Department of Conservation and Land Management on 13 March 1987.

Table 2. Estimates of population and number of small boats in the coastal metropolitan area northwest of Perth (area between Trigg and Quinns Rocks and west of Wanneroo Road), 1900-2010.

1. Population figures extrapolated from Commonwealth census figures for the Shire/City of Wanneroo 1911-1986, State Planning Commission's estimated resident population figures for the Shire/City of Wanneroo 1981-2001, and Metropolitan Region Planning Authority (1977) report on population trends in the North-West Corridor.

2. Percentages of population owning small boats extrapolated from estimates given in P A Australia (1981).

3. Estimated numbers of beach shacks and boat houses, Trigg-Burns, derived from Newell & Weller (1980) and anecdotal recollections of people interviewed.

4. Estimated numbers of small boats derived from (2) and (3) above, where the assumption is made that, on average, there was one small boat for each beach shack or boat shed.

YEAR	ESTIMATED POPULATION OF NORTH-WESTERN COASTAL SUBURBS[1]	PERCENTAGES OF LOCAL POPULATION OWNING SMALL BOATS[2]	ESTIMATED NUMBER OF BEACH SHACKS AND BOAT HOUSES[3]	ESTIMATED NUMBER OF SMALL BOATS[4]
1900	<100	-	5	5
1910	150	-	30	30
1920	250	-	40	40
1930	350	-	55	55
1940	500	-	80	80
1945	650	-	95	95
1950	750	(1.0)	145	150
1955	900	(1.0)	80	90
1960	1 100	(1.2)	80	95
1965	1 300	(1.5)	70	95
1970	2 000	2.0	90	130
1975	10 000	3.0	20	300
1980	29 000	4.0	0	1 200
1985	69 000	4.8	0	3 300
1990	110 000	(5.3)	-	6 000
2000	190 000	(5.5)	-	10 000
2010	270 000	(5.5)	-	14 000

between 1900 and 1940, and, considering the rapid development of roads and suburbs adjacent the area from about 1970 onwards (Section 3.5; Figure 10), by a factor of well over 40 between 1940 and 1985.

Changing target species, or significantly increased pressure on particular species, resulted from introduction of underwater diving and spearfishing equipment, in the 1950's, and changes in local eating habits. This is discussed further in 4.2 below.

In parallel with the change in the other two factors, there has been marked change in efficiency of existing fishing techniques. Before the Second World War, offshore fishing relied mostly on conventional fishing vessels powered by inboard motors; inshore fishing relied mostly on smaller, but still heavy clinker-construction dinghies powered by inboard motors or oars. After this, lightweight dinghies with outboard motors made it easier to launch and retrieve vessels, and faster to travel to offshore fishing locations. Thus, it became easier, quicker and safer to fish the metropolitan nearshore and offshore waters. The efficiency of fishing local waters has continued to increase with the development of synthetic monofilament lines, improved fishing tackle and equipment, and construction of all-weather launching ramps at Marmion (1954), Ocean Reef (1978), and Hillarys (1986).

4.2 MOLLUSCS AND CRUSTACEANS

Prior to the 1950's, rock lobsters and abalone were considered abundant on the onshore and nearshore reefs. Rock lobsters were plentiful in these areas possibly because it was too dangerous to manoeuvre the small boats of the time, and set or retrieve lobster pots close to these reefs. Abalone were plentiful on easily accessible onshore reefs, and on other reefs, because collecting pressure was negligible as the local population was not, generally, accustomed to this type of seafood. Cowries and other molluscs on the offshore reefs also had negligible collecting pressure on them, because underwater diving equipment was rare and the species were therefore mostly inaccessible.

As a food collected by the local population, abalone became popular in the 1960's and 1970's. Also, since the late 1960's, a valuable commercial abalone fishery developed to supply the Japanese and south-east Asia markets (Anonymous 1987). An amateur bag limit (36 per day per person) was introduced in 1975, and a size limit (60 mm shell size) was introduced in 1980. Nevertheless, the then Department of Fisheries and Wildlife considered that excessive collecting activity was occurring by 1982, and in March of that year closed metropolitan reefs from Moore River to Cape Bouvard to amateurs. The reefs were reopened to amateurs in October 1982, but after introduction of a restricted collecting season from 1 October to 28 February. Apparently even these measures (minimum size limit, maximum bag limit and restricted season) were not sufficient to keep the increasing collecting pressure at acceptable levels because the Department later (October 1984) reduced the bag limit to 20 abalone per person per day, and shortened the open seasons for recreational collectors (1986/87: 1 October - 24 December; 1987/88: 1 October - 8 January, with collecting only permitted at weekends and public holidays).

Despite these restrictions designed to prevent overcollecting by either the general community or by any particular amateur, there have been persistent reports that supposedly "amateur" collectors have taken large quantities of abalone for sale (for example, see Farrell 1986). Subsequently, these reports were substantiated by successful prosecutions under the Fisheries

Act; for instance, people have been fined for taking 670 abalone of which 255 were undersize, and another person has been fined for taking 285 abalone of which 76 were undersize ("The West Australian", 19 December 1986).

Available information, however, indicates that the problem is not one of general depletion of abalone stocks along metropolitan reefs, but rather a rapidly increasing number of amateurs collecting a limited annual production of abalone from the easily accessible onshore reefs. With a minimum legal shell size of 70 mm, about six professional abalone divers take an annual catch of about 15 000-20 000 kg, mostly from offshore, nearshore and deeper parts of the onshore reefs. The amateur collectors take abalone mostly from parts of the onshore reefs accessible by wading at low tides (Anonymous 1987), and, in December 1984, 400 amateurs were counted taking abalone in one day during peak fishing conditions (Jones 1986). Thus, while commercial activity has been well-controlled for many years, by restricting the numbers of licences to 12 professionals licenced to collect Roe's abalone from Cape Leeuwin northwards (Stewart 1986; Anonymous 1987), numbers of amateurs collecting have increased probably by at least several thousand since the 1960's. This has lead to a decrease in the relative abundance of abalone on the accessible parts of the onshore reefs, some local depletion (Anonymous 1987), and to the reports of 'overfishing'. Notwithstanding, it is likely that the productivity of the overall abalone stock in the park area, and the total amount collected annually, has actually increased over the past 30 years as a result of the generally well-managed fishing pressure. As the number of recreational collectors increases, however, which is inevitable as suburban development continues in Perth's northwestern corridor, there will be few management options available other than to progressively reduce bag limits for abalone, reduce the length of the open season, increase the minimum legal shell size, increase enforcement activity, and possibly introduce licences to restrict the numbers of amateur collectors.

For cowries and other molluscs, there is insufficient information on numbers of divers collecting or on total catches over time for us to to draw any conclusion. The reported declining catch rates, if correct, could be due to either markedly increased numbers of divers collecting an essentially consistent total annual catch, to overfishing depleting the local stock, or to some other factors.

The reported decline of recreational rock lobster catches appears to have a similar explanation to the supposed declining catches of Roe's abalone. The professional rock lobster fishery has been operating in the Marmion Marine Park area since the 1930's (Stewart 1986), and, taking into account natural, year-to-year fluctuations in juvenile recruitment, professional catches have remained consistent for some years (about 80 000 kg in 1984/85). At present the area supports five professional vessels for most of the year and about 20 vessels in November-January (Jones 1986, Stewart 1986). Amateur fishing pressure was probably negligible prior to the 1950's. After that, inshore rock lobster habitats became much more accessible to recreational lobster potters and divers, due to the introduction of lightweight dinghies, outboard motors, and underwater diving equipment. Lobsters were easily found and taken from the nearshore and onshore reefs by divers using either hands or spears.

Licences and a bag limit, of eight rock lobsters per day per licence, were introduced for amateurs in 1969.

While it may be that feeding or sheltering habitats for rock lobsters are now under-utilised, because of possible excessive reduction in numbers on parts of the nearshore habitats due to recreational fishing pressure, Fisheries Department estimates that amateurs still take an annual catch of 3 200-4 000 kg from the park area defined in the System Six reports (DCE 1981; EPA 1983; Jones 1986). It seems more likely, therefore, that the reported declining amateur catch rates are largely a direct consequence of the massive increase, since the 1950's, in numbers of recreational collectors taking rock lobsters from the accessible reefs. Also, there is some evidence to suggest lobsters may be avoiding feeding at night on the tops of the onshore reefs, as a consequence of light-aversion behaviour related to the construction of street lights along the West Coast Highway. Even though underwater ledges crowded with lobsters may be a sight of the past, it is also quite likely that, as with the abalone, productivity of the overall lobster stock within the park has actually increased. Lack of 'jumbo' lobsters, since the 1950's, is a normal consequence of decreasing mean size of individuals taken, resulting from the increased fishing pressure over the past 30 years.

4.3 REEF FISH

No figures are available for professional or amateur fin fish catches in the park area, but it seems that most of the fishing pressure is from amateurs (Jones 1986). Whether anglers or spearfishermen have had the greater impact on reef fish is not known, but is worth investigation.

From the anecdotal accounts of divers and anglers interviewed, catch rates of dhufish, banded sweep, blue groper, baldchin groper, and six other species of reef fishes had all declined in the past 30 years. Some divers also noted that less of these species were now seen, and made strong inferences that there had been marked population declines due to overfishing. In the absence of actual data these inferences must be considered only speculation, but nevertheless also worth investigation.

4.4 DEMERSAL FISH

Catches of gummy sharks have reportedly declined, while those of whiting have remained consistent. Jones (1986) and Stewart (1986) noted that six professionals had netted the area for sea mullet and yelloweye mullet, which were both migratory demersal species, taking consistent catches for many years. The two professionals we interviewed suggested that their catches may have declined. Again, however, in the absence of total catch figures for the park area we cannot draw any firm conclusion.

4.5 PELAGIC FISH

Information from anglers suggested that Australian herring had been the most abundant species and had given the most consistent catches since the 1950's. Southern sea garfish catches had also been consistently high. Catches of tailor and skipjack trevally may have declined slightly. The limited available information suggests that professional net fishermen have taken consistent catches of blue sardines for many years (Jones 1986).

5. CONCLUSIONS

(i) Since the 1950's there have been major advances in fishing equipment, fishing techniques, small boat design and construction, and in outboard motors. This has made fishing, and in particular recreational fishing in nearshore coastal waters, much more convenient and efficient.

(ii) In the period 1900-1985, the population in the near hinterland of the now gazetted Marmion Marine Park has increased by a factor in the order of 500-1000. The period of most marked increase was 1965-1985.

(iii) In the period 1900-1985, numbers of small boats owned by people in that same area, have increased by an estimated factor of 300-700. The most marked increase in boat ownership was also in the period 1965-1985, as a consequence of the population increase and because an increasing proportion of people were purchasing boats.

(iv) Major road access to the coast, between Trigg and Burns Beach, and launching facilities for small boats have improved markedly, especially in the past 20 years.

(v) It is clear that there has been a massive increase in recreational fishing pressure on the area, especially in the past 30 years, from shore anglers, boat anglers, divers spearing fish or collecting rock lobsters and abalone, and from people gathering abalone off the intertidal, onshore reefs.

(vi) In some instances, such as whiting, sea mullet, yelloweye mullet, blue sardines, Australian herring and southern sea garfish, available information generally suggests that catches have been consistent since the 1950's, despite markedly increased fishing pressure.

(vii) In the instances of species such as Roe's abalone and western rock lobster, the reported declining recreational catch rates over the past 30 years can be substantially attributed to the massive increase in numbers of people taking the species. There may have been some local depletions of stock, in small, restricted areas, but it seems likely that the productivities of the overall stocks have increased over the past 30 years, as a result of managed, regulated fishing pressure. Mean sizes of the animals taken would have also decreased, over the same period, as a normal consequence of the fishing pressure.

(viii) Owing to the lack of detailed scientific information, the situation is unclear with respect to cowries, West Australian dhufish, banded sweep, blue groper and baldchin groper. Reported declining catch rates may, again, be due to the markedly increased numbers of people taking essentially finite local resources; however, from their observations, some divers have strongly suggested that these species may be overfished and significantly depleted in the park area. Some anglers (for example, Farrell 1986) share a similar view.

(ix) Similarly, some anglers have reported declining catch rates of gummy shark, tailor and skipjack trevally. It is not known whether this is simply related to the relatively increased numbers of anglers taking the species, or because of stock depletion or some other factors.

(x) The Marmion Marine Park, already, is one of the most heavily fished areas in Western Australia. While scientific data are generally lacking, we nevertheless believe there must have been major changes in the local population structures of many target species, over the past 30 years. Predictions of population growth and boat ownership in Perth's northwestern corridor indicate that numbers of people fishing in the park could, potentially, at least double between 1985 and the year 2000. It is suggested therefore that immediate, detailed assessment of the existing stocks of molluscs, crustaceans and fish would be appropriate, for scientifically-based future management of the park's resources.

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APPENDIX 1

SPECIES COLLECTED AND CAUGHT BY ANGLERS AND DIVERS IN THE AREA OF THE PROPOSED MARMION MARINE PARK SINCE THE 1930's

MOLLUSCS
Δ * Roe's abalone *(Haliotis roei)*
Δ * Cowrie *(Cypraea (Zoila) friendii friendii)*
Δ * Cowrie *(Cypraea (Zoila) venusta* forma *sorrentensis)*
* Cowrie *(Cypraea (Zoila) marginata)*
Conch *(Syrinx aruanus)*
Baler *(Melo miltonis)*

CRUSTACEAN
Δ * Western rock lobster *(Panulirus cygnus)*

REEF FISH
* Western red scorpion-cod *(Scorpaena sumptuosa)*
* Breaksea cod *(Epinephelides armatus)*
* Harlequin fish *(Othos dentex)*
Δ * West Australian dhufish *(Glaucosoma hebraicum)*
Δ * Banded sweep *(Scorpis georgianus)*
* Queen snapper *(Nemadactylus valenciennesi)*
* Dusky morwong *(Dactylophora nigricans)*
Δ * Blue groper *(Achoerodus gouldii)*
* Western foxfish *(Bodianus frenchii)*
Δ * Baldchin groper *(Choerodon rubescens)*

DEMERSAL FISH
Δ * Gummy shark *(Mustelus antarcticus)*
Δ Whiting *(Sillago spp)*
Δ * Tarwhine *(Rhabdosargus sarba)*
Pink snapper *(Chrysophrys auratus)*
* Yelloweye mullet *(Aldrichetta forsteri)*
* Sea mullet *(Mugil cephalus)*
Striped sea pike *(Sphyraena obtusata)*

PELAGIC FISH
* Bronze whaler shark *(Carcharhinus brachyurus)*
Δ Southern sea garfish *(Hyporhamphus melanochir)*
Δ * Tailor *(Pomatomus saltator)*
Δ Skipjack trevally *(Pseudocaranx dentex)*
Δ Samson fish *(Seriola hippos)*
Δ * Salmon spp *(Arripis spp)*
Δ Australian herring *(Arripis georgianus)*
Δ Mulloway *(Argyrosomus hololepidotus)*
* Narrow barred spanish mackerel *(Scomberomorus commerson)*

Δ commonly caught or collected species.
* indicates a reported decline in catch rates, since either the 1960's or 1970's (based on recollections of the 41 people interviewed).

Other species seen and caught, but not mentioned in this report owing to lack of information, were: yellowtail scad, cobbler, flathead, sea trumpeter, blue spotted goatfish, leatherjacket, blowfish and snook.

SURVEY OF BEACH LITTER IN THE PROPOSED MARMION MARINE PARK NEAR PERTH, WESTERN AUSTRALIA

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Abstract

The results of a beach litter survey, carried out in July 1985 on eight beaches within the proposed Marmion Marine Park, are given. An average of 274 items, weighing 5.44 kg, were collected per 100 m transect. Sixty-eight percent by weight of the total was found to be generated by the general public and 32% by rock lobster fishermen who were mainly professionals. Litter from the general public consisted mostly of cans, bottles, plastic bags and containers discarded by beach users; whereas rope and plastic bait wrapping were the major components from rock lobster fishing boats. The Ocean Reef boat launching facility beach was found to be the 100 m transect most contaminated by litter.

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FIGURE

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1. INTRODUCTION

Frequent complaints by the general public, in local newspapers and to the former Department of Conservation and Environment, of litter contaminating beaches within the proposed Marmion Marine Park lead the M10 study team to undertake a survey of litter. The aim was to determine broadly the quantity, type and origin of the beach litter.

2. METHODS

Beach litter was collected on week days in July 1985 following the closure of the rock lobster fishing season and during a period of low activity by beach users. The litter was collected along a 100 m transect line, parallel to the shoreline, between the waters edge and the vegetation line, at eight beach sites from Trigg to Ocean Reef boat launching facility (Figure 1). Each site was sampled once.

The beach sites sampled were:

(1) Bennion Street Beach, close to Trigg.

(2) North Beach, opposite Sorrento Street.

(3) Marmion, 200 m north of Marmion Angling and Aquatic Club.

(4) Sorrento, 1 km north of Sorrento Surf Life Saving Club.

(5) Mullaloo, 500 m south of Mullaloo Point.

(6) Whitford Beach, opposite Whitford Avenue.

(7) Mullaloo Beach.

(8) Ocean Reef, inside Ocean Reef boat launching facility (south-east corner).

In the laboratory, litter from each beach site was divided into general litter from beach users, and litter obviously originating from rock lobster fishing activities. Under each of these two categories, litter was again divided into different types of litter (Table 1).

The number of items and total weight (wet) of all items in each litter type, for each transect, were recorded.

3. RESULTS

An average of 274 items and approximately 5.4 kg of beach litter were collected along each 100 m beach transect in the proposed Marmion Marine Park (Table 2).

The total amount of litter collected at each site ranged from 1.00 kg, made up of 145 items at Mullaloo Beach, to 17.47 kg, comprised of 637 items in the south-east corner of Ocean Reef boat launching facility (Table 2).

Litter from beach users was more common, (68% of total litter weight) than from rock lobster fishing activities (32% of total litter weight). The major components of beach litter were cans, bottles, plastic bags and plastic containers.

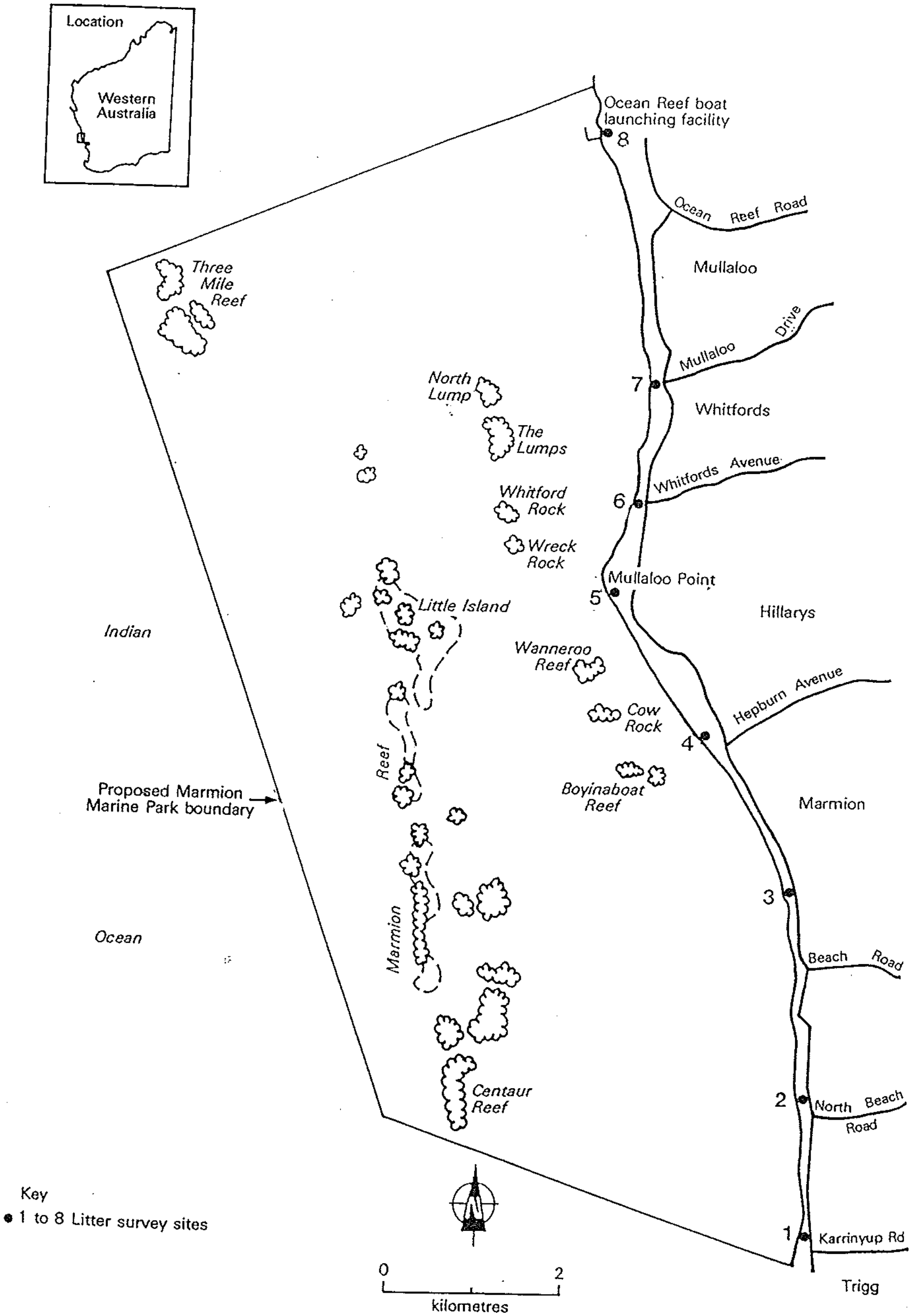

Figure 1. Location of the eight 100 m transects sampled in beach litter survey within the proposed Marmion Marine Park.

Table 1. Types of litter discarded by beach users and professional and amateur rock lobster fishermen.

LITTER FROM BEACH USERS	LITTER FROM ROCK LOBSTER FISHERMEN
cans/bottles	lengths of rope
plastic bags/containers	plastic bait wrapping
wood	plastic catch bags
plastic	miscellaneous plastic
food wrapping	plastic bait straps
paper	bait baskets
rubber	floats or parts of floats
cloth	miscellaneous
glass	
bottle tops	
polystyrene	
fishing line	
metal	
miscellaneous	

Cans and bottles formed the highest proportion of beach user litter at four of the eight sites, ranging from 11.1% of the total litter at Bennion Street Beach to 64.2% of the total litter at the northern end of Sorrento Beach (Table 2). Plastic bags and containers were the major beach user components at two sites, comprising 20.8% of the total litter, 500 m south of Mullaloo Point, and 28.3% of the litter inside Ocean Reef boat launching facility. Broken glass and wood were the major beach user components at the remaining two sites; broken glass comprising 18% of the total litter at North Beach, and wood accounting for 14% of the total litter of Marmion.

Although at six of the eight sites litter from beach users constituted the majority of the litter, at Bennion Street Beach and Mullaloo Beach 63.0% of the total litter weight was from rock lobster activities (Table 2).

The major components of rock lobster litter were rope and plastic bait wrapping. Rope formed the highest proportion of rock lobster litter at six of the eight sites, ranging from 7.1% of the total litter at Marmion to 38.9% of the total litter at Mullaloo Beach. Plastic bait wrapping constituted 9.1% and 10.7% of the total litter at North Beach and Ocean Reef sites, respectively.

The beach with the most litter was inside the Ocean Reef boat launching facility (637 items). Large amounts of litter were found also at Bennion Street Beach near Trigg and Marmion Beach (520 and 308 items, respectively).

4. DISCUSSION

This brief, superficial study provides baseline data on the problem of beach litter in the proposed Marmion Marine Park.

The survey was carried out in winter when beach use by the general public was minimal. Coincidentally, sampling was done immediately following the rock lobster fishing season, and therefore the amount of litter during this

Table 2. Weight, number of items and main litter type collected along 100 m transects at eight beach sites.

TRANSECT NO & SITE	LITTER WEIGHT (kg)			% OF TOTAL LITTER WEIGHT		NO OF ITEMS			LITTER TYPE (%) (% BY WEIGHT)	
	BEACH USERS	ROCK LOBSTER FISHER-MEN	TOTAL	BEACH USERS	ROCK LOBSTER FISHER-MEN	BEACH USERS	ROCK LOBSTER FISHER-MEN	TOTAL	BEACH USERS	ROCK LOBSTER FISHER-MEN
1. Bennion St Beach	3.21	5.46	8.67	37.0	63.0	270	250	520	Cans & Bottles 11.1	Rope 22.4
2. North Beach	1.30	0.32	1.62	80.2	19.8	204	27	231	Broken Glass 18.0	Plastic Bait Wrap 9.1
3. Marmion	5.10	1.28	6.38	79.9	20.1	247	61	308	Wood 14.0	Rope 7.1
4. Sorrento	1.70	0.27	1.97	86.3	13.7	68	18	86	Cans & Bottles 64.2	Rope 6.9
5. Mullaloo Point	1.17	0.16	1.33	88.0	12.0	90	25	115	Plastic Bags/ Containers 20.8	Rope 7.2
6. Whitford Beach	4.21	0.89	5.10	82.5	17.5	74	73	147	Cans & Bottles 60.8	Rope 7.5
7. Mullaloo Beach	0.37	0.63	1.00	37.0	63.0	72	73	145	Cans & Bottles 12.8	Rope 38.9
8. Ocean Reef	12.40	5.07	17.47	71.0	29.0	373	264	637	Plastic Bags/ Containers 28.3	Plastic Bait Wrap 10.7
Average per site (x)	3.68	1.76	5.44	67.6	32.4	175	99	274	Cans & Bottles	Rope

period, July 1985, was biased towards litter from the rock lobster fishermen. During summer, litter deposited by beach users would be much more evident on the beaches, both relatively and in absolute terms.

Litter from the rock lobster fishermen was mainly from professionals who used commercial packets of bait, wrapped in distinctive plastic wrapping sealed by equally distinctive blue plastic straps. Discarded fishing gear can result in the entanglement of marine animals such as whales, dolphins, seals, sharks, turtles and seabirds (see reference list).

Although weight and number of items were used as indicators of the extent of the litter problem, litter can also cause aesthetic and health problems which are difficult to quantify. For example, broken glass was uncommon in the litter collected, but during times of peak usage could result in serious injuries on beaches.

Litter from rock lobster fishermen possibly results from their reluctance to carry discarded wrappers and other items to disposal points on shore; it is not clear what further steps could be taken to minimise litter from this source, other than continuing the Fisheries Department effort to educate the fishermen. Litter from recreational beach users might be reduced by the provision of more rubbish bins on beaches, in addition to public education.

5. CONCLUSION

Although sampling was carried out when beach use was minimal, beach litter was prolific; an average of 274 items weighing 5.4 kg on a 100 m transect. Weight of litter, mostly cans, bottles, plastic bags and containers, from beach users (68%) was greater than that from rock lobster fishing activities (32%), which generated mostly rope and plastic bait wrapping. The proportion of litter from the relatively few crayfishing boats is thought to be high when compared with that from the beach users. Most litter was found on the beach inside the Ocean Reef boat launching facility. Bennion Street Beach, near Trigg, and Marmion Beach were also heavily littered.

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