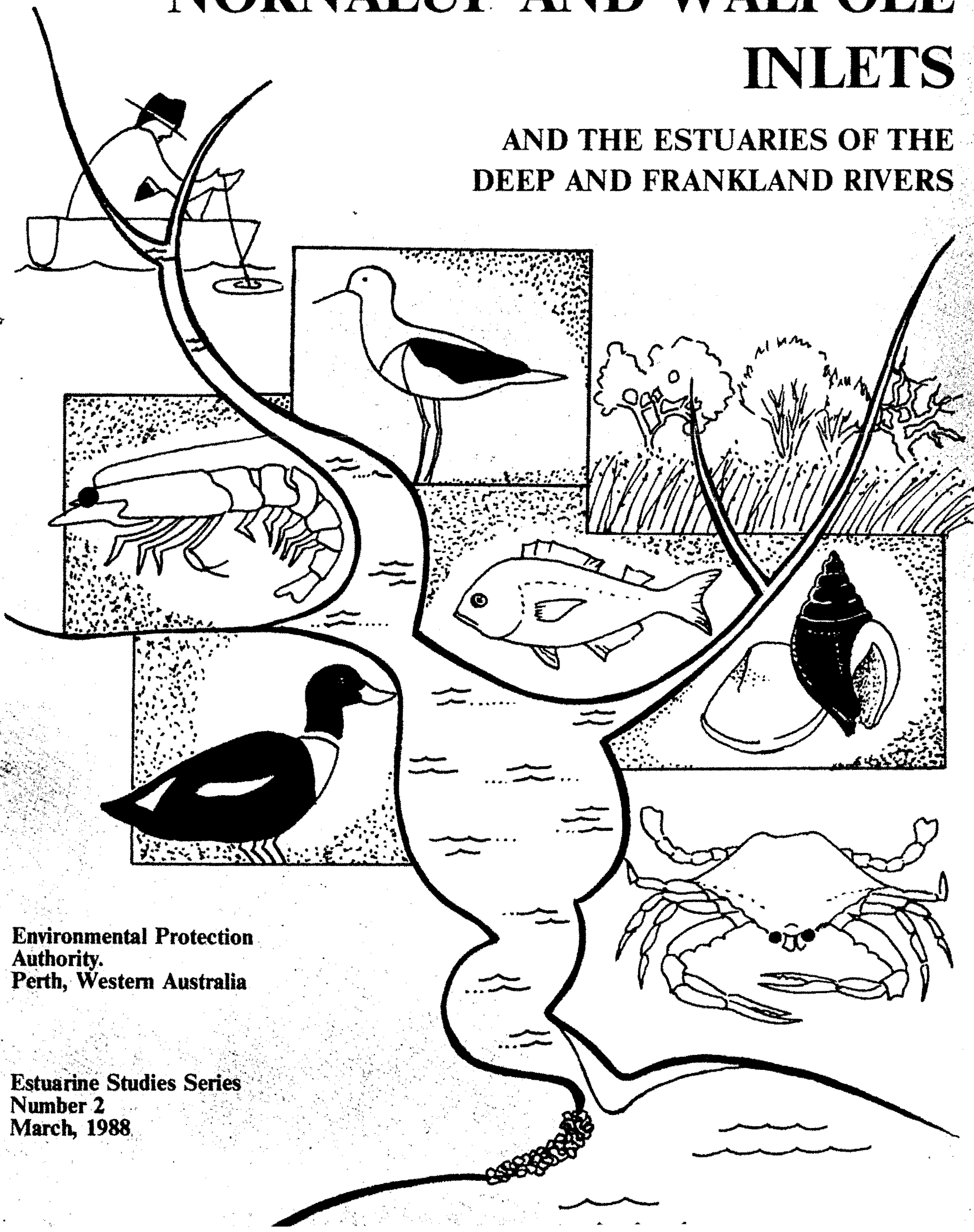
ESTUARIES AND COASTAL LAGOONS OF SOUTH WESTERN AUSTRALIA

NORNALUP AND WALPOLE INLETS

AND THE ESTUARIES OF THE DEEP AND FRANKLAND RIVERS



Environmental Protection Authority.
Perth, Western Australia

Estuarine Studies Series
Number 2
March, 1988

An Inventory of Information on the
Estuaries and Coastal Lagoons of South Western Australia

NORNALUP AND WALPOLE INLETS

and the estuaries of the Deep & Frankland Rivers

By: Ernest P Hodgkin and Ruth Clark

Nornalup-Walpole Estuary March 1988 — Photo Land Administration, WA

Environmental Protection Authority
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COMMON ESTUARINE PLANTS AND ANIMALS

Approximate sizes in mm.

Plants
- A Rush - *Juncus kraussii*
- B Samphire - *Sarcocornia* spp.
- C Paperbark tree - *Melaleuca cuticularis*
- D Seagrass - *Ruppia megacarpa*
- E Diatoms 0.01

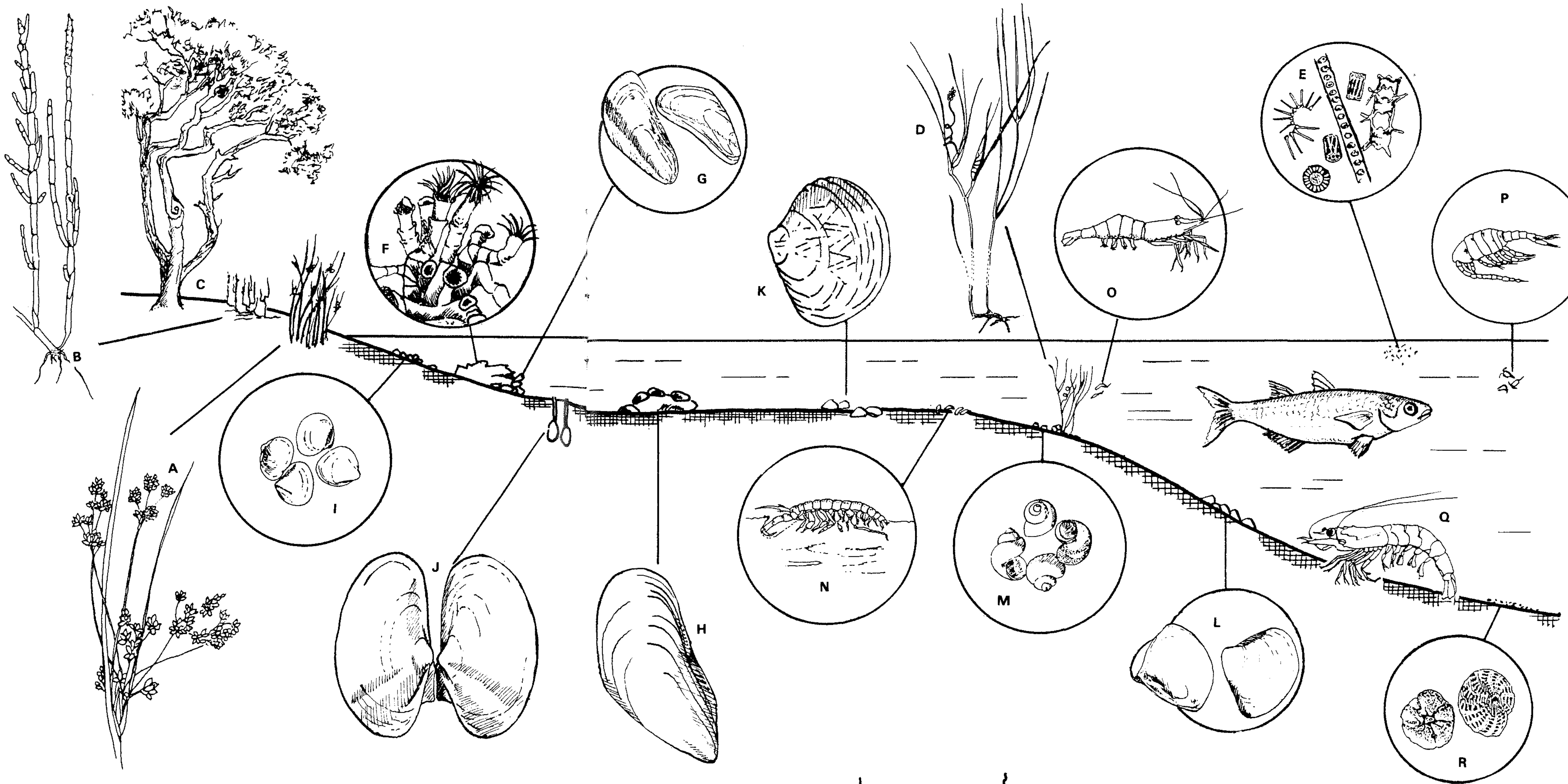
F Tubeworms - *Ficopomatos enigmaticus* 20

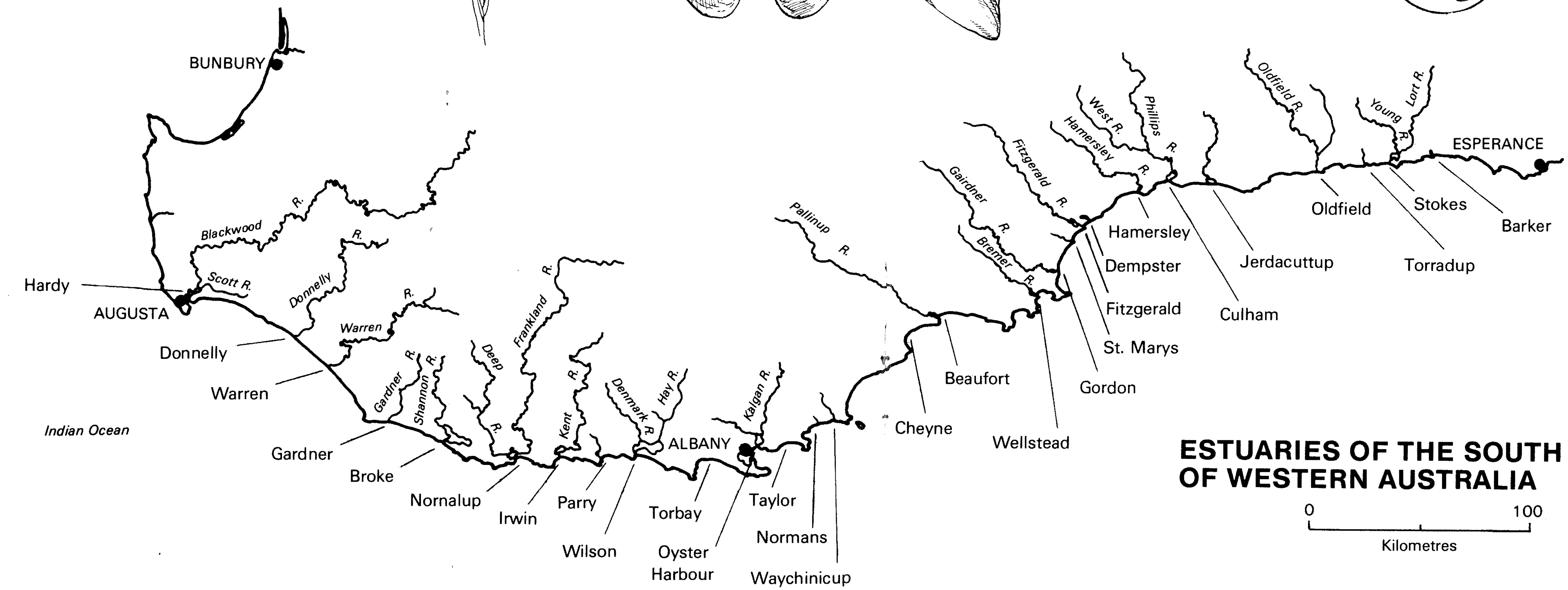
Bivalve molluscs
- G Estuarine mussel - *Xenostrobus securis* 30
- H Edible mussel - *Mytilus edulis* 100
- I *Arthritica semen* 3
- J *Sanginolaria biradiata* 50
- K Cockle - *Katelysia* 3 spp. 40
- L *Spisula trigonella* 20

Gastropod molluscs
- M Snail - *Hydrococcus brazieri* 4

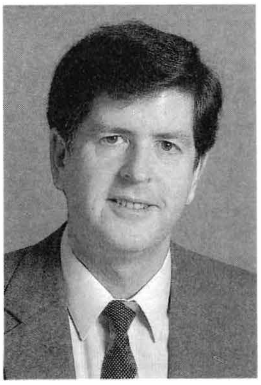
Crustacea
- N Amphipod - *Corophium minor* 15
- O Shrimp - *Palaemonetes australis* 40
- P Copepod - *Gladioferens imparipes* 2
- Q King Prawn - *Penaeus latisulcatus* 100

R Foraminifera 0.02





ESTUARIES OF THE SOUTH COAST OF WESTERN AUSTRALIA



Hon Barry Hodge, MLA

Minister for the Environment

FOREWORD

In 1987, on behalf of the State Government, I released the State Conservation Strategy for Western Australia.

The Environmental Protection Authority's studies of the estuaries of the south-west of Western Australia is one of the steps in the Strategy.

This inventory of the Nornalup-Walpole estuarine system is the second in the Estuarine Studies Series - the first was on the Wellstead Estuary.

The aesthetic attraction of estuaries for residential development and their recreational potential have placed them under increasing pressure, and the varied interests of those who use them often present the authorities with difficult conflicts to resolve. Clearing and cultivation in the catchments of tributary rivers alter the pattern of river flow, increasing sedimentation and nutrient supply.

The studies summarise and interpret data on the estuaries and provide background information for those interested in managing, conserving and studying the estuaries.

Nornalup and Walpole Inlets and the estuarine reaches of the Deep and Frankland rivers are fortunate in that they are mainly within national park and much of the catchment is in State forest, all under the care of the Department of Conservation and Land Management. Also this is one of few estuaries in the south-west that are permanently open to the sea, allowing flushing and permanent access for marine fauna.

The principal author and co-ordinator of this study - Dr Ernest Hodgkin - is a much respected scientist who has dedicated much of his work to estuarine and marine areas subject to environmental stress. His work on Hardy Inlet at Augusta, and more recently on the Peel-Harvey estuary, has led to a better understanding of these sensitive environments and how they function, as well as providing management solutions to environmental problems. He has developed these information inventories on the south-west estuaries with the assistance of his co-author Ruth Clark.

Our estuaries are different in many respects from those in other parts of the world. They present unusual problems for management, and for the plant and animal life. These and other aspects of the estuaries and coastal lagoons of the south coast - their geological history, coastal features, climate, riverflow and sedimentation - will be discussed in a comparative account that is being prepared as part of this Estuarine Studies Series and will stress the similarities and differences between them.

I highly recommend this inventory of the Nornalup - Walpole estuary as a valuable information source to organisations such as local authorities, planners and conservation groups concerned with management, as well as to individuals interested in further study of our estuaries and coastal lagoons.

Contents

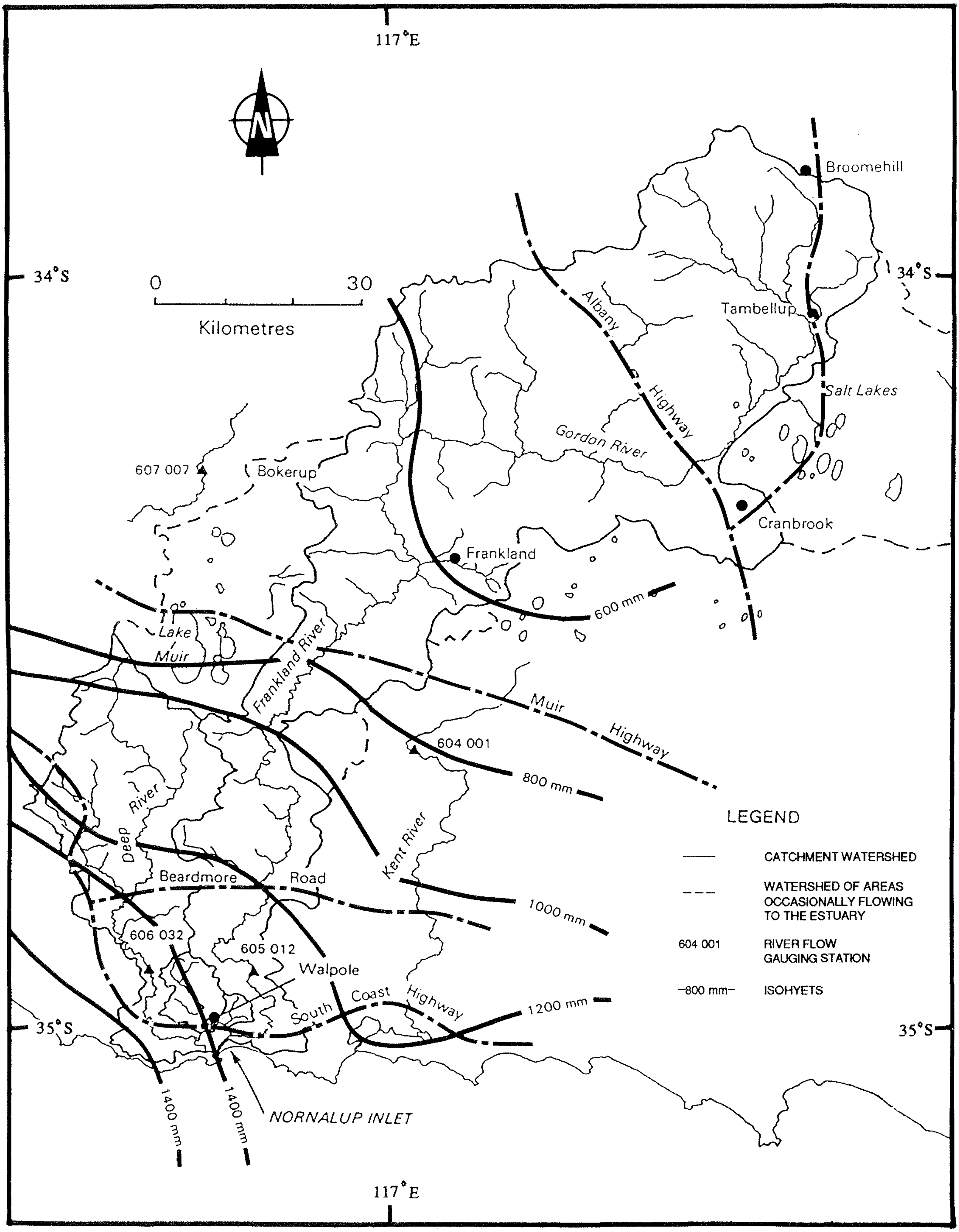


Figure 1 The catchment of the Nornalup-Walpole estuary.

1 Introduction

The Nornalup - Walpole estuarine system consists of the two coastal lagoons Nornalup Inlet and Walpole Inlet together with the tidal reaches of the Deep and Frankland rivers and the small Walpole River. It lies between the steep, granite hills on the southern edge of the Western Shield plateau and high Pleistocene dunes of the south coast. The Deep River is estuarine for 6 km and the Frankland River for 12 km. The small, shallow Walpole Inlet is linked to the larger, deeper Nornalup Inlet by a kilometre-long channel between steep rocky headlands. The channel from Nornalup Inlet to the sea opens against the granite cliffs of Rocky Head to the west and on the east the dunes which flank the 10 km long Bellanger Beach. The ocean bar, unlike those of most south coast estuaries, does not close and the estuary is always tidal.

The estuary is in the highest rainfall region of the south west (1400 mm), and the Deep and Frankland rivers discharge a large volume of fresh water into the estuary in winter. Surface water of the Inlets approximates marine salinity (35 ppt) in summer, but it freshens greatly in winter. Marine water extends far up the rivers in summer, but is often overlain by a layer of fresher water. The deep water of Nornalup Inlet is seldom less than 30 ppt salinity and in consequence it has a more varied invertebrate fauna than other estuaries on the south coast, except Oyster Harbour.

Although the bar does not close, the entrance channel is shallow, variable and dangerous for navigation by small craft because of the heavy swell which constantly rolls into the bay, even during light winds and fine weather.

The first settlers, the Bellanger family arrived by sea in 1910, landed on the beach near the entrance, and ferried their belongings across Nornalup Inlet, to a site on the Frankland River at Nornalup. Later the Thompson's settled 5 km up the Deep River, at Tinglewood (Bellanger, 1980).

The Nornalup-Walpole estuary has a scenic beauty unlike anywhere else in Western Australia. The open waters of Nornalup and Walpole Inlets lie among the steep forest-clad hills and coastal dunes of the Walpole - Nornalup National Park, with its fine stands of tall Karri and Red Tingle trees that also border the peaceful waters of the Frankland River where it twists and turns in the deep valley it has carved through high hills. The sheltered lower reaches of both Frankland and Deep Rivers, with their swamps and deltas backed by forest, too have their special charm. The Nuyts Wilderness area stretches from the Deep River to the coast and its dense coastal scrub now holds a small population of the rare Noisy Scrub bird (introduced from Two Peoples Bay).

The town of Walpole and the small settlement of Nornalup are the only centres of population in the southern, largely forested part of the catchment of the estuary. There are a number of towns in the low rainfall, agricultural area of the upper Frankland-Gordon River catchment from which there is little flow to the rivers (Figure 1).

1.1 LOCATION AND ACCESS

The estuary is located between 116° 40' and 116° 45' East and 34° 58' and 35° 03' South: map reference 2227 Rame Head and 2228 Deep River 760235 on the 1:100,000 topographic map series published by Natmap.

Walpole Inlet is 110 km west of Albany on South Coast Highway and 120 km by road from Manjimup to the north west. The town of Walpole is on the north shore of the Inlet and access to the Inlet is either through the town or at Rest Point, 2 km to the west. A road 2 km east of Walpole gives access to Nornalup Inlet at Coalmine Beach Caravan Park. Boats are launched to the Inlets at Walpole town, Rest Point Caravan Park and Coalmine Beach; to the Frankland River at Nornalup and to the Deep River at Tinglewood Lodge.

The estuary is in the Shire of Manjimup. The Frankland River and the southern shore of Nornalup Inlet form the boundary between Manjimup Shire and Denmark Shire to the east. The catchment of the Frankland River extends into the Plantagenet, Cranbrook, Kojonup, Tambellup and Broomehill Shires.

2 Catchment Characteristics

The boundaries of the upper catchment are ill-defined and there are extensive areas in the Lake Muir basin and the salt lake country of the Frankland - Gordon River where drainage is normally internal.

The catchment is made up of the following areas (km^2):

	river drainage	internal drainage	total
Frankland River	4291	1431	5722
Deep River	894	687	1581
Walpole River	76	—	76
Collier Creek	19	—	19
Overall total	5280	2118	7398

A total of 54 % of the catchment had been cleared for agriculture by 1968, most of this in the wide, wheatbelt area north of Muir Highway where much of it had been cleared before 1930. By 1982, 85 % of the Frankland River catchment had been cleared above the Frankland River gauging station 605012 (PWD, 1984). South of Muir Highway most of the catchment is in State Forest and only small areas have been cleared; very little in the Deep River catchment is cleared above gauging station 606032 (except in the Lake Muir area). Most of the Lake Muir and salt lakes areas have been cleared. There is only minor clearing in the catchment of the Walpole River.

2.1 LANDFORMS, GEOLOGY AND SOILS

The catchment lies on the southern edge of the Western Shield plateau, the Precambrian granitic rocks of which determine the main physical features. The area north of Muir Highway is open, gently undulating country at about 300 m above sea level with granite outcrops and laterite residuals. South of the Highway the land is hilly, mainly forested country with valleys that become deeply incised as they approach the coast.

The coastal strip, south of and beside the estuary, is formed by dunes between steep granitic headlands that are outliers of the plateau. The older, Pleistocene, dunes contain calcareous sands and are lithified to dune limestone of varying degrees of hardness, with hard rock (travertine) often forming a cap over softer rock below. The younger, Holocene, dunes consist mainly of quartz sands; they are only stabilized by the vegetation cover and there are a number of blowouts from the beach. Dune sands also often cap the granitic hills.

Most of the lower rainfall area north of Muir Highway is in the catchment of the Frankland River and its major tributary the Gordon River. It is largely occupied by sandy or loamy yellow duplex soils with moderate slopes and so the erosion risk is high in summer. The Gordon River catchment extends east to plains with salt lakes. The southern third of the Frankland River catchment and that of the Deep River is a hilly, dissected part of the plateau with a thinner laterite cover and leached sandy and gravelly soils. Erosion is normally low under the forest cover, though there is a slight risk of sediment movement with clear felling operations.

Much of the small Walpole River catchment is a low-lying, valley with hilly country in the north and sandy swampy soils near the estuary. The catchment includes a small area of dairy farming.

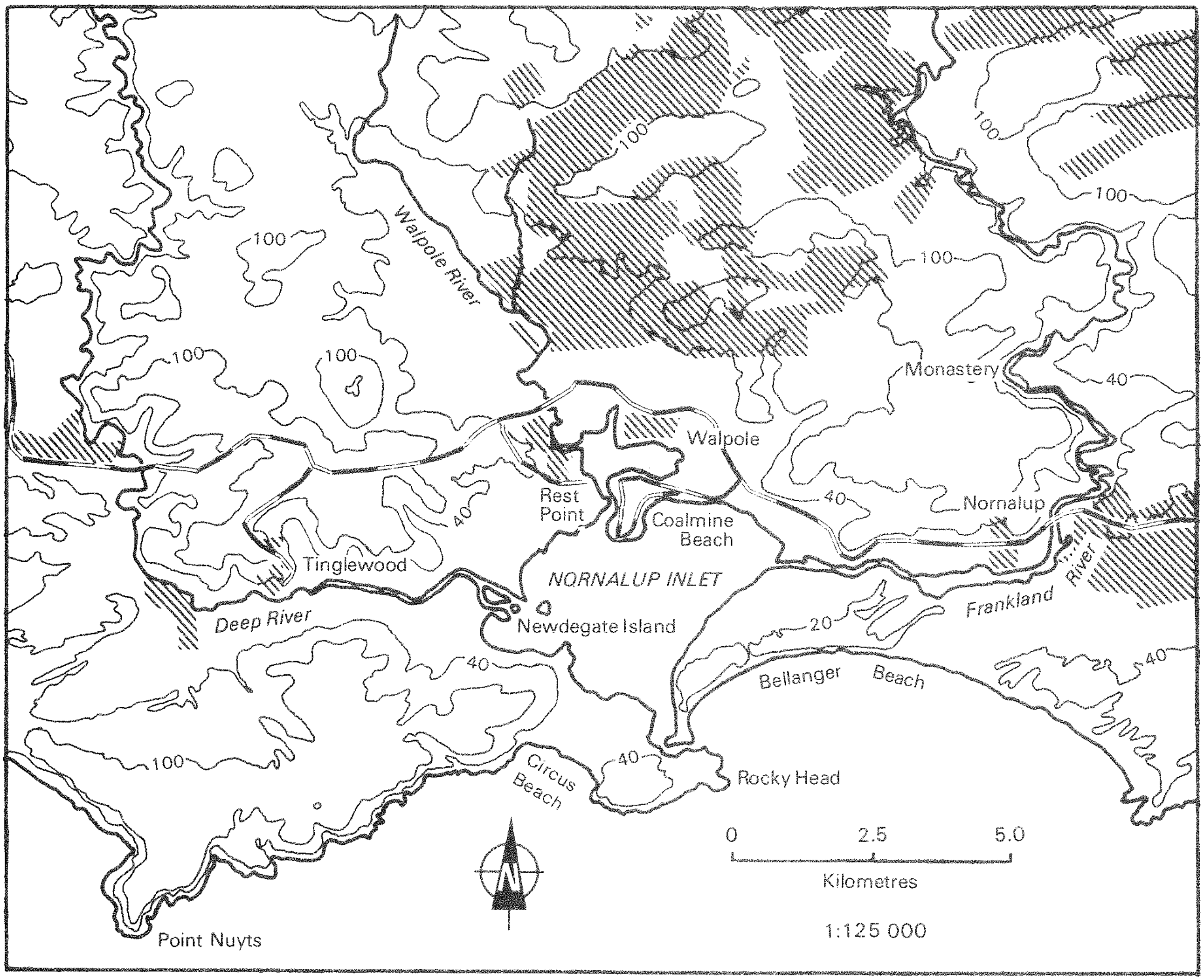


Figure 2.2 The Nornalup-Walpole estuary. Contour map. Shaded areas cleared land, 1987.

2.2 COASTAL FEATURES Figure 2.2

The mouth of the estuary is at the extreme western end of the 10 km long, south-facing Bellanger Beach, protected from south westerly winds and swell by a high granitic headland. In this sheltered location tidal exchange and river flow keep the bar open, and although it shallows in summer it never closes. Transport of sand is not pronounced in either direction along the beach; during winter the drift is predominantly from west to east, away from the entrance, and in summer from east to west bringing sand from the beach and depositing it near the mouth, so shallowing the bar when there is no river flow to help keep it scoured.

West of the mouth Rocky Head is linked by the low-lying sandy peninsula of Circus Beach and The Peppermints to the precipitous coastline that stretches 8 km westwards to Point Nuyts and beyond. Eastwards, along Bellanger Beach, the dunes rise from the bar to 20 to 40 m high for 5 km and then to a section of dune limestone cliffs up to 80 m high bordering the beach. The pattern of dune blowouts reflects the direction of the prevailing winds: near the mouth, in the shelter of Rocky Head, the easterly and south-easterly winds of summer; along the exposed eastern end of Bellanger Beach and at Circus Beach the strong winter south-westerlies. Holocene dunes have invaded the estuary at The Peppermints and in the vicinity of the mouth.

2.3 RAINFALL

Rainfall decreases progressively inland from the coast, with nearly 1400 mm a year, to less than 500 mm in the north eastern part of the catchment (Figure 1) (Table 2.3). This is mainly winter rainfall (Figure 2.3), but there are occasional summer storms: 163 mm at Walpole in February 1955 and 125 mm at Bokerup in January 1982. There has been a gradual decrease in rainfall in the lower catchment since the early 1950's; at Walpole the decrease in mean annual rainfall was 200 mm:

1956 to 1965	1465 mm
1966 to 1975	1319 mm
1976 to 1985	1265 mm

Table 2.3 Highest and lowest rainfalls for the Walpole Post Office and Bokerup rainfall stations since 1951 and 1959 respectively (Commonwealth Bureau of Meteorology).

	Walpole P.O.		Bokerup	
Average annual	1363 mm		595 mm	
Lowest annual	991 mm	(1972)	365 mm	(1972)
Highest annual	1997 mm	(1955)	717 mm	(1961)
Highest monthly	422 mm		169 mm	
Highest two monthly	616 mm		331 mm	

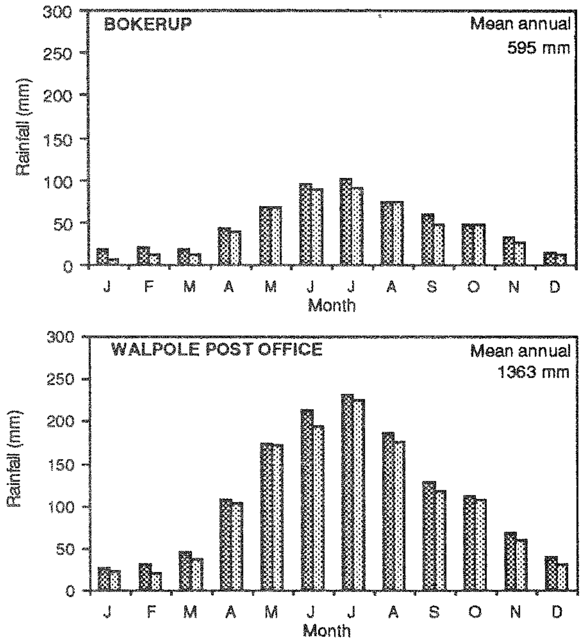


Figure 2.3 Monthly rainfall at Bokerup Station (1959-1984) and Walpole Post Office Station (1951-1986). ▣ means, ⊞ medians. (Commonwealth Bureau of Meteorology)

2.4 RIVERS

The Frankland-Gordon River is about 400 km long, the Deep River 120 km, and the Walpole River 15 km. Several small creeks enter Walpole Inlet from the north and east. Both the large rivers flow throughout the year, but 80% of flow comes during the five months June to October (Figure 2.4).

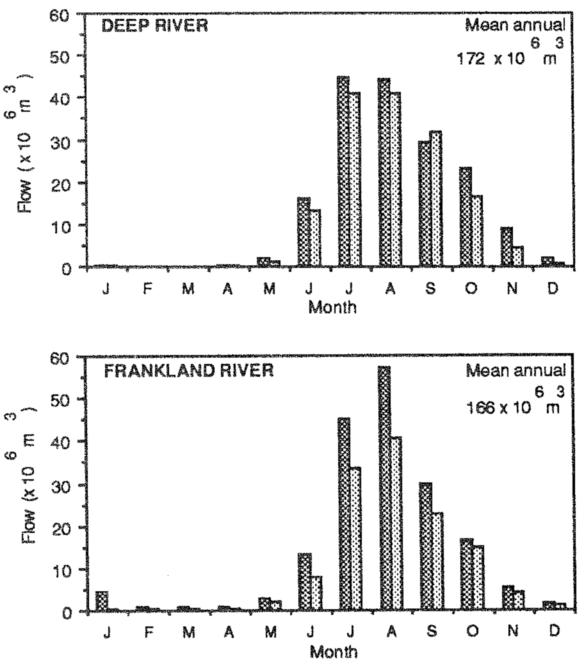


Figure 2.4 Monthly flows at the Deep River, 606 032 (1964-1972) and Frankland River, 605 012 (1940-1982) gauging stations. ▣ means, ⊞ medians. (WA Water Authority)

RUNOFF The estimated mean annual runoff for the whole catchment is 91 mm and the total mean annual inflow to the estuary is 558 x 10^6 m^3 (WAWA). However most of this is from the high rainfall forested area south of Muir Highway, as shown by the following figures estimated for the Frankland River catchment north and south of the Highway:

	North	South
Area, km^2	4806	916
Mean annual		
Rainfall, mm	400-800	800-1400
Runoff, mm	18	190
Flow, $10^6 m^3$	60	498

There is great variation in flow from year to year, with up to 5 times the mean (1945) and less than one third in dry years. Moreover a large proportion of the annual flow occurs over brief periods; for example in August 1964, a flow of 146 x 10^6 m^3 was recorded at gauging station 605012 following 387 mm of rain in July at Walpole; this was almost half the total for the year and about three times the volume of the estuary. The downpour of January 1982 produced an exceptional summer flow of 118 x 10^6 m^3.

SEDIMENT TRANSPORT During winter, river water has a high content of suspended matter of silt- and clay-sized particles, mostly clay minerals, organic matter and fine siliceous sand which are carried into the estuary (Hassell, 1962). Fine sediment flocculates in contact with salt water and settles out in the Inlets, but during strong river flow much also goes out to sea.

It is unlikely that there has as yet been any great increase in the volume of sediment entering the estuary as the result of clearing in the catchment; most of the coarse sediment probably collects in river pools. However, there are no data on the volume of sediment transport and it would be valuable to have records of both fine suspended and coarse bed load sediment during river flow, when most movement occurs, especially during floods.

The lower estuarine reaches of both large rivers are dredged every few years to maintain navigable channels, especially near the deltas, but the need for this is probably mainly because of redistribution of sediment already present in those parts of the rivers and scoured from the banks, rather than as the result of an increase in sediment brought to the estuary.

WATER SALINITY The waters of both Deep and Walpole rivers are fresh. The Frankland River is saline; the average for the 10 years 1973-82 was 1980 mg/l TSS (2 ppt), but salinity has increased progressively over the last 40 years by over 40 mg/l a year from only 590 mg/l in the 1940-49 decade (figures from WAWA gauging station 605012). As in the Blackwood and other major rivers of the south west, salinity increases progressively upstream and the saline water (about 10 ppt) of the Gordon River in the low rainfall upper catchment is diluted by fresh water from the high rainfall area of the lower catchment.

2.5 LAND OWNERSHIP AND USE

North of Muir Highway the catchment is mainly alienated agricultural land for cereal production and sheep farming. Most of the Deep River catchment and that of the Frankland between Muir Highway and Beardmore Road is Forest Reserve (Figure 1). The Nornalup Land Settlement began in the 1920s and the southern part of the Frankland catchment is partly cleared for grazing. Most of the land south of the estuarine reaches of the Deep and Frankland rivers and an area immediately north and west of the estuarine part of the Frankland is in the Walpole - Nornalup National Park. A bushfire burnt through parkland south of Nornalup Inlet in December 1986 and a large bush fire in January 1987 burnt areas north of the Frankland river. Only a small portion of the National Park is now untouched by fire in recent time.

The town of Walpole covers 2 km^2 on the northern shore of Walpole Inlet. The towns of Walpole and Nornalup can accommodate up to 760 and 40 visitors respectively during the summer (RAC, 1986). The caravan park at Coalmine Beach on the north shore of Nornalup Inlet is controlled by the Department of Conservation and Land Management. The Walpole Yacht Club leases 0.8 ha here (excised from the Park in 1964).

2.6 VEGETATION

Much of the coastal sand dune country is covered by Peppermint (*Agonis flexuosa*) scrub or woodland with some open heath. Inland from the dunes, stands of Karri (*Eucalyptus diversicolor*) with Red Tingle (*E. jacksonii* and *E. guilfoylei*), Marri (*E. calophylla*) or Jarrah (*E. marginata*) dominate higher ground, depending on the soils. Lower sandy ridges carry *Banksia* woodland, while low ground is occupied by Paperbark (*Melaleuca*) woodland and sedge swamps.

Karri forest covers hilly country with loamy soils in the southern part of the forest, giving way to Jarrah and Marri forest northwards, with Jarrah reaching its best development in the hilly, dissected laterites with a mean annual rainfall above 900 mm and becoming more open and depauperate as the rainfall decreases. Blackbutt (*Eucalyptus todtiana*) and Bullich (*E. megacarpa*) occur in the damper valley floors and along streamlines. Throughout the forest, broad swampy drainage lines and open sandy flats subject to seasonal inundation carry a low open woodland of *Melaleuca* and *Banksia* with an understorey of heaths and sedges. Logging activity has been widespread through the forests, but current integrated logging for sawlogs and chiplogs is mainly concentrated in the Karri-Marri forest.

3 Estuary

Nornalup and Walpole Inlets together cover an area of 13.2 km^2. Nornalup Inlet is 5 km east-west, parallel to the coast and 3 km north-south and Walpole Inlet is also elongate, 2 km east-west. The Deep River is estuarine for 6 km and the Frankland for 12 km. Because the bar is open, water level in the Inlets varies tidally, but the daily range is only 40% of the ocean range (at Albany), being damped by the small, shallow entrance (Marine and harbours). There can be dramatic rises of water level in the riverine stretches during floods, with a much smaller rise in the Inlets. In January 1982 the water rose 4.5 m in the Frankland River at Nornalup, over the hand rail of the bridge.

3.1 LANDFORMS Figure 3.11

RIVERS Upstream of Nornalup the Frankland River winds for 6 km in a well defined channel through steep-sided, forest-clad hills and is navigable for most of that distance. It is scoured to 5 m deep in places. For 6 km downstream it flows in a wide, shallow (less than 1 m) stretch, through parts of which a navigation channel has been dredged, and is flanked by riverine flats, swamps, and a rocky shore near the Inlet. The Deep River also has a well defined channel between steep hills on its north bank and sandy flats and swamps on the south bank; it is 1-2 m deep in the lower reaches and to 5 m in the upper reaches. There are three river channels through the Deep River delta only, one of which is navigable. The uppermost estuarine reaches of both rivers are blocked by fallen logs.

Both rivers discharge through extensive riverine deposits and deltas and over the wide sandy shallows into Nornalup Inlet, and navigation channels are dredged through these. The Deep River was originally dredged in 1954. L. H. Thompson (local resident) reported that nearly 2000 mm of rain had fallen over the whole of 1955 and a lot of silt had come down the River, but the dredged channels were not filled in. The banks fell in and left a course about 35 feet wide which was a fraction wider and approximately a foot deeper than the original bed. On the southside of the river, the sediment fell in to a small part of the channel. Progressive siltation occurred but no dredging was required until 1956. In the summer of 1961/62 explosives were used to increase the depth slightly .

The Frankland River was also dredged in 1954. No siltation was observed when the channels were examined in 1956 and 1958, but in 1963, 30 m^3 had to be dredged. During the January 1982 flood the Frankland River banks were seen to be falling in near the Monastery and one of the dredged channels had silted up to almost half its depth since the last dredging (Marine and Harbours).

The delta sands have been reworked by wave action to form a series of beach ridges that are now fixed by vegetation. These are particularly well developed in the Deep River delta.

WALPOLE INLET There are rocky shores on the southern and north eastern shores; the eastern and western shores are low-lying and sandy or swampy where the Walpole River and Collier Creek discharge to it. The 1 km long channel from Walpole Inlet to Nornalup Inlet is bordered by steep granite hills with rocky shores.

NORNALUP INLET The shoreline is granite on either side of the Walpole Inlet channel entrance; eastwards the northern shore is in the softer Tertiary Siltstone of Coalmine Beach which is eroded into a cliff with a narrow beach at its foot. Along the south-eastern shore the dunes are truncated against the shoreline and sand eroded from the shore has formed wide shallow marginal shoals that continue north of the Frankland River mouth to Coalmine Beach. The western shore is formed by the swamps and beach ridges on either side of the Deep River delta. South of this a sand spit is progressively enclosing a small bay. A shoal links the delta to the granite Newdegate Island (Snake Island), which rises to 19 m. The sandy south-western shore is interrupted for a short distance by rock and poorly consolidated sandy lignite outcrops on the floor of the Inlet.

INLET CHANNEL and BAR The channel from Nornalup Inlet to the sea has taken different routes through the mobile sands of the flood tide delta (Figure 3.12). It now first hugs the eastern shore, swings south west and then sharply eastward against a limestone cliff and the granite at the mouth. (Figure 3.11). The channel here narrows to about 20 m, being constricted by the sand spit from the coastal dunes to the north east. It may be several metres deep here, but shallows to less than 1 m where it crosses the wide flood tide delta. The ebb tide (sea) bar shallows to less than 1 m, but never closes completely. The sand spit on the eastern shore is about 2 m above mean sea level, with only sparse vegetation for 500 m to the stable dunes. The beach is made of well sorted, fine sand with 65% quartz and 25% shelly material.

3.2 WATER DEPTHS

A hydrographic survey of Nornalup Inlet was made by PWD in 1912 (Chart 16302) and Walpole and Nornalup Inlets were resurveyed in 1985 (Figure 3.2). There are only minor differences between the two charts. Walpole Inlet is very shallow (less than 1 m) except for the dredged boat channels. The channel connecting Walpole Inlet to Nornalup Inlet has a maximum depth of 2 m. The marginal shoals of Nornalup Inlet slope steeply to the wide central area which is 3 to 5 m. A well defined channel persists off the mouth of the Frankland River to the central deep part. The wide flood tide delta is very shallow except where the narrow channels cut through it.

3.3 SEDIMENTS

The marginal shoals and deltas have clean, well sorted sands and, with a small water content, they are generally firm. There are muddy sands with shells on

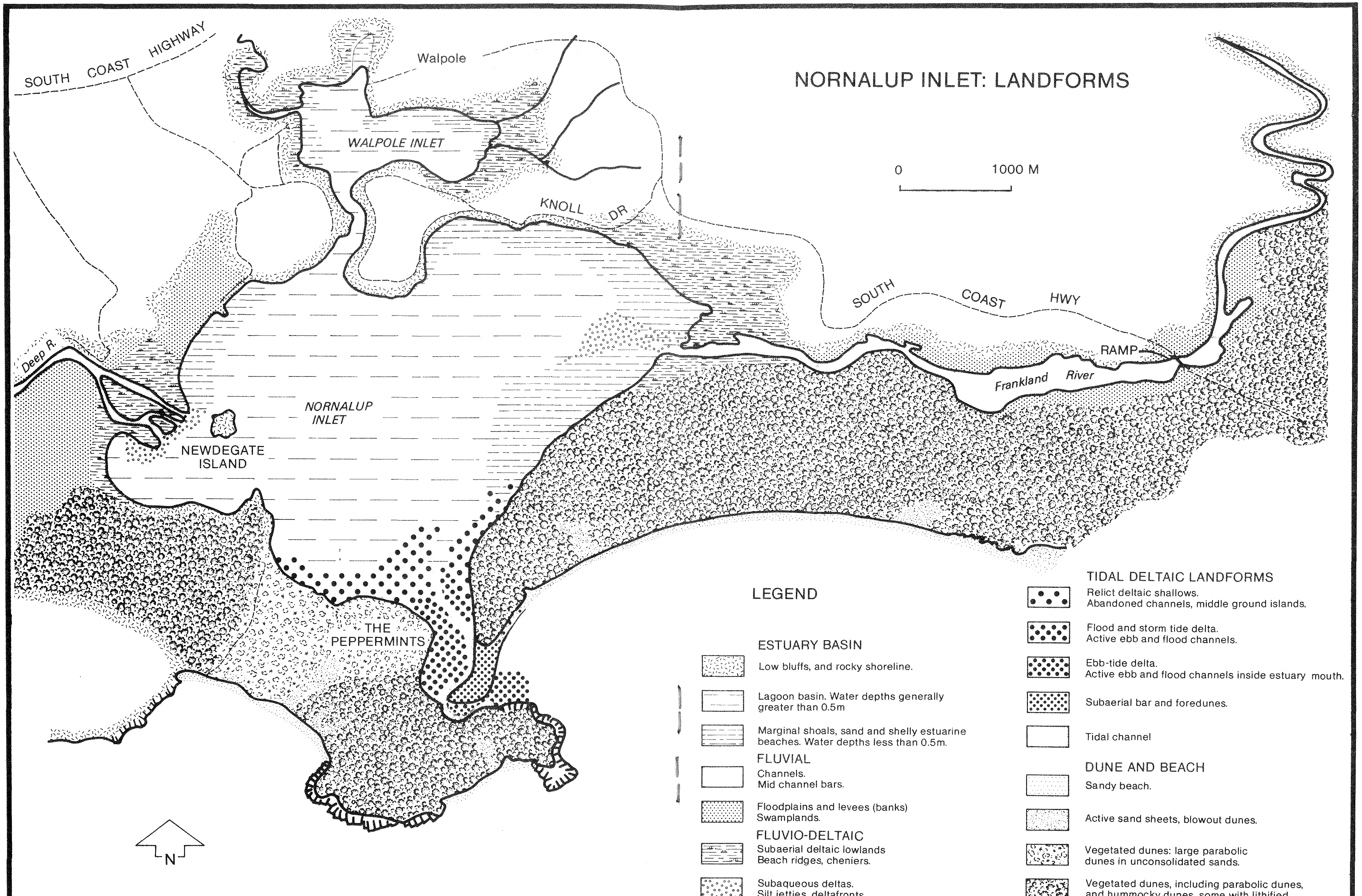


Figure 3.11 Landforms of the Nornalup-Walpole Inlet surrounds. (I. Eliot)

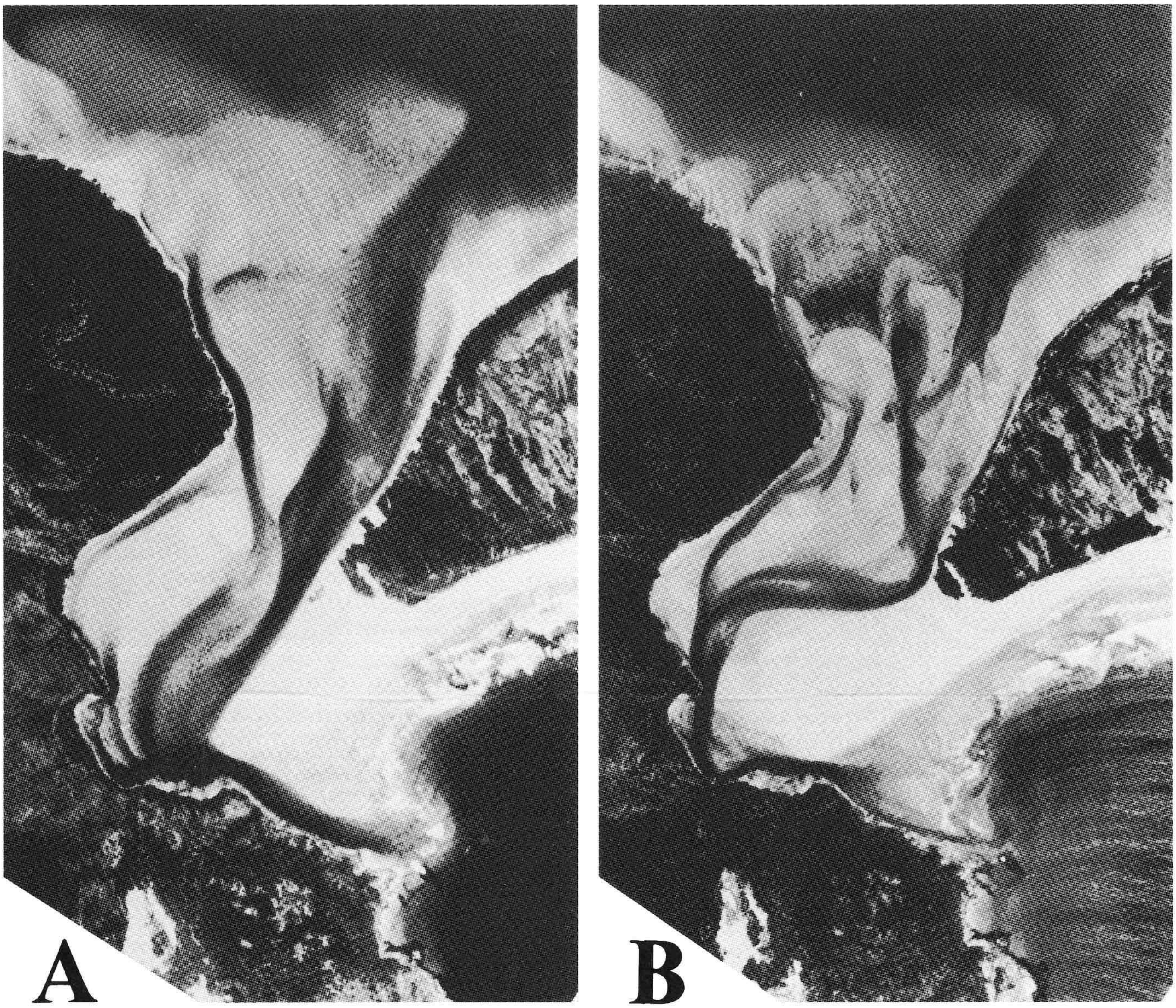


Figure 3.12 Nornalup Inlet. The inlet channel, tidal delta and bar. A January 1966, B January 1987. (Photos, Department of Land Administration, WA).

the margins of the shoals (1 - 2 m deep). In the deeper parts of Nornalup Inlet the sediment consists of sandy and clayey silts with a high water content, up to 80%. Hassell (1962) examined the sediments and reported on their mineralogical content. In Walpole Inlet the sediment is mainly a fine organic mud.

Probes taken in the dredged channels of the Frankland River produced soft mud for 2-4 m and then clay (Marine and Harbours map: 33962-5-1B). A test bore at the Frankland River Bridge penetrated 16 m of sediment over weathered granite (PWD, quoted by Hassell).

3.4 GEOLOGICAL HISTORY OF THE ESTUARY

The Deep and Frankland are ancient rivers that have cut deep valleys through the hard rocks of the plateau over millions of years. However the estuary is of very recent origin. Early in the Pleistocene it would have been an open marine embayment and the granitic headlands would have been islands. It can only have been closed off from the sea after development of the coastal dunes along Bellanger Beach and Circus Beach. During the last glaciation, sea level was more than 100 m lower than it is now and Nornalup Inlet would then have been an open valley with river channels through it, many metres below its present soft bottom (the Frankland River channel was then at least 16 m below its present level at Nornalup). It only became an estuary when the Holocene rise in sea level flooded the valley 8000 to 6000 years ago. The estuary was deep and had a wide, deep channel to the sea.

Within the last 6000 years the entrance channel has narrowed by the westward growth of the dunes along Bellanger Beach and the sand spit from them. The

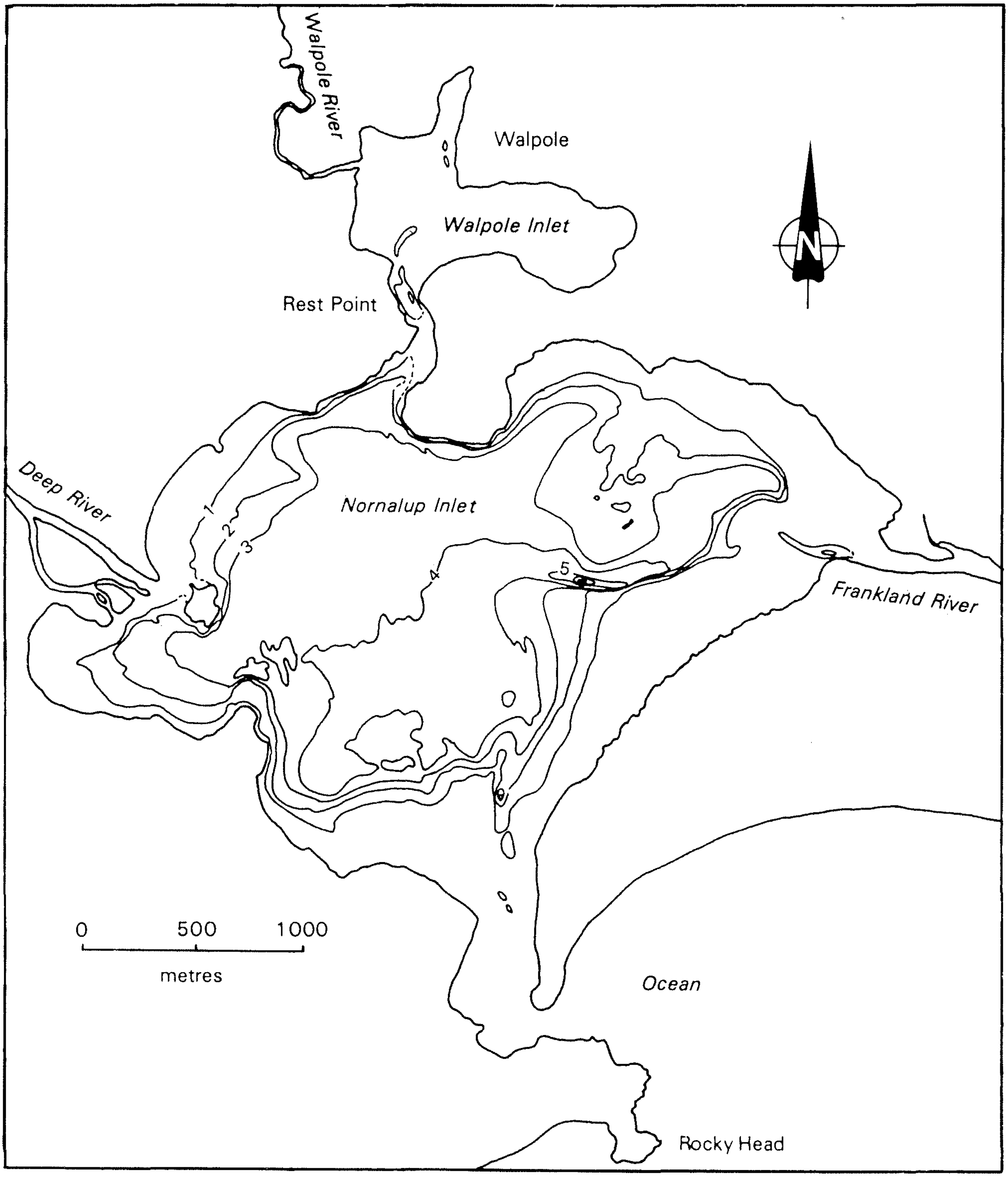


Figure 3.2 Water depths of Nornalup and Walpole Inlets. Depths in metres below chart datum, approximately 0.2 m above mean sea level (AHD) (Marine and Harbours 142-1-1, May-June 1985).

flood tide delta has formed from sand washed in from the beach, greatly shallowing the entrance channel and the southern part of Nornalup Inlet. This has reduced exchange with the ocean and so the marine influence. A considerable depth of river sediment has accumulated in the estuary and has formed a relatively flat bottom. There has been shoreline erosion by wave action in the estuary, especially along the northern and south eastern shores, and the sand has been redistributed to form the wide, sandy marginal shoals. The river valleys have silted up and the river deltas and adjacent beach ridge flats have grown out into the Inlet. All these processes of erosion and sedimentation continue at the present time, but there are no data on the quantities involved or the current rate of change.

4 Water Characteristics

4.1 SALINITY

The CSIRO Division of Fisheries took water samples at eight stations in the estuary at roughly quarterly intervals from 1944 to 1951, with data for temperature, salinity (chlorinity), oxygen, phosphate and nitrate (Rochford, 1953a , 1953b, Rochford & Spencer, 1953a, 1953b and Spencer, 1952). This, and more recent salinity data, are summarised in Figure 4.11. In summer the salinity of Nornalup Inlet water is approximately that of sea water (35 ppt) for about six months; the deep water is rarely less than 30 ppt at any time, but in winter surface salinity can fall to 10 ppt, or less in a wet winter. Salinity can be lower in winter in Walpole Inlet, but even there deep water may be half sea water salinity.

In the Frankland River the deep water is greater than 30 ppt almost to the head of the estuary in summer with lower salinity water flowing over the surface. With river flow in winter all salt water can be flushed out or may persist below the fresh surface flow (Figure 4.12). Marine salinity water also penetrates to the head of the Deep River estuary in summer, however in its sheltered reaches there is

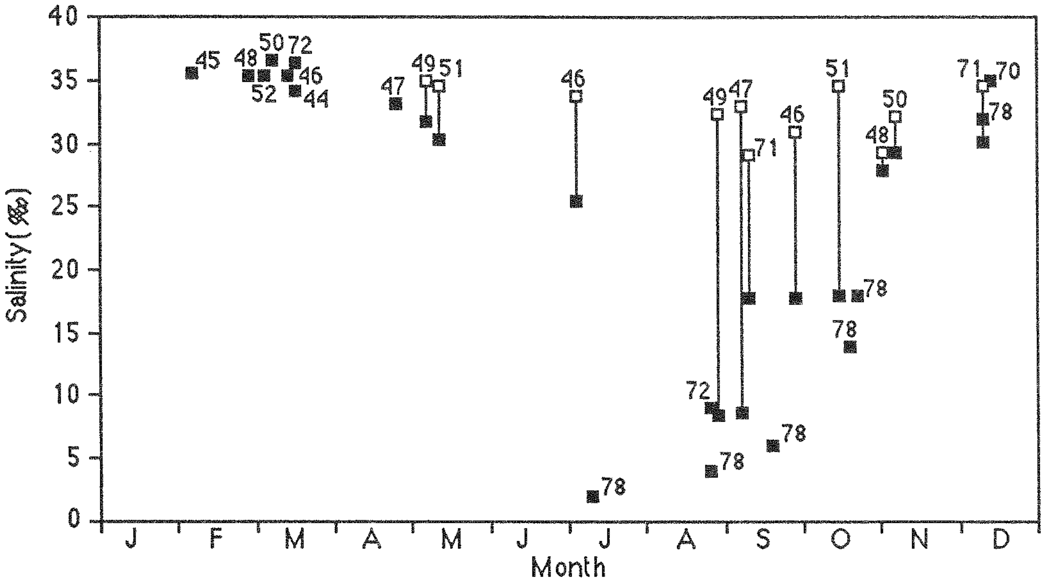


Figure 4.11 Salinities in the centre of Nornalup Inlet between 1944 and 1978, ■ surface, □ benthic. (Spencer, 1952, Lenanton and Hodgkin)

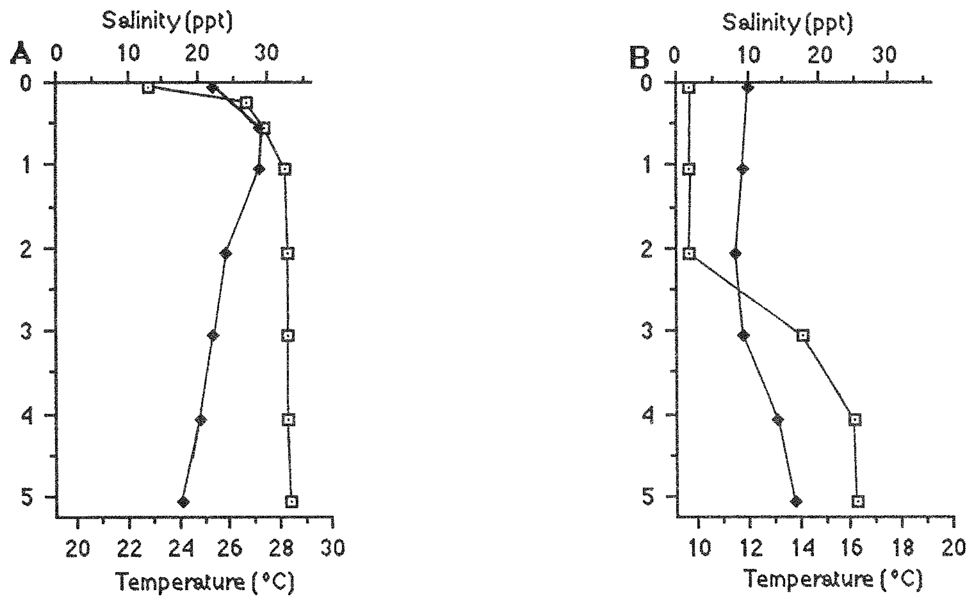


Figure 4.12 Salinity and temperature profiles in the Frankland River **A** Summer (16.2.1971, 11 km upstream) **B** Winter (21.8.1971, 6 km upstream). □ salinity, ◆ temperature. (Hodgkin)

frequently a change (halocline) between a surface layer of fresh water and highly saline bottom water, with the surface layer becoming more saline as it moves down estuary (Figure 4.13).

4.2 TEMPERATURE

In summer, water temperature in Nornalup Inlet is 20°C to 22°C and in winter it ranges from 12°C to 17°C at the surface and the deep water is often several degrees warmer. River waters show a greater range of temperature, from 11°C to 26°C at the surface and up to 28°C in deep water near the end of summer (Figures 4.12 & 4.13) .

4.3 LIGHT

The rivers carry dark tannin-stained water and fine suspended sediment in winter so reducing light penetration. In summer the intrusion of sea water makes the water much clearer.

4.4 OXYGEN

The open water of the Inlets is well oxygenated most of the time, but when stratified in winter there can be some degree of deoxygenation of bottom water. CSIRO figures for river water are generally somewhat lower than for the Inlets, with more deoxygenation (50% saturation) of bottom water when stratified. There could be severe oxygen lack in the deep water if the extreme stratification shown in Figures 4.12 and 4.13 is prolonged.

4.5 NUTRIENTS

The limited nutrient data (Spencer,1952; WA Fisheries Dept data 1975; EPA data 1987) indicate that nutrient levels are low in river and estuary water. The Fisheries Department data are shown in Tables 4.51 and 4.52. The somewhat higher total P figures for Walpole River and Inlet suggest some degree of nutrient enrichment.

Table 4.51 Nitrogen, µg/l, August 1974 (winter) and February 1975 (summer), S=surface, B=bottom. Lenanton and Edmonds, 1975, unpubl.

Sample site	S/B	Winter		Summer	
		NO_3	TOT	NO_3	TOT
Deep River	S	20	700	30	620
	B	20	960	20	600
Walpole River	S	30	1100	20	400
	B	20	1300	20	510
Frankland River	S	20	1600	20	500
	B	20	1600	20	410
Nornalup Inlet	S	20	1400	30	230
	B	20	480	20	300
Walpole Channel	S	30	640	20	390
	B	20	450	20	980

Table 4.52 Phosphorus, µg/l, August 1974 (winter) and February 1975 (summer), S=surface, B=bottom. Lenanton and Edmonds, 1975, unpubl.

Sample site	S/B	Winter		Summer	
		PO_4	TOT	PO_4	TOT
Deep River	S	10	10	10	10
	B	10	10	10	10
Walpole River	S	40	60	10	30
	B	30	60	10	40
Frankland River	S	30	30	10	10
	B	10	40	10	30
Nornalup Inlet	S	10	30	10	10
	B	10	30	10	20
Walpole Channel	S	10	40	20	40
	B	10	40	10	40

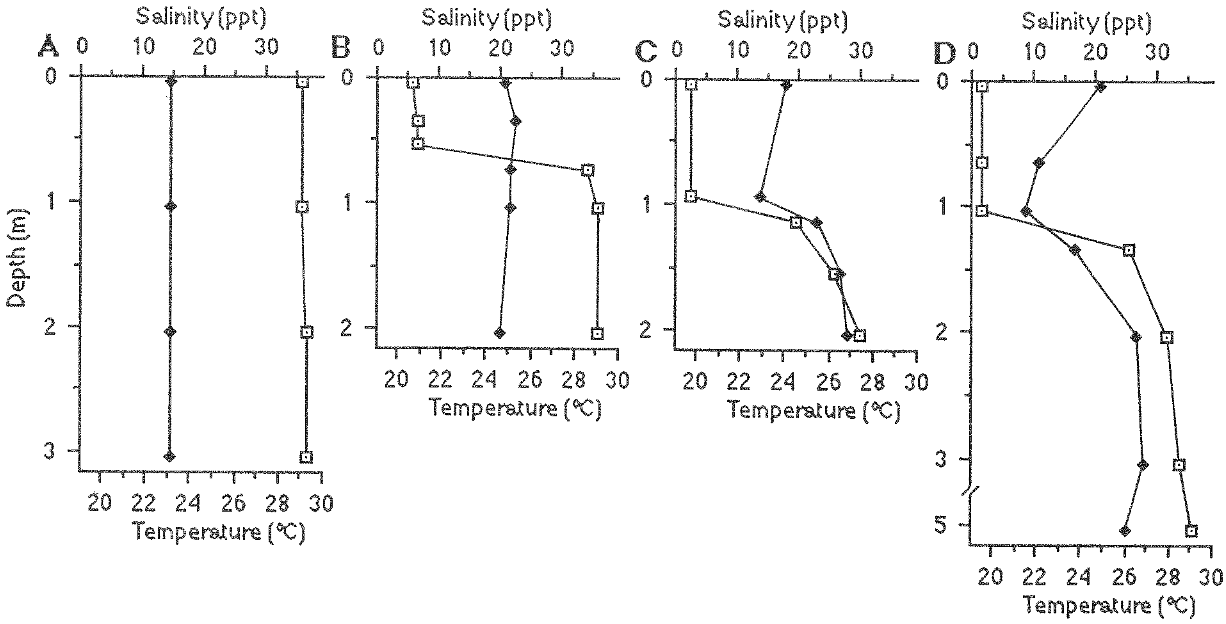


Figure 4.13 Salinity and temperature profiles along the Deep River on 5 March 1972 at, **A** the mouth, **B** 2.4 km, **C** 4.5 km and **D** 5.9 km upstream. ▫ salinity, ◆ temperature. (Hodgkin)

5 Vegetation Figure 5

5.1 AQUATIC PLANTS

The aquatic vegetation was surveyed in October 1976 (M. Cambridge) and again in January 1987 (J. Chambers) and on both occasions was found to be sparse.

The seagrass *Ruppia megacarpa* occurs in shallow water on sandflats near the Deep River delta and stunted plants on the south eastern shore, where the more marine species *Heterozostera tasmanica* was also found towards the mouth in 1976. A brown alga *Cystoseira trinodes* covered the sublittoral rocks near the mouth of the Walpole-Nornalup channel in 1987; both this and the *Ruppia* were heavily overgrown by the epiphytic filamentous green alga *Chaetomorpha billardieri* and the fine filamentous red alga *Monosporus australis*. The *Ruppia* was healthier in slightly deeper water in 1976 and was then flowering.

The green algae *Chaetomorpha linum* and *C. aurea* were abundant in Walpole Inlet in 1973-74 (Lenanton pers. comm.) and *Cladophora* was reported as growing on muddy sand in 1976. Occasional mats of floating green algae *Enteromorpha intestinalis* and *Chaetomorpha billardierii* were noted in the shallows on the eastern side in 1987. The small green alga *Acetabularia calyculus* was commonly attached to rocks and shells in the shallows. In 1976, living algae covered a layer of dying and dead algae 10-20 cm thick over black deoxygenated ooze in water 1-2 m deep in Walpole Inlet.

5.2 MARSH PLANTS

The rocky shores are steep and allow little colonisation by fringing marsh. Elsewhere the rush *Juncus kraussii* fringes the estuary in front of all the terrestrial plant communities except coastal heath. In general the rush band is only one plant wide due to the steep slopes. In slightly flatter areas the sedges and grasses *Baumea juncea, Ammophila arenaria**, *Lepidosperma gladiatum, Paspalum vaginatum** and *Isolepis nodosa* are found behind the *Juncus* community.

The Scented Boronia (*Boronia megastigma*) and the insectivorous pitcher plant (*Cephalotus follicularis*) grow in the peaty swamps of the National Park.

5.3 TERRESTRIAL VEGETATION

The sand spit at the mouth is sparsely colonised by *Ammophila arenaria**, *Arctotheca populifolia** and *Isolepis nodosa and* marram grass has been planted on it. The nearby dune vegetation includes these plants, but is dominated by the shrubs *Leucopogon parviflorus, Olearia axillaris, Acacia littorea* and the sedge *Lepidosperma gladiatum.*

On the lee side of the dune, on the banks of the Inlet, this coastal heath gives way to a community dominated by Peppermint trees (*Agonis flexuosa*) together with the shrubs *Spyridium globulosum, Olearia axillaris, Rhagodia baccata, Billardiera variifolia* and the sedge *Lepidosperma gladiatum.*

In low-lying areas near the mouths of the rivers and near Walpole a low scrub community is dominated by the yellow-flowered shrub *Oxylobium heterophyllum* (Table 5.3). Near Walpole this community contains numerous weed species, bracken and grasses, and is covered with native dodder (*Cassytha* sp.).

Table 5.3 Species identified in the *Oxylobium heterophyllum* community (J. Chambers).

Jacksonia horrida	*Macrozamia riedlei*
Beaufortia sp.	*Xanthorrhea preissii*
Acacia pulchella	*Lepidosperma gladiatum*
Astartea fasicularis	*Euphorbia* sp.
Anigozanthos sp.	

The steep, forested hillsides fringing the Walpole-Nornalup channel, the southwestern shore of Nornalup Inlet, and along the Deep and Frankland rivers, have fine stands of Karri (*Eucalyptus diversicolor*), with Red Tingle (*E. jacksonii*) and Yellow Tingle (*E. guilfoylei*). On the headlands a narrow community dominated by Peppermints separates the forest from the *Juncus* fringe. On the southern shore peppermints are replaced by *Oxylobium heterophyllum* .

6 Fauna

6.1 ANIMAL PLANKTON

The common estuarine copepod *Gladioferens imparipes* dominates the true plankton of the Deep and Frankland rivers, over the full range of salinites experienced. The euryhaline marine species *Acartia tonsa* is dominant at higher salinities in the Inlets, but *G. imparipes* is also common there at lower salinities (Table 6.1). The larvae of benthic animals are also abundant at times, particularly the veliger larvae of gastropod molluscs.

Table 6.1 Copepods taken in zooplankton samples, 1970-72 (Hodgkin).

	Rivers		Inlets	
	Deep	Frankland	Nornalup	Walpole
Gladioferens imparipes	++++	+++	+	+++
Acartia sp.	+	+	+++	++++
Oithona sp.	++	+	++	+
Kelleria sp.	++	+		
Sulcanus conflictus	+		+	
Halicyclops sp.	+	+		

*Introduced species

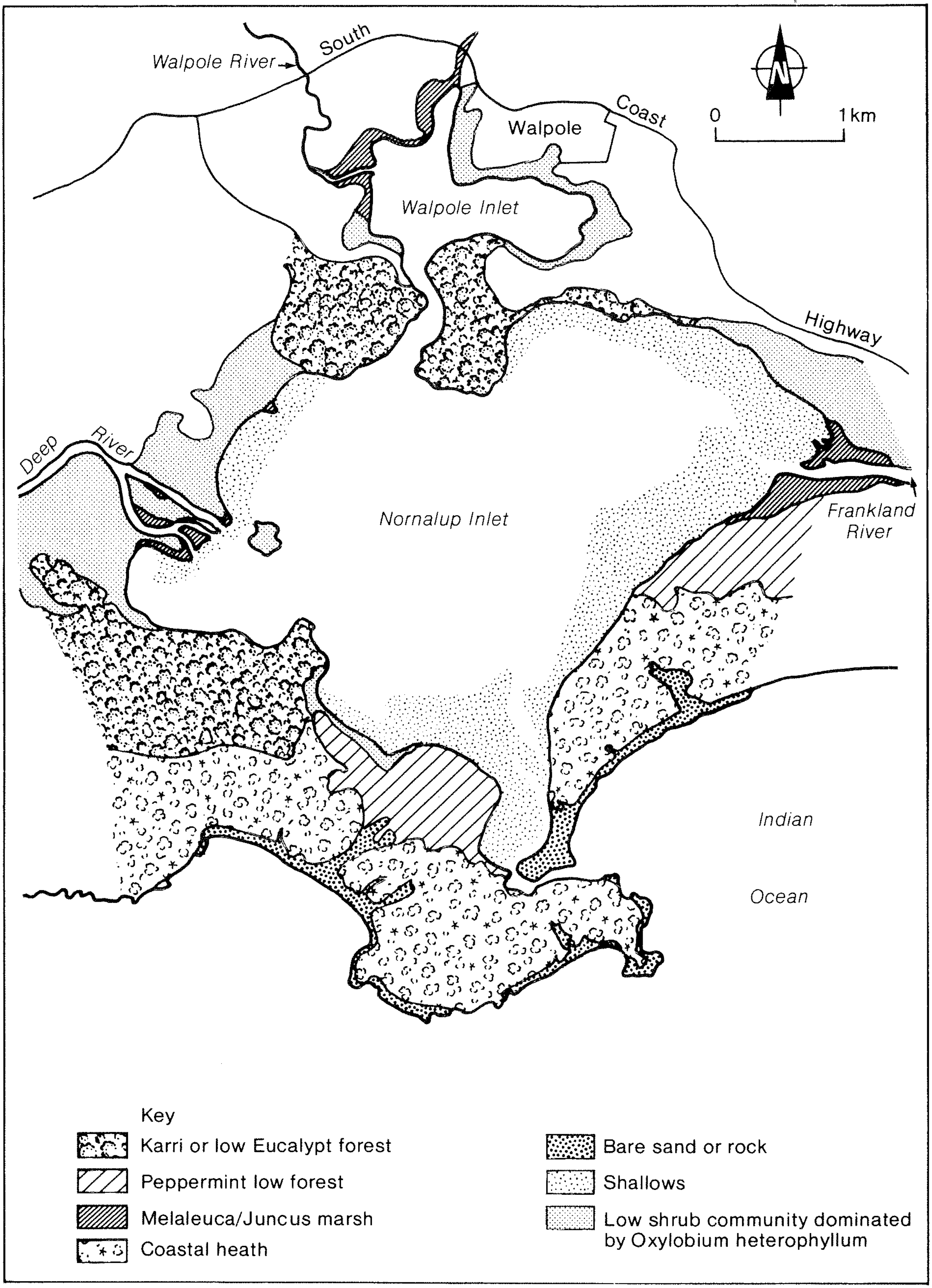


Figure 5 The Nornalup-Walpole estuary. Marsh and terrestrial vegetation. (J. Chambers)

6.2 BOTTOM FAUNA

The benthic fauna of the estuary was surveyed by J. Shaw in April 1987 (Table 6.21) and J. Wallace in October 1976 (Table 6.22).

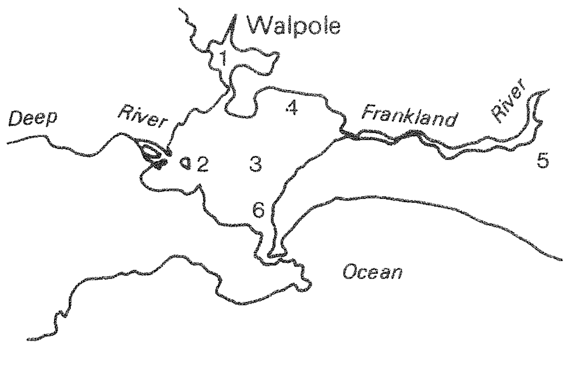
The permanently open bar and high salinity of Nornalup Inlet water permit the establishment and survival of more invertebrate species than are found in other estuaries of the south coast, except in Oyster Harbour.

Table 6.21 Benthic invertebrate fauna. Nornalup-Walpole estuary, April 1987 (J. Shaw).

Sample site		Walpole Inlet[1]	Newdegate Island[2]	Nornalup basin[3]	Coalmine Beach[4]	Frankland River[5]	Tidal delta[6]
POLYCHAETA:							
Phyllodocidae	- Phyllodoce sp.	+	+	—	+	+	—
Hesionidae	- Gyptis sp.	—	+	+	++	—	—
Nereididae	- Ceratonereis aequisetes	—	+	—	+	+++	—
	- Laeonereis sp.	—	—	—	++	—	++
	- Neanthes sp.	—	—	—	—	—	++
Nephtyidae	- Nephtys inornata	++	++	++	—	—	—
Orbiniidae	- Scoloplos simplex	++	—	+	++	++	++
Paraonidae	- Polydora sp.	—	—	—	—	+	—
	- Prionospio sp.	+	+	+	—	—	—
	- Boccardia sp.	+	—	—	+	—	—
Opheliidae	- Armandia sp.	—	—	—	—	—	+
Capitellidae	- Capitella capitata	+++	+++	+++	+++	++	+++
Serpulidae	- Mercierella enigmatica	—	++	—	—	—	—
CRUSTACEA:							
Cirripedia	- Balanus variegatus	+	—	—	++	+	—
	- Eliminus modestus	—	—	—	+	—	—
Mysidacea	- Mysid sp.	+	—	—	+	—	+
Amphipoda	- Corophium minor	+++	+	—	—	+	+
	- Paracorophium sp.	—	—	—	++	—	—
	- Neomicrodeutopus sp.	+++	—	—	—	—	—
	- Melita sp.	+	—	—	—	—	—
Decapoda	- Halicarcinus ovatus	+	—	—	+	+	++
	- Pilumnus fissifrons (cf)	—	++	—	+	—	—
	- Ovalipes australiensis	—	—	—	—	—	+
	- Portunus pelagicus	—	—	—	—	—	+
	- Palaemonetes australis	+	—	—	+	+	+
	- Macrobrachium intermedium	—	—	—	—	—	+
MOLLUSCA:							
Gastropoda	- Diala sp.	—	—	—	—	+	—
	- Nassarius burchardi	+	—	—	++	—	++
	- Nassarius pauperatus	—	—	—	—	—	+
	- Liloa brevis	+	—	—	—	—	—
	- Philine sp.	+	++	—	++	+	+
Bivalvia	- Xenostrobus securis	—	—	—	—	++	—
	- Musculus paulucciae	—	—	—	+	+	+
	- Anomia trigonopsis	—	—	+	—	—	—
	- Wallucina assimilis	—	+	—	+	—	++
	- Arthritica semen	—	—	—	—	+++	—
	- Spisula trigonella	++	—	—	++	++	+
	- Soletellina donacioides	—	—	+	+	—	+++
	- Katelysia peroni	—	—	—	+	—	—
	- Katelysia scalarina	—	—	—	+	—	+
	- Irus crenata	—	—	—	—	+	—
	- Theora lubrica	++	+	++	—	+	—
	- Macomona deltoidalis	—	—	—	—	+	—
	Depth (m)	2.5	1-2.5	3	2	1-1.5	0.5-2
	Bottom type	Mud			Sand		

— not found
\+ present
++ abundant
+++ very abundant

Sites are referred to above.



Two amphipod species dominated the mud of Walpole Inlet in 1987; occurring only sporadically at other sites. The small 'opportunistic' polychaete *Capitella capitata* was abundant throughout the estuary.

Table 6.22 Additional benthic fauna (Hodgkin, Kendrick & Wallace; Wells, 1984).

POLYCHAETA:	MOLLUSCA: Gastropoda
Arenicola sp.	*Salinator fragilis*
	Opistobranch
CRUSTACEA:	MOLLUSCA: Bivalvia
Metapenaeus dalli	*Mytilis edulis*
Palaemonetes serenus	*Xenostrobus pulex*
Leander sp.	*Ostrea* sp.
Cyclograpsus audociuni	*Fulvia tenuicostata*
Portunus pelagicus	*Paphies elongata*
	Sanguinolaria biradiata
MOLLUSCA: Gastropoda	*Fluviolanatus subtorta*
Haminoea sp.	*Pholas australasiae*
Nerita atramentosa	
Tatea preissii	INSECTA:
Assiminea sp.	*Pontomyia cottoni*
Hydrococcus brazieri	Chironomid

In Nornalup Inlet the fine mud of both the Newdegate Island and the deeper basin site had a relatively impoverished fauna compared with the three sandy sites. This was particularly evident with the total lack of crustacea and few molluscs collected in the basin.

A range of mollusc species was collected from all the sandy sites. The Frankland River site was dominated by the typical estuarine bivalves *Xenostrobus, Arthritica* and *Spisula*. Crustacea of the flood tide delta were mostly marine decapods, few of which occurred at other sites.

There are no data on the seasonal abundance of the fauna in Nornalup Inlet, however Lenanton (pers. comm.) found a decrease in diversity of species and of their abundance in winter while studying the fauna of Walpole Inlet in 1973/74.

The large number of species of Foraminifera found by Hassell (1962) also reflects the relatively marine condition of the estuary (Table 6.23).

Table 6.23 Forminifera of Nornalup and Walpole Inlets (Hassell,1962).

Massilina secans	*Sigmoilina schlumbergeri*
Labrospira wiesneri	*Ammobaculites agglutinans*
Miliammina arenacea	*Quinqueloculina bosciana*
Quinqueloculina seminula	*Halplophragmoides canariensis*
Spiroloculina cushmani	*Triloculina oblonga*
Vertebralina striata	*Fissurina* sp. 1
Lagena globosa	*Guttulina pacifica*
Bolivina bassensis	*Bolivina punctata*
Bolivina subreticulata	*Cassidulina crassa*
Anomalina bassensis	*Elphidium macellum*
Elphidium poeyanum	*Robertina* sp.

6.3 FISH

Table 6.3 lists 37 fish species identified from the estuary. Most species are of marine origin although estuarine and inshore marine species are individually the most numerous. The few true estuarine species are also individually abundant. Apart from Black bream, the recreationally important species are primarily estuarine and inshore marine species. They include Whiting, Trevally, Herring and juvenile WA salmon.

Table 6.3 Fish of Nornalup and Walpole Inlets (Lenanton pers. comm.).

Common name	Scientific name
<u>Anadromous</u>	
Wide mouthed lamprey	*Geotria australis*
<u>Estuarine</u>	
Black bream	*Acanthopagrus butcheri*
Blue spot goby	*Pseudogobius olorum*
Hardyhead	*Atherinosoma wallacei*
Hardyhead	*Atherinosoma elongata*
<u>Predominantly estuarine</u>	
Sea mullet	*Mugil cephalus*
Tarwhine	*Rhabdosargus sarba*
<u>Estuarine and inshore marine</u>	
Hardyhead	*Atherinosoma presbyteriodes*
Yelloweye mullet	*Aldrichetta forsteri*
King George whiting	*Sillaginodes punctata*
Southern blue-spotted flathead	*Platycephalus speculator*
Striped trumpeter	*Pelates sexlineatus*
Sand trevally	*Pseudocaranx wrighti*
W.A. salmon	*Arripis truttaceus*
Pink snapper	*Chrysophrys auratus*
Long-snouted flounder	*Ammotretis rostratus*
Cobbler	*Cnidoglanis macrocephalus*
Herring	*Arripis georgianus*
Tailor	*Pomatomus saltator*
Southern anchovy	*Engraulis australis fraseri*
<u>Predominantly marine</u>	
Beardie	*Lotella rhacinus*
Southern school whiting	*Sillago bassensis*
Long-finned goby	*Favonigobius lateralis*
Lemon tongue sole	*Paraplagusia unicolor*
Spiny-tailed leatherjacket	*Bigener brownii*
Toothbrush leatherjacket	*Penicipetta vittiger*
Trevally	*Pseudocaranx dentex*
Banded toadfish	*Torquigener pleurogramma*
Rosy weedfish	*Heteroclinus roseus*
Wirrah	*Acanthistius serratus*
Porcupine fish	*Dicotylichthys jaculiferus*
Serpent eel	*Ophisurus serpens*
Gummy shark	*Mustelus antarcticus*
Southern shovelnose ray	*Aptychotrema vincentiana*
Yellow-finned whiting	*Sillago schomburgkii*
Beaked salmon	*Gonorynchus greyi*
Red gurnard	*Cheilidonichthys kuma*

Because the bar does not close recruitment of marine species is not restricted, as it is to most south coast estuaries. The only hinderance may be when the water in the channel is extremely turbulent in the shallow entrance as a result of sea swell, or during periods of strong outflow from the estuary in winter.

6.4 WATERBIRDS

Table 6.4 lists 21 species of waterbird recorded by various observers.

Table 6.4 Waterbirds recorded at Nornalup-Walpole Inlet (Ashby & LeSouef (1928); R. Clark; J. Lane; Munro; Peden; RAOU; P. Yewers). Numbers indicate highest recorded.

Common name	Scientific name	
Australian Pelican	*Pelecanus conspicillatus*	43
Great Cormorant	*Phalacrocorax carbo*	
Little Black Cormorant	*Phalacrocorax sulcirostris*	
Pied Cormorant	*Phalacrocorax varius*	
Little Pied Cormorant	*Phalacrocorax melanoleucos*	
White-faced Heron	*Ardea novaehollandiae*	
Black Swan	*Cygnus atratus*	468
Pacific Black Duck	*Anas superciliosa*	140
Silver Gull	*Larus novaehollandiae*	
Crested Tern	*Sterna bergii*	
Caspian Tern	*Hydroprogne caspia*	
Musk Duck	*Biziura lobata*	3
Grey Teal	*Anas gibberifrons*	50
Australian Shelduck	*Tardorna tadornoides*	2
Eurasian Coot	*Fulica atra*	
Wood Duck	*Chenonetta jubata*	
Pacific Gull	*Larus pacificus*	3
Sacred Ibis	*Threskiornis aethiopicus*	2
Osprey	*Pandion haliaetus*	1
White Breasted Sea Eagle	*Haliaeetus leucogaster*	2
Red Capped Plover	*Charadrius ruficapillus*	1

7 Management

Nornalup-Walpole is the only permanently open estuarine system surrounded by predominantly forested National Park. As such it is scenically and aesthetically one of the state's most spectacular estuarine environments. For many years it has been the recreational focus both for the many visitors to the Walpole-Nornalup National Park and for the local community, all of whom enjoy activities such as fishing and boating (many through the facilities of the sailing club situated at Coalmine Beach). Thus every effort should be made to preserve this unique estuarine environment and protect it from undesirable developments that would compromise this outstanding recreational facility.

Net fishing and spear fishing are prohibited throughout the estuary at all times. Other than legal minimum sizes for nominated species, there is no restriction on line fishing. The long standing net fishing ban has helped conserve estuarine fish stocks and so contributed to the excellent recreational fishing oportunities in this system today.

Nornalup Inlet is not eutrophic and it is unlikely to become so while the major river flow continues to come from forested land, the mouth remains open and the lands adjacent to the estuary remain largely undeveloped. However, Walpole Inlet is potentially eutrophic, the restricted exchange with Nornalup Inlet, the very shallow water, and the proximity of unsewered residential areas make it vulnerable.

Boat channels were dredged in Walpole Inlet in 1974 and though there have been complaints about weed accumulating in them they have not needed to be dredged since. The channels through the lower reaches and deltas of the Deep and Frankland Rivers have to be dredged from time to time, especially following major floods. They were last surveyed in 1970 (PWD WA 33962-5-1 and 16302-10-1). Logs brought down by the river obstruct the uppermost reaches of the Frankland river, preventing boat access, and some logs remain as snags lower down. They protect the banks from erosion, particularly by the wash from speeding boats, and provide sheltered habitats for fish and other fauna. There is an 8 knot speed limit in the rivers and through the channel between Walpole and Nornalup Inlets. The channel through the flood tide delta is shallow and ill defined; the sea bar (the ebb tide delta) is often very shallow and made dangerous by waves breaking on it.

Extrapolating from the history of other south coast estuaries, closure of the bar must be considered a possibility. The greater river flow and the geometry of the entrance are probably the principal relevant features in which Nornalup Inlet differs from the nearby Broke and Wilson Inlets, both of which close seasonally. For half the year the bar is kept open by tidal exchange across the massive flood tide delta and the sea bar that at times has less than a metre of water over it. The bar could close in summer but, even in the driest year, the volume of flow in the rivers is several times the volume of the estuary so that it is most unlikely that the bar would ever fail to break in winter -- unless the rivers were dammed. However, closure of the bar in summer would greatly alter the hydrology of the estuary, making it more like Broke or Wilson Inlets, and so too the ecology of the system would change with the disappearance of a large proportion of the present diverse fauna.

It is premature to speculate as to the effect of the projected rise of sea level of 0.2 to 1.4 m over the next 30 to 50 years as the result of the 'greenhouse effect'. There would be flooding and erosion of low-lying shore lines, but the extent of this and other processes such as growth of the delta and bar would depend greatly on the magnitude and rate of rise of sea level and climatic changes.

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9 Acknowledgements

The data in this inventory have been gleaned from a variety of sources - published reports, unpublished records of Government departments, the records and recollections of fishermen and others with local knowledge, from personal records, and the results of a few specially contracted studies. There are obvious gaps in our knowledge of this and the other estuaries named on the map, studies of which are now being drafted in this Estuarine Studies Series. The authors will greatly appreciate the continued assistance of those who have contributed to preparation of this study and of anyone else who has relevant information on these estuaries.

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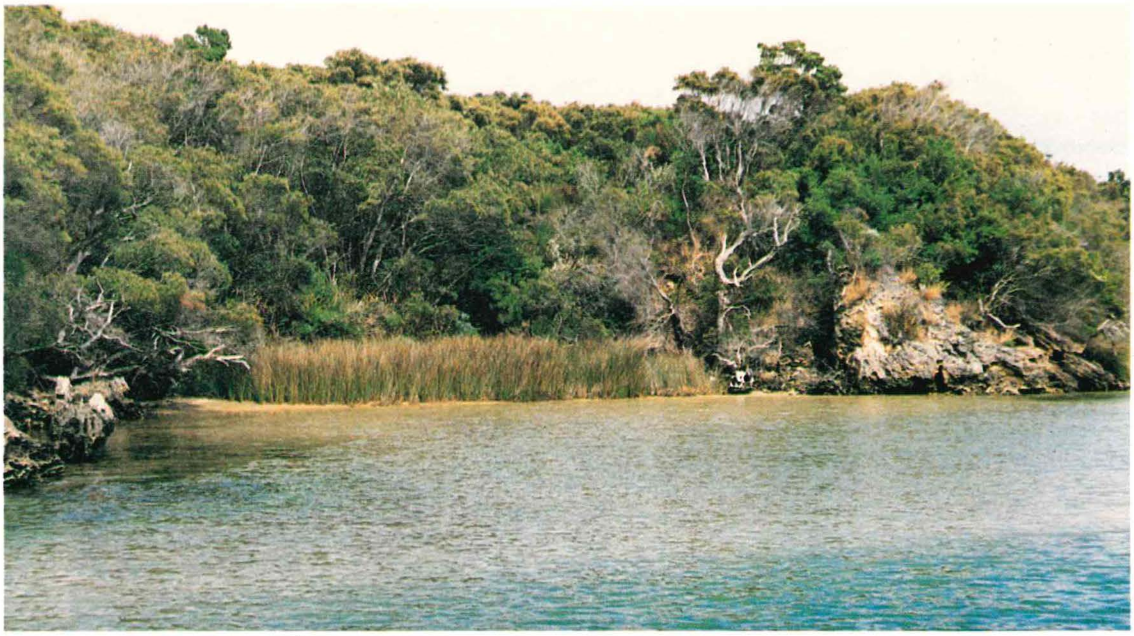

Limestone rocks and a patch of the rush, *Juncus kraussii*, near the mouth of Nornalup Inlet. Photo E P Hodgkin.

Siltstone cliffs at Coalmine Beach. Photo E P Hodgkin.

The channel from Walpole Inlet to Nornalup Inlet. Rest Point Caravan Park on the right. Photo Ruth Clark.