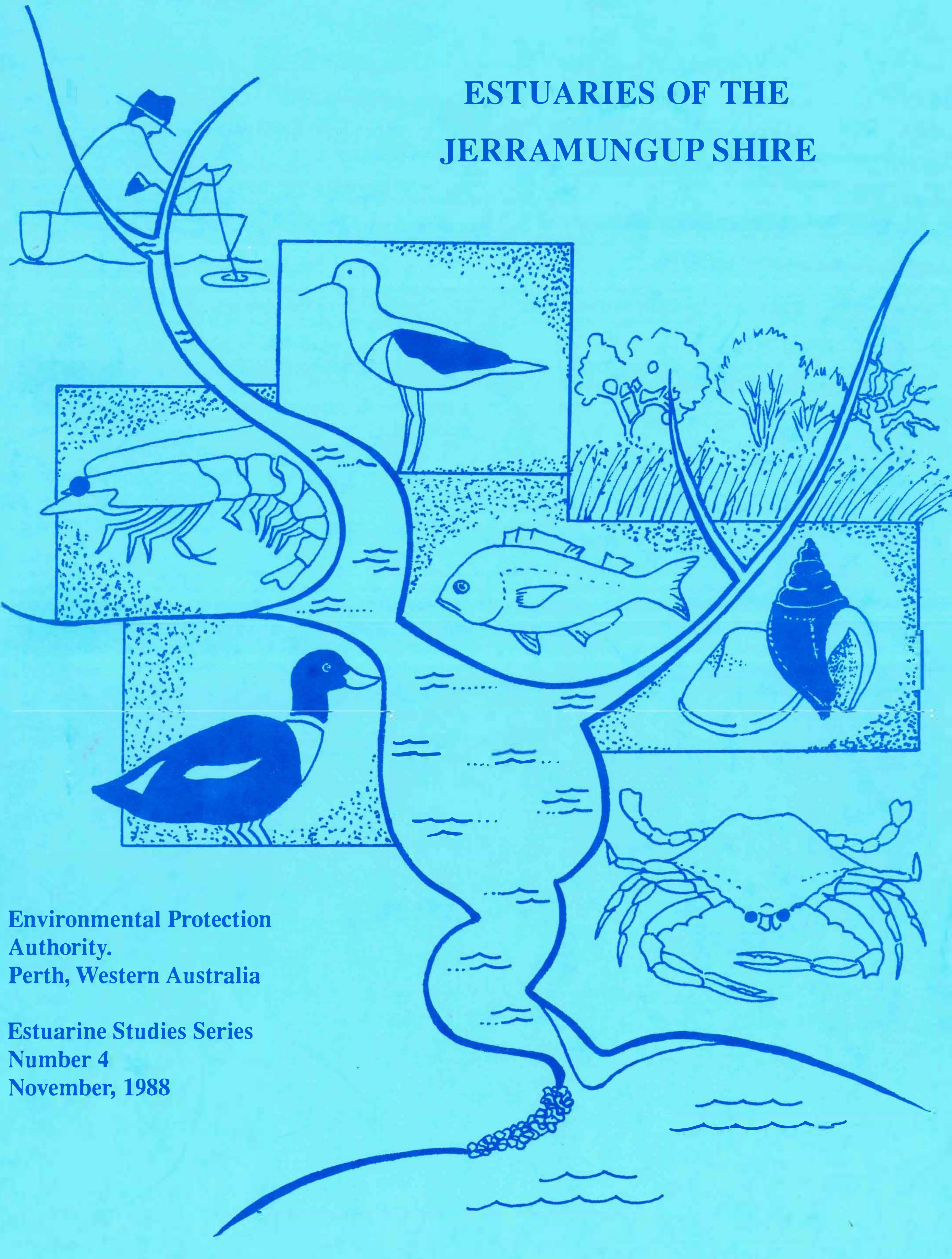
ESTUARIES AND COASTAL LAGOONS OF SOUTH WESTERN AUSTRALIA

BEAUFORT INLET AND GORDON INLET

ESTUARIES OF THE JERRAMUNGUP SHIRE



Environmental Protection Authority.
Perth, Western Australia

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Other published documents in the Estuarine Studies Series
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Wellstead Estuary No. **1**
Nornalup and Walpole Inlets No. **2**
Wilson, Irwin and Parry Inlets No. **3**

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

BEAUFORT INLET AND GORDON INLET

Estuaries of the Jerramungup Shire

By Ernest P. Hodgkin and Ruth Clark

Beaufort Inlet October 1988

Gordon Inlet. Spongolite cliff and samphire swamp.

Gordon Inlet October 1978

Environmental Protection Authority
Perth, Western Australia

Estuarine Studies Series - No. 4
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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

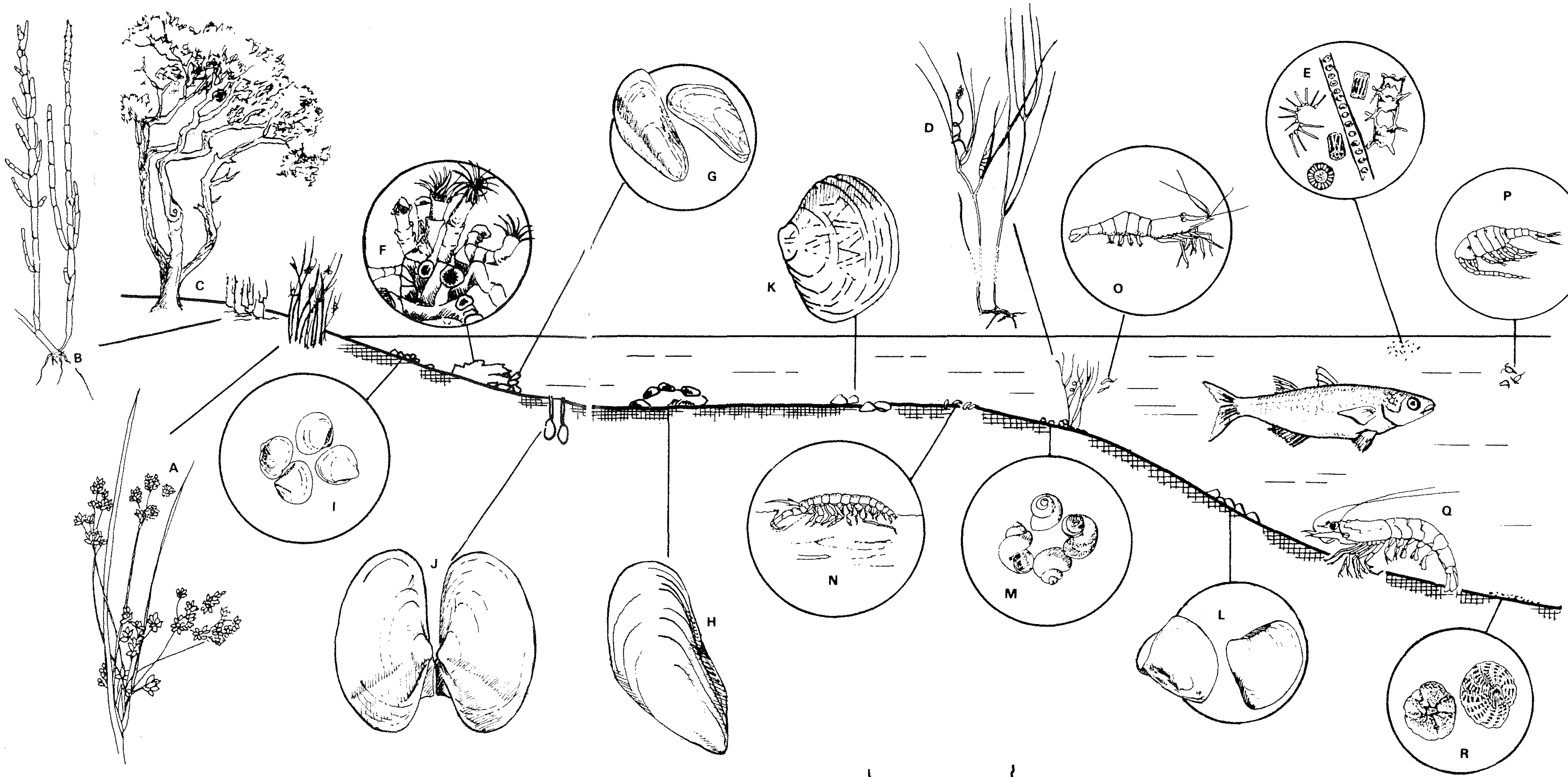
F Tubeworms - *Ficopomatos enigmaticus* 20

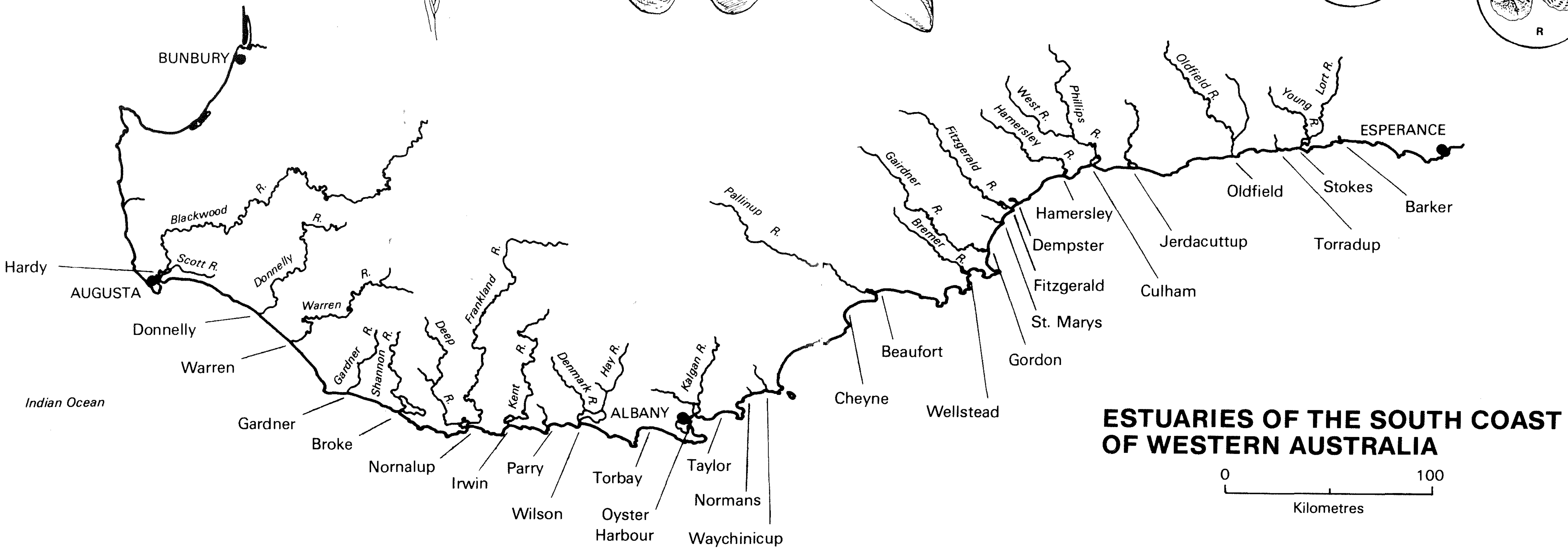
Bivalve molluscs
- G Estuarine mussel - *Xenostrobus securis* 30
- H Edible mussel - *Mytilus edulis* 100
- I *Arthritica semen* 3
- J *Sanguinolaria biradiata* 50
- K Cockle - *Katelysia* 3 spp. 40
- L *Spisula trigonella* 20

Gastropod molluscs
- M Snail - *Hydrococcus brazieri* 4

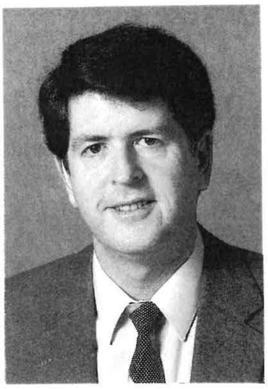
Crustacea
- N Amphipod - *Corophium minor* 15
- O Shrimp - *Palaemonetes australis* 40
- P Copepod - *Gladioferens imparipes* 2
- Q King Prawn - *Penaeus latisulcatus* 100

R Foraminifera 0.02





ESTUARIES OF THE SOUTH COAST OF WESTERN AUSTRALIA



Hon. Barry Hodge, MLA
Minister for the Environment

FOREWORD

This study of Beaufort and Gordon Inlets, in the Shire of Jerramungup, is the fourth in the series of studies prepared on the estuaries of the south west as part of the State Conservation Strategy. The three previous studies were on Wellstead Estuary (also in the Jerramungup Shire) the Nornalup - Walpole estuarine system and Wilson, Irwin and Parry Inlets.

The attraction of estuaries for recreation and for residential development have placed them under increasing pressure. The varied interests of those who use or want to use them often present authorities with difficult conflicts to resolve. Although here has been little direct pressure on Beaufort and Gordon Inlets, clearing and cultivation in the catchments has already had an impact.

This study provides valuable information for local authorities, planners and conservation groups concerned with management of the area, as well as for individuals interested in further study of our estuaries and coastal lagoons.

It has been established that there has been a great increase in the input of plant nutrients and sediment to the estuaries. They are in an area of low rainfall and high evaporation and are already very shallow. As a result, the water in Beaufort Inlet in summer is twice as salty as sea water, the nutrients make it highly eutrophic, and fish death rates are often extremely high.

I therefore commend the valuable work being done by the Soil Conservation Committees to reduce soil loss from the catchments by tree planting and other measures. However, much more still needs to be done to halt the degradation of the estuaries and their tributary rivers.

Clearly an overall approach is needed toward land use in these areas. Sensible catchment and waterway management will only occur when local residents know and care about existing and potential degradation problems.

In this regard I welcome the interest being shown by local people and local authorities and hope that this report will assist in achieving better planning and management.

CONTENTS

1 INTRODUCTION

There are three estuaries in the Shire of Jerramungup: Beaufort Inlet, the estuary of the Pallinup River; Wellstead Estuary, the estuary of the Bremer River; Gordon Inlet, the estuary of the Gairdner River (Figure 1). Wellstead Estuary was the subject of the first Study in this series of Inventories and the present Study focuses mainly on Beaufort Inlet and Gordon Inlet, with reference to Wellstead Estuary where appropriate. Until 1982 the Jerramungup Shire was part of the Shire of Gnowangerup, the history of which was written by Bignell (1977). The only town on the coastline of the Shire is Bremer Bay, on the western shore of Wellstead Estuary.

The three estuaries and their catchments lie in a region of relatively low rainfall which decreases from about 600 mm a year on the coast to 400 mm in the upper catchment, and where infrequent unseasonal heavy rains and floods can be as important to the estuarine ecology as the seasonal winter rainfall. They have common features, but also differ in important respects. All have small, shallow lagoons and relatively long riverine reaches. The sea bars of all three estuaries may remain closed for several years at a time and only break following unusually heavy rain. The Beaufort bar only stays open for a few weeks, the Wellstead bar sometimes stays open for years, and the Gordon Inlet bar for months.

Evaporation is high from the shallow water of the lagoons. The salinity of the water varies from one third to about twice that of sea water in Beaufort Inlet and Wellstead Estuary and to much more in Gordon Inlet. This is an unfavourable environment for most marine animals and plants. The permanent aquatic fauna and flora is restricted to a few estuarine species, many of which are very abundant. Marine fish and invertebrates enter when the bars are open but most do not survive long in the high salinities and there can be catastrophic mortality of the fauna. This happens at intervals of a few years in Beaufort Inlet, frequently in Gordon Inlet, which often dries up almost completely, but seldom in Wellstead Estuary. Extensive shell beds on the shores show that the estuaries had a much richer and more varied marine fauna when they were permanently open to the sea, until about 4000 years ago.

The estuaries and their single tributary rivers have a roughly north-west to south-east alignment. They have long, winding riverine reaches through narrow valleys cut into the soft spongolite rock, which is exposed in cliffs and steep slopes on the banks of the three estuaries. The Pallinup River has cut down to the hard basement granitic rock that underlies the spongolite. The mouths of the estuaries are constricted by dunes and the sea bars are part of the beaches in the bays to which the rivers discharge. The bars differ in height and structure because of their different exposure, so influencing the water retaining capacity of the estuaries. Beaufort Inlet has a high bar so that water level varies greatly between flood and late summer conditions. Both Wellstead Estuary and Gordon Inlet have low bars and there is much less variation in water level in the shallow lagoons.

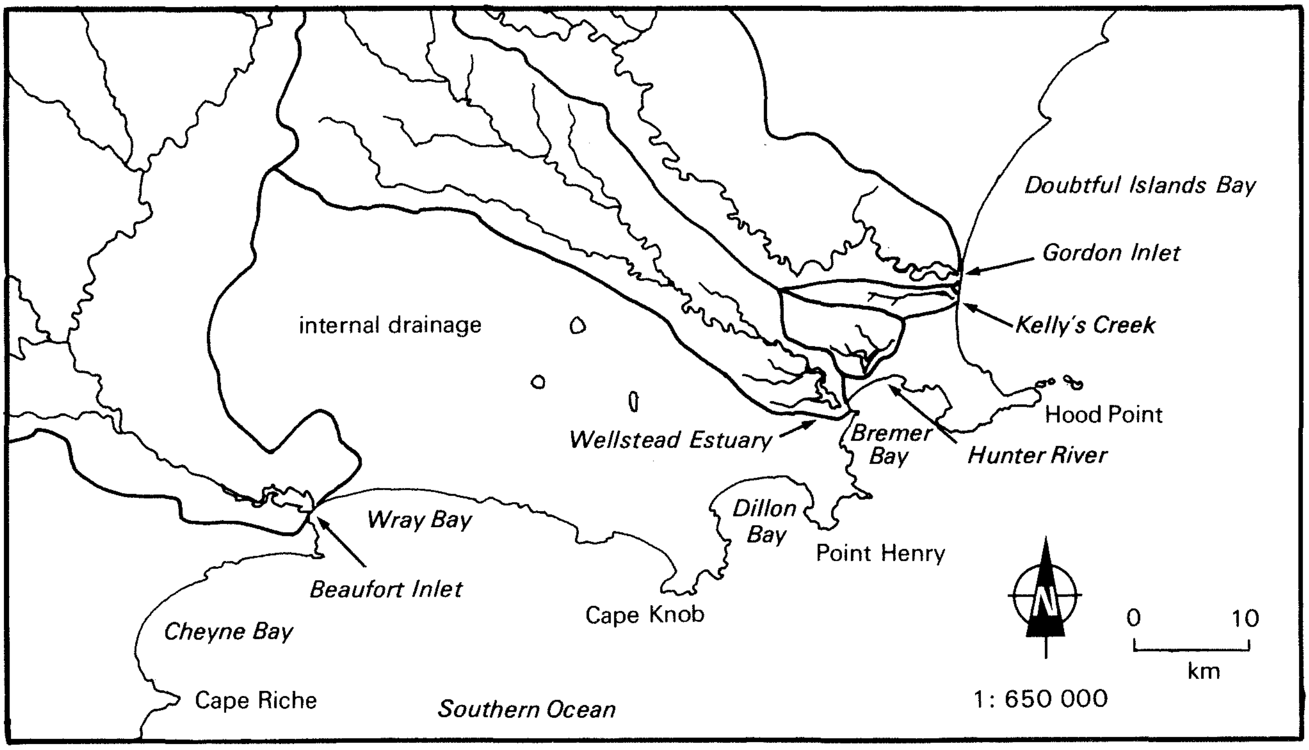


Figure 1 The location of the estuaries in the Jerramungup Shire.

The catchments differ greatly in size. The Pallinup River is the largest on the low rainfall part of the south coast east of Albany, the Bremer River catchment is one seventh its size and the Gairdner River catchment rather more than one third. In consequence the volume of flow to the estuaries differs greatly. Also while 84% of the Pallinup catchment has been cleared for agriculture, and 80% of the Bremer catchment, only 60% of the Gairdner catchment has been cleared. In all three the major clearing has taken place only recently, in the 1950s and 1960s. The effect of this on the estuaries has yet to be adequately assessed, but there is good reason to believe that the rate of sediment transport to the estuaries and sedimentation in them has increased considerably, especially in Beaufort Inlet.

Sediment both from land and sea has almost filled the lagoons and all three estuaries are now much shallower than they would have been 6000 years ago when first flooded by the post-glacial rise of sea level. Sedimentation is the major long term environmental issue, but the estuaries pose different short term management problems. The kilometre long inlet channels of Gordon Inlet and Wellstead Estuary are almost blocked by marine sand which has washed or blown into them. Gordon Inlet is now so shallow that it has reached the stage in its evolution at which it no longer warrants the name 'estuary' in the usual sense of the term. The lagoon dries up and only the riverine reaches always retain water and have a permanent, though restricted, flora and fauna. Beaufort and Wellstead are little better in this respect; the lagoons always retain water but from time to time it becomes dangerously hypersaline, more than twice sea water salinity. Beaufort Inlet is now seriously eutrophic, a condition that probably results from the heavy use of superphosphate fertilizer in the catchment of the Pallinup River. The periodic mass mortality of fish may be a product of this, of the hypersalinity of the water, or a combination of the two.

Wellstead Estuary has a number of intractable problems related to its small catchment and closure of the bar for years at a time, making the shallow water of the lagoon stagnant (Hodgkin and Clark, 1987).

Wellstead Estuary has a small permanent human population in its vicinity, holiday homes and a well frequented caravan park. Beaufort Inlet attracts a small seasonal influx of visitors, mainly locals and professional fishermen. The relative inaccessibility of Gordon Inlet and lack of facilities make it unattractive to all except professional fishermen who net the Inlet when it is full and amateurs who net the sometimes abundant fish in the riverine reaches. But when the Bremer bar is closed many tourists with four-wheel drive vehicles also explore Gordon Inlet.

1.1 LOCATION AND ACCESS

Access to all three estuaries is from South Coast Highway and the Boxwood Hill—Bremer Bay Road. Beaufort Inlet is 134 km by road east of Albany, Wellstead 152 km, and Gordon Inlet another 18 km over bush tracks from Bremer Bay. Grid references are to maps 2629 Pallinup and 2729 Bremer on the 1:100 000 topographic map series published by Natmap.

Beaufort Inlet lies between 118°47' and 119°00' East and 34°26' and 34°28' South. The mouth is at grid reference 745840. The main access to the estuary is via Millers Point Road, a good gravel road (6 km) which leaves the Boxwood Hill—Bremer Bay Road 13 km east of its junction with South Coast Highway. Apart from this there are only four-wheel drive tracks which may be boggy in winter and have patches of loose sand in summer. Paperbark Road leads to the upper estuary about 10 km from the bar and Pallinup Estuary Road leads to the north end of the bar. Access to the south side of the estuary is by Boat Harbour Road off South Coast Highway 8 km SW of the Pallinup River bridge; this is a gravel road which deteriorates to poorly marked tracks leading from Mt Groper to the south end of the bar. Small boats can be launched from the steep sandy beach at Millers Point.

Wellstead Estuary lies between 119°19' and 119°24' East and 34°20' and 34°23'30" South. The mouth is at grid reference 200915. The Boxwood Hill—Bremer Bay Road runs to the mouth of the estuary. Small boats can be launched opposite the caravan park and at the end of a rough track through the town. This can be difficult when the bar is closed and the water level is low. Four-wheel drive tracks give access to the upper estuary shoreline from Swamp Road.

Gordon Inlet lies between 119°25' and 119°30' East and 34°16' and 34°18' South. The mouth is at grid reference 300028. Access is from Bremer Bay, either across the bar and along Gairdner and Gordon Inlet Roads through Fitzgerald River National Park or, when the bar is open, along Swamp Road and Gordon Inlet Roads. These are formed gravel roads until just short of the Inlet, but may be in very poor condition. A sand track continues around the south side of the Inlet over the dunes to the mouth. Several bush tracks lead off Gordon Inlet Road to various parts of the estuary and north along Gairdner Road to the Park Ranger's house at Quaalup Homestead.

1.2 GEOLOGICAL HISTORY OF THE ESTUARIES

The estuaries are of very recent origin geologically although the valleys in which they lie are ancient; the rivers first cut their channels in the hard granitic Proterozoic bedrock (more than 1600 million years old). Then 40 million years ago the land was flooded by the Eocene sea to about 140 metres above present sea level and marine sediments filled the existing valleys and covered the lower land. These sediments formed the flat bedded spongolite rock (Plantagenet Siltstone) and when sea level fell once more the rivers again cut their channels through this softer rock. Both of these rocks and the more recent Pleistocene (the last 2 million years) sandplain that overlie them, are exposed in the valley of the Pallinup River.

Coastal dunes formed during the Pleistocene have hardened to limestone. They probably partly closed the valley mouths. Then during the last major glaciation, and until only 20,000 years ago, sea level was more than 100 metres lower than it is now and the rivers flowed out across the dry land of the continental shelf for some 30 km beyond the present coastline (von der Borch, 1968). Today's estuaries were valleys and the rivers flowed through them, many metres below the present shallow bottoms. With the Holocene rise of sea level 10,000 to 6000 years ago the valleys were flooded by the sea and for some time sea level may have been about 2 m higher than it is now, as shown by the extensive shell beds at all three estuaries.

Mollusc shells from the shell beds on which the Bremer Bay Caravan Park is situated, and from 5 km up the estuary, have been dated as between 4000 and 5000 years old (Hodgkin and Clark, 1987) as have shells from similar deposits in Stokes Inlet and Culham Inlet. They include large numbers of the common clam *Katelysia* and 17 species of gastropods. The abundant sub-fossil shells in Beaufort Inlet and Gordon Inlet most probably belong to the same period. They are clear evidence that when first flooded the estuaries were wide open to the sea, tidal and not subject to the salinity extremes they now experience. They were sheltered marine embayments much like Oyster Harbour is today.

The ocean beaches formed during and following the rise in sea level from sand eroded from the seabed. The finer sand was blown up into dunes and was stabilised by vegetation. Wave action moved sand onshore-offshore and alongshore, gradually narrowing the mouths of the estuaries and building the sea bars, so forming major barriers to water flow. For a time the channels would have continued to be open to the sea, but neither the seasonal river floods nor the small tides of the south coast could for long prevent the bars closing seasonally. They probably closed the estuaries off from the sea between 3000 and 4000 years ago.

Tidal currents and overwash by waves during major storms carry sand into the estuaries to form flood tide deltas and obstruct the channels. This is especially so for Wellstead and Gordon Inlets the mouths of which are in relatively sheltered positions, within a bay and facing east respectively, and it is largely for that reason that their bars sometimes stay open for months or years while Beaufort only stays open for a few weeks. Mud and fine sand brought down by the rivers settled in the basins, greatly shallowing them, and coarser material collected on the river deltas and spits in the riverine reaches. Wave action has redistributed the sediments, leveling the lagoon bottoms and shaping the bays and beach ridges around them.

The estuarine environments are not static, they are constantly changing and these processes of erosion and sedimentation continue at the present time. The estuaries are filling from both ends; though the rate of change is slow in human terms it is rapid on the geological time scale. It is a natural process that has accelerated in the last hundred years. Evidence from the Pallinup River and from Stokes Inlet suggests that the rate of sedimentation has increased dramatically following clearing in the catchments.

2 CATCHMENT CHARACTERISTICS

The catchments of the Pallinup and Gairdner Rivers rise from the coast to the southern edge of the plateau at about 300 m. The catchment of the Pallinup River has an area of 4795 km^2, the Bremer River catchment 716 km^2, and the Gairdner River 1770 km^2. The northern watersheds are ill defined and there are areas of internal drainage and salt lakes north of the Gairdner and Pallinup River catchments, some of which may occasionally flow to these rivers. River water is saline and the salinity has increased following clearing in the catchments.

The greater part of the catchment of the Pallinup River, upstream of Chillinup, is in the Shire of Gnowangerup and the headwaters of the river are in the Shire of Broomehill. On the east, the boundary with the Shire of Ravensthorpe lies north - south through Gordon Inlet.

2.1 LANDFORMS AND GEOLOGY

Figure 2.11 shows the catchment of the Pallinup River and Figure 2.12 the catchments of the Bremer and Gairdner Rivers. The upper parts of the catchments lie on the Yilgarn Block of the plateau and the lower reaches (south of Chillinup) are on the Albany Frazer geological Province. The hard granitic bedrock is exposed in the river valleys and along the riverine reaches of Beaufort Inlet and it outcrops again on the coastal headlands that delimit the bays around Mount Groper, Cape Knob, Point Henry and the Doubtful Island peninsula. Within about 40 km of the coast this rock is overlain by spongolite rock composed of clays, sponge spicules, sand and scarce fossil shells. This softer rock is more readily eroded and in the vicinity of the estuaries has been cut into V-shaped valleys with steep slopes and cliff (Figure 2.13). The cliff on the north side of Beaufort Inlet is the geological type section for this Plantagenet

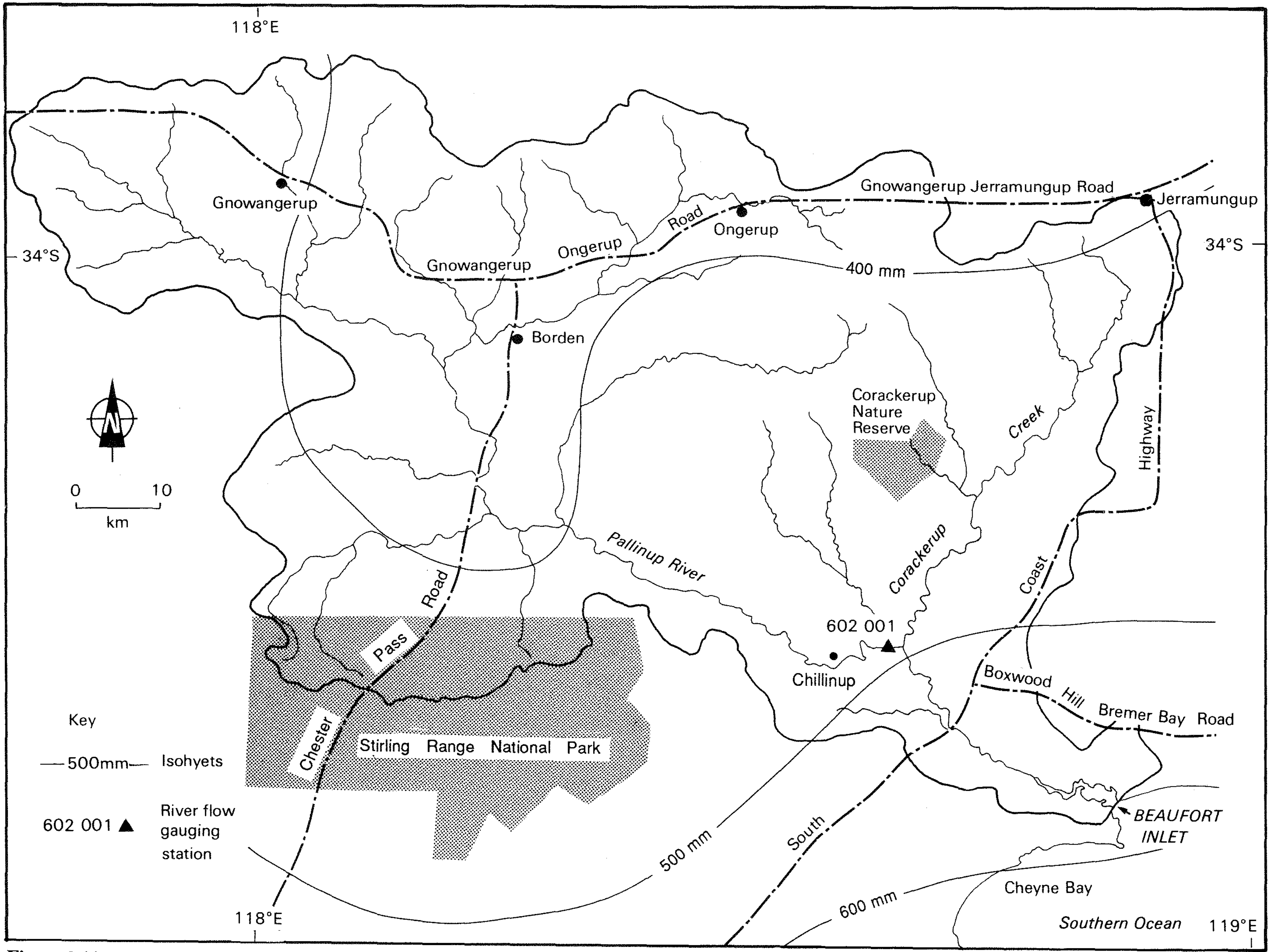


Figure 2.11 Catchment of the Beaufort Inlet.

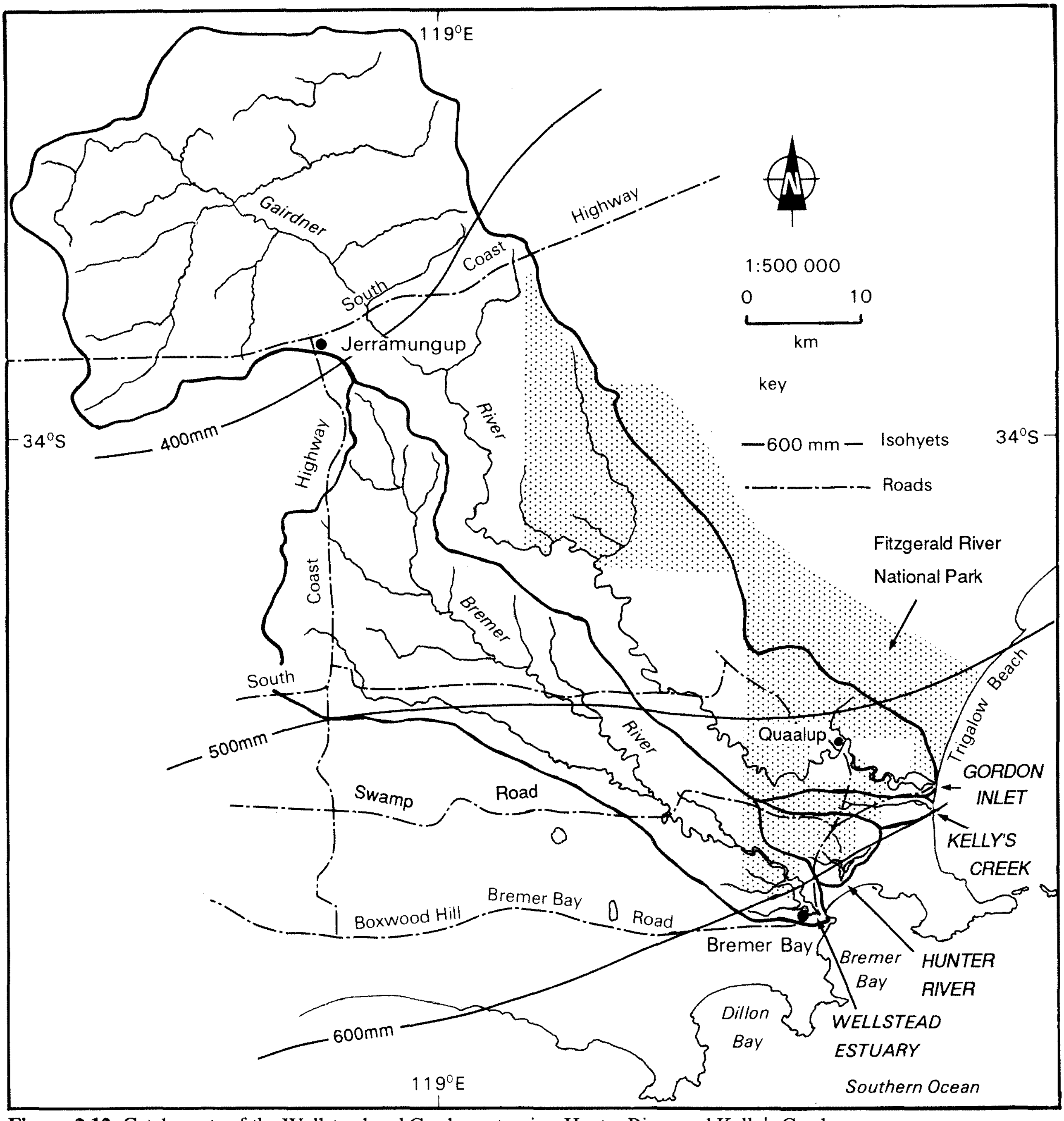


Figure 2.12 Catchments of the Wellstead and Gordon estuaries, Hunter River and Kelly's Creek.

Siltstone (spongolite) rock. Much of the catchment between the valleys is covered by sandplain. Calcareous, Pleistocene dune rock (less than 2 million years old) and recent mobile dune sands border the coast and the lower reaches of the estuaries, where they overlie the older rocks. The geology of the catchments is described and mapped in the Geological Survey 1:250 000 geological series (Thom and Chin,1984; Thom *et al.*, 1984; Muhling and Brakel, 1985).

The catchments rise from sea level to about 100 m over the southern part of the sandplain and then gradually through undulating valleys to 300 m north of South Coast Highway. Between the Pallinup and Bremer Rivers there is an area of sandplain with numerous swamps and no external drainage. The three rivers and Corackerup Creek have cut deeply into the spongolite rock and in places also into the harder rocks. On the coast the granite headlands rise up to 200 m; the rock is covered with dune sand or calcareous sandstone.

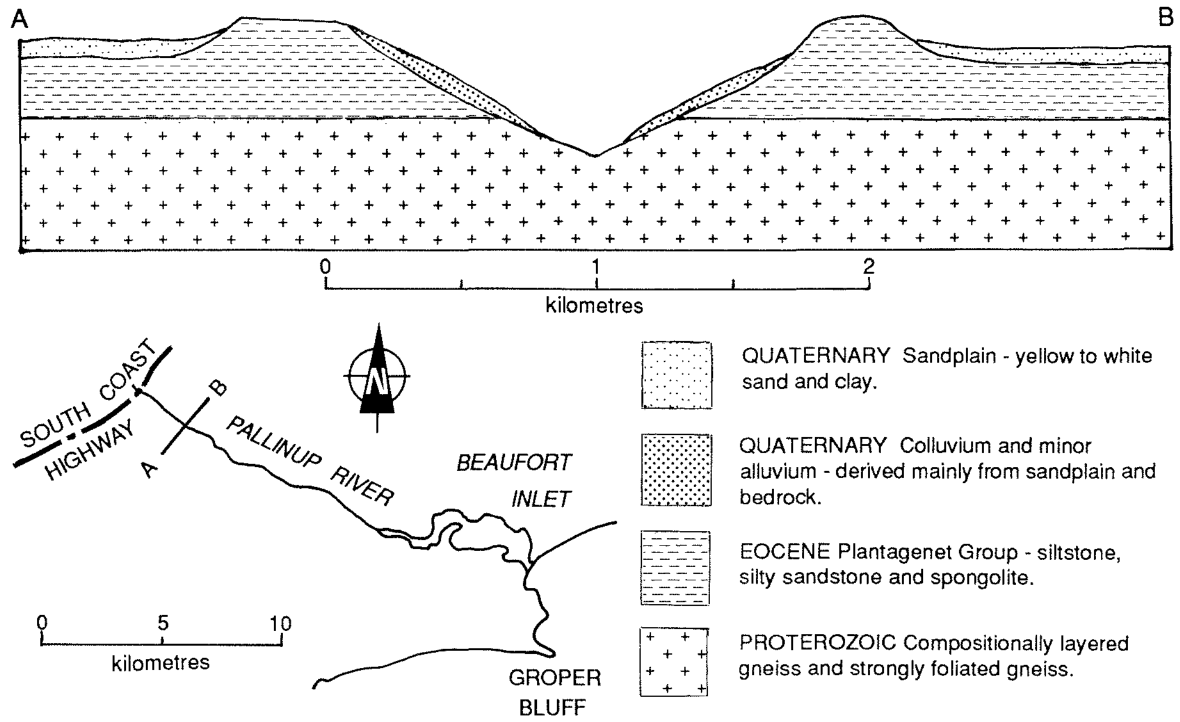


Figure 2.13 Geological cross section through the Pallinup River valley. Vertical scale exaggerated. (Bill Moir)

2.2 SOILS AND VEGETATION

Most soils are duplex, the sandy clay subsoil (B horizon) being overlain with a topsoil (A horizon) ranging from sand to loam. Other soils are gradational with clay-loam or clay topsoils. Almost all are well drained and, except for the heavy soils, are acidic and have a pH of 6.0 to 6.5. Most bare soils on slopes of more than 2 degrees, are readily eroded; the topsoil of sand or loam lacks sufficient clay to bind the soil against erosion by water and wind.

There are four main groups of soils in the catchments: heavy, light, young and alluvial. They are characterised by different types of vegetation. Heavy soils are found mainly in the Gnowangerup and south Borden area with a smaller area around Ongerup. York Gum (*Eucalyptus loxophleba*), Morrel (*E. longicornis*), Moort (*E. platypus*) grow in these areas with an occasional patch of Salmon Gum (*E. salmonophloia*).

Lighter soils are common south of the Gnowangerup - Jerramungup Road, mainly on the sandplain. These soils are some of the most ancient in the world and have been leached over many millions of years. In some places the topsoil of almost pure sand is more than 30 cm deep. There are scattered patches of mallees, with *E. redunca* on loamy sands and *E. transcontinentalis* on clayey sands. West of Gnowangerup *E. redunca* is replaced by White Gum (*E. wandoo*). Scattered Lerp's Mallee (*E. incrassata*) may be present on the poorer soils, or there may be no mallees at all. Near Beaufort Inlet, Redheart Mallee (*E. decipiens*) grows on fine, loamy soils and mallees of *E. transcontinentalis* and *E. gardneri* grow on clayey sand on valley slopes.

Young soils are present on the middle and lower slopes of the Pallinup River and its tributaries. The topsoil is loamy sand, more fertile than those described above. York Gum is common with Flat-topped Yate (*E. occidentalis*) often on lower slopes near drainage lines.

Alluvial soils occur mainly in narrow strips along the rivers and their major tributaries. Flat-topped Yate is common, with small patches of Flooded Gum (*E. rudis*) along the north-western tributary of the Pallinup River. The Swamp Oak *(Casuarina obesa)* is also common along the river.

2.3 COASTAL FEATURES

All three estuaries and their tributary rivers have a roughly north-west to south-east alignment, but they differ greatly in their orientation to the coastline (Figure 1). The mouth of **Beaufort Inlet** faces south east near the western end of the 25 km long, south- facing Wray Bay where it is protected from south-westerly winds and swells by Mount Groper and Groper Bluff. The **Wellstead Estuary** mouth faces east at the extreme south-western end of Bremer Beach deep in the shelter of Bremer Bay. **Gordon Inlet** opens directly onto the long, east-facing Tooregullup Beach 10 km north of the prominent Hood Point. Although the mouths of all three are sheltered from the prevailing winter south-westerly winds and swell by headlands the shorelines of the bays onto which they open have very different exposures.

At **Beaufort Inlet** the narrow beach of Wray Bay is backed by steep dunes over 40 m high. Limestone outcrops as reefs and platforms in the nearshore zone, and to the east of a small granite headland the reef line has broken through exposing loose sand and a large blowout. Hard limestone outcrops in the beach at the southern end of the bar at the mouth of the Inlet, though it is often covered with beach sand, and there is 1 km of beach between the mouth and the granite rock of the headland to the south. The coarse beach sand builds up into a high bar that closes the mouth of the Inlet.

At **Wellstead Estuary** the wide beach is of fine quartz sand and the low dunes of Bremer Beach are unconsolidated. It has a gentle slope and only builds up into a low bar at the mouth of the estuary. Half way along Bremer Beach and 1 km inland the **Hunter River** has a small fresh water lake that is impounded by a marl bar covered by sand. The bar broke on 10 August 1979 following heavy rain in the small catchment. The water breached the sand bar and carried trees and other dune vegetation with it, but the marl bar retained some water and the sand built up again. It broke again in 1986. It is reported to have broken in the late 1890s and about 1940.

The mouth of **Gordon Inlet** opens onto a sandy shore where the nearest hard rock is 8 km to the south, on the Point Hood peninsula. The wide beach of fine white quartz sand only builds up to a low bar that closes the mouth. Rock in the beach and on the northern side of the mouth may be covered by sand or exposed by heavy seas. North and south of the mouth the beach is backed by low, well vegetated dunes about 1 km wide, the length of the inlet channel through them. About 2 km south of the mouth the small **Kelly's Creek** winds through the dunes for 1.5 km to a small perched lake that is often dry. Sea water washes over the beach into the mouth of the Creek.

TIDES The tides are mainly of the daily type and small range typical of the south west, with a maximum daily range of 0.7 m. Seasonal and meteorological factors result in an overall range of about 1.2 m and storm events may cause an extreme range of about 1.8 m (Albany). The estuaries are only tidal when the bars are open and the tides are greatly attenuated by the narrow, shallow entrances.

2.4 RAINFALL

The mean annual rainfall is about 600 mm at the coast (571 mm at Cape Riche, 626 mm at Bremer Bay and 544 mm at Quaalup) decreasing to 400 mm inland (407 mm at Gnowangerup and 451 at Jerramungup), but the extreme ranges are much greater (Table 2.4). This is mainly winter rain (Figure 2.4). However summer cyclonic storms may precipitate 200 mm or more in a few days. Gnowangerup recorded 232 mm of rainfall in February 1955 and 206 mm in January 1982. At Millers Point (Beaufort Inlet) 172 mm fell in 3 days in January 1982. In May 1988 Jerramungup recorded 289 mm and Bremer Bay 210 mm, with most of it falling over three days at the beginning of the month. These storms caused extensive flooding and broke the bars of the three estuaries (no record for Gordon Inlet for 1982).

2.5 RIVERS

Each of the three estuaries has a single river flowing to it. Of them only the Pallinup River has cut down to the granitic basement rock where it enters the estuary; the Bremer and Gairdner Rivers flow through valleys in the overlying spongolite rock for some distance upstream of the estuaries. The three catchments differ greatly in size, as does the volume of flow to the estuaries (Table 2.51).

Beaufort Inlet The Pallinup River is approximately 250 km long from where it rises near Broomehill. Corackerup Creek is the main tributary to the river from the north. Several small creeks drain from the northern slopes of the Stirling Range. Much of the bed of the river and its tributaries is sandy in the upper reaches, but there are a number of long pools in the granitic rock of the the river bed in its lower reaches. These are scoured by floods but hold water in summer.

Table 2.4 Highest and lowest, monthly and annual rainfalls (mm) for Gnowangerup, Cape Riche, Jerramungup and Bremer Bay. (Commonwealth Bureau of Meteorology)

	GNOWANGERUP 1913-1984	CAPE RICHE 1897-1985	JERRAMUNGUP 1963-1986	BREMER BAY 1885-1986
Average annual	407 mm	571 mm	451 mm	626 mm
Lowest annual	232 mm (1954)	273 mm (1936)	255 mm (1969)	389 mm (1957)
Highest annual	712 mm (1955)	957 mm (1917)	617 mm (1978)	959 mm (1955)
Highest monthly	232 mm Feb (1955)	326 mm Apr (1913)	176 mm Nv (1971)*	401 mm My (1921)
Highest two monthly	237 mm Jn/Fb (1955)	397 mm Jn/Jy (1978)	250 mm Jn/Jy (1978)	443 mm My/Jn (1921)

* Highest monthly rainfall recorded at Jerramungup was in May 1988, 289 mm,and highest two monthly in May/June 1988 was 350 mm.

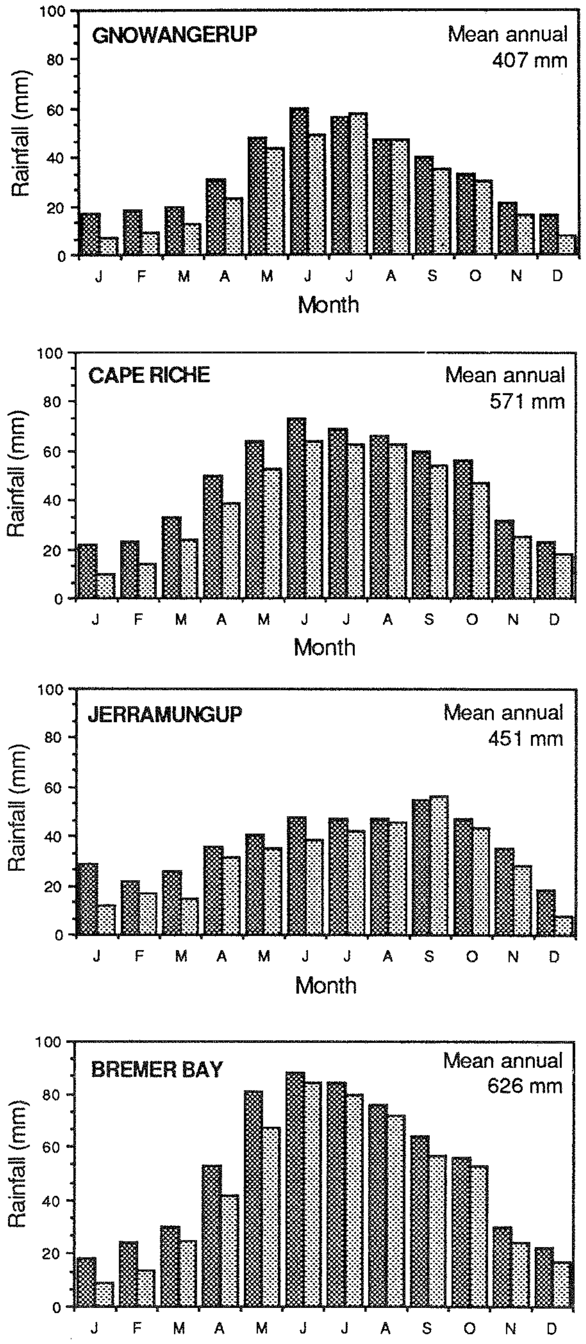


Figure 2.4 Monthly rainfall at Gnowangerup station (010558) 1913-1984, Cape Riche station (009520) 1897-1985, Jerramungup station (010792) 1963-1986 and Bremer Bay (009654) 1885-1986. means ▩ , medians ▨ . (Commonwealth Bureau of Meteorology)

Wellstead Estuary The Bremer River is about 70 km in length. It is only in the upper catchment that hard rock is exposed in the river bed.

Gordon Inlet The Gairdner River is approximately 130 km long from where it rises 25 km north west of

Table 2.51 Estimated average annual runoff and flow to the three estuaries and cleared areas of their catchments. (WA Water Resources Branch, PWD)

	Beaufort	Wellstead	Gordon
Area of catchment km^2	4795	716	1770
Area cleared to November 1984 km^2	4004	573	1062
Runoff mm	5.3	3.8	5.3
Flow x 10^6 m^3	25.4	2.7	9.4

Jerramungup. Needilup Creek and Cobomup Creek enter the river in its upper reaches. South of South Coast Highway the river meanders along a narrow valley cut through the sandplain, first into granitic rocks and then into spongolite below Devils Creek Road. Throughout its length there are many pools in the river bed, some fed by springs.

RUNOFF and RIVER FLOW There is only one Water Authority gauging station in the area: 602001 on the Pallinup River (Figure 2.11). The record is only for 10 years (1973 to 1982) and it will be appreciated that the annual averages quoted below can be misleading because of the great range in annual flow (56.4 x 10^6 m^3 in 1978 to 4.3 x 10^6 m^3 in 1980). The average annual flow was 17.6 x $10^6 m^3$, but flow was less than 7 x 10^6 m^3 in 7 out of 10 years, and the median annual flow was only 5.6 x 10^6 m^3. Extrapolating from the gauged flow at 602001, the estimated average annual flow to the three estuaries is as shown in Table 2.51.

The monthly means in Figure 2.5 are also distorted by the great volume of flow which follows single storm events. The flood of July 1978 produced 86% of the total flow for the year and the January 1982 flood accounted for 90% of the year's flow of 53.2 x $10^6 m^3$. The flash flood of May 1988 must similarly have been a major part of the year's flow for the three rivers, especially the Gairdner. There is often no flow for prolonged periods in summer, for approximately 80 days in the year.

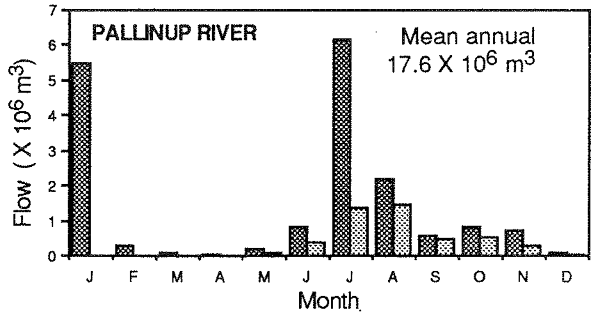


Figure 2.5 Monthly flows at Pallinup River gauging station 602 001, (1973-1982).means ▩, medians ▨.(WA Water Resources Branch, PWD, 1984)

Comparing the runoff figures in Table 2.51 with the rainfall data in Table 2.4, it will be seen that runoff is only about 1% of rainfall.

There are no dams or obstructions on the three rivers although there are many farm dams across small creeks in tributaries, some now abandoned because of increased salinity of the water.

SEDIMENT TRANSPORT Sediment is mostly transported by major floods. At such times fine sediment is washed by sheet erosion from cleared land, coarser material is eroded by gullying and from the river beds, trees are torn up and dropped in the lagoons or carried out to sea. The only data on sediment transport are for the January 1982 flood. This was estimated to have brought down 100 000 t of sediment from the bed of the Pallinup River to Beaufort Inlet.

Floods in the Gairdner River bring down large quantities of sand and rocks and much sediment has been deposited along the river as sand spits. The 1955 flood cut across a meander upstream from Quaalup depositing a large sand bank. In May 1988 flood water rose 6.5 m at the Quaalup bend and it swept across the property on the northern end of the peninsula.

There can be little doubt that there has been a considerable increase in the amount of sediment being mobilised in the catchments as the result of clearing and the consequent sheet erosion and gully wash. This is especially true of the Pallinup River catchment of which 90% is cleared and of the upper Gairdner River catchment. The loss of soil would have been greatest while the land was being cleared in the 1950s and 1960s. It is reported that much sediment collected in the river pools following the Gairdner River Development of the 1950s and 1960s, though no doubt much of this has since been scoured out again by major floods and carried downstream.

WATER SALINITY River water has become increasingly saline. Salinity now varies from about 10% of sea water salinity (3-4 parts per thousand) when the rivers are flowing to 150% (over 50 ppt) in stagnant pools in the river beds in summer. There are two sources of salt: connate salt which continues to seep from the Eocene marine spongolite rock; cyclic salt, sea salt deposited from rainfall within the last 100 000 years. The latter has collected in the subsoil and now comes to the surface following clearing. In the long term this salt will decrease as it is washed out by rainfall, probably over hundreds of years.

NUTRIENTS The few samples of Pallinup River (Table 2.52) and Gairdner River water have shown relatively high levels of total phosphorus (over 100 μg/L Total P), in contrast to samples taken from rivers in the Fitzgerald River National Park (10 μg/L or less). The very high levels observed in Beaufort Inlet water (Section 3.4) also indicate a high rate of nutrient loss from fertilizer application in the catchment.

Table 2.52 Nutrient values (μg/L) in Pallinup River water (at South Coast Highway), 30 August 1974 and 19 February 1975. (Lenanton and Edmonds pers. comm.)

		Phosphorus		Nitrogen	
Year	S/B	PO_4-P	Total P	NH_4-N	Total N
1974	S	10	50	20	1500
	B	10	40	20	1700
1975	S	60	190	20	4500

2.6 LAND OWNERSHIP AND USE

The very productive sandalwood industry of the 1840s preceded clearing in the area. John Hassell took up land at Jerramungup in 1849 and developed a large pastoral business, using ringbarking and burning to assist the growth of natural pastures. Small scale clearing for agriculture began in the 1850s along the Pallinup River where there was the best grazing for sheep. This was the more densely wooded country, in contrast to the adjacent open woodland and sandplain. More extensive clearing began for mixed farming from 1910 to 1912 on heavier soils in the Gnowangerup, Borden, Ongerup area. In the 1920s the soldier settlements west of Gnowangerup may have increased the salinity of river water. It was not until the 1950s, following the discovery of trace element deficiency, that there was widespread clearing on sandy soils north of Chillinup and in the upper catchment around Ongerup and Borden. Light land south west of Chillinup was released in the 1960s. Clearing involved the broadscale removal of almost all the bush, transforming the face of the area; only about 5% of alienated land remains uncleared. Twigg (1987) records the history of settlement and land use in the area.

Fertilizer application was at the rate of 1 bag of superphosphate to the acre or more on newly cleared land, until the price rise of 1974 when it was reduced to about half that rate. Little nitrogen was applied until about 1955 with the clearing of lighter soils. Stocking rates increased to 4 to 6 sheep to the acre until the dry 1969 season, when much wind erosion occurred on the sandy soils.

The towns of Gnowangerup, Borden and Ongerup lie in the upper part of the catchment of the Pallinup River near the source of tributaries to the river. Jerramungup is near the divide between the three rivers, at the head of the Corackerup Creek tributary of the Pallinup River. Bremer Bay is the only town on the coast; it has about 100 houses, many of them holiday homes, and a caravan park with facilities for 1600 people (RAC,1988). There is a small hutted settlement at Millers Point on the north shore of Beaufort Inlet, with borehole toilets, and a few caravans can be accommodated, but no more building is permitted there. Camping is possible on both sides of the Inlet and at the Paperbarks 10 km up estuary. There are no facilities at Gordon Inlet.

Beaufort Inlet The greater part of the Pallinup River catchment is alienated land, mainly for cereal production and sheep grazing. About 70% (3300 km^2) of the catchment had been cleared by 1968 and 84% by 1984 (Table 2.51). Most of the land north of the Stirling Range National Park is cleared, but there is still a considerable area of uncleared bush along Corackerup Creek and the Corackerup Nature Reserve (approx. 45 km^2) lies north west of the Creek. There has been recent clearing on valley slopes south of South Coast Highway, but the immediate vicinity of the estuary is largely uncleared land under the control of the Jerramungup Shire, surrounded by uncleared Crown land (Figure 2.6).

Wellstead Estuary About half (350 km^2) of the catchment of 716 km^2 had been cleared by 1968 and 80% had been cleared by 1984. A narrow strip of reserve vested in the Jerramungup Shire borders the lower reaches of the river and the upper part of the estuary and this is surrounded by the Fitzgerald River National Park. The town of Bremer Bay and the caravan park are located on the southern shore of the estuary.

Gordon Inlet About 60% (1060 km^2) of the Gairdner River catchment had been cleared by 1968 and there has been little further clearing. Almost all the catchment north of South Coast Highway and along a narrow strip west of the river is alienated land and is cleared, mainly for sheep grazing and seed crops. To the east of the river there is still largely virgin bush, some of it in the Fitzgerald River National Park. There is a small area of alienated land at Quaalup, within the National Park, some of which has been cleared for grazing. The catchment is in the Jerramungup Shire but the Shire boundary with the Ravensthorpe Shire to the east lies north - south through the channel to the sea.

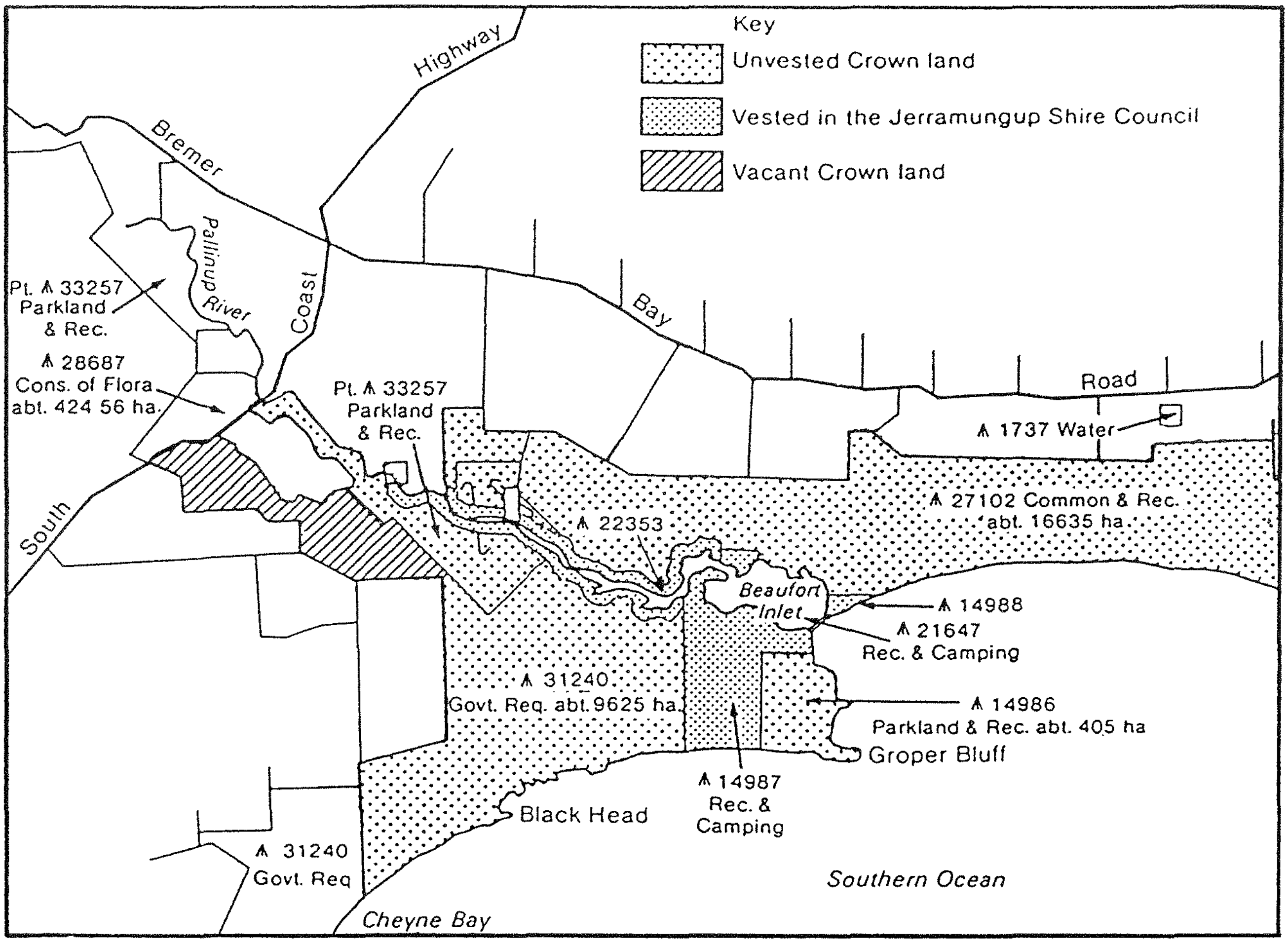


Figure 2.6 Landownership surrounding Beaufort Inlet. (Newbey, 1986)

3 BEAUFORT INLET — PHYSICAL FEATURES

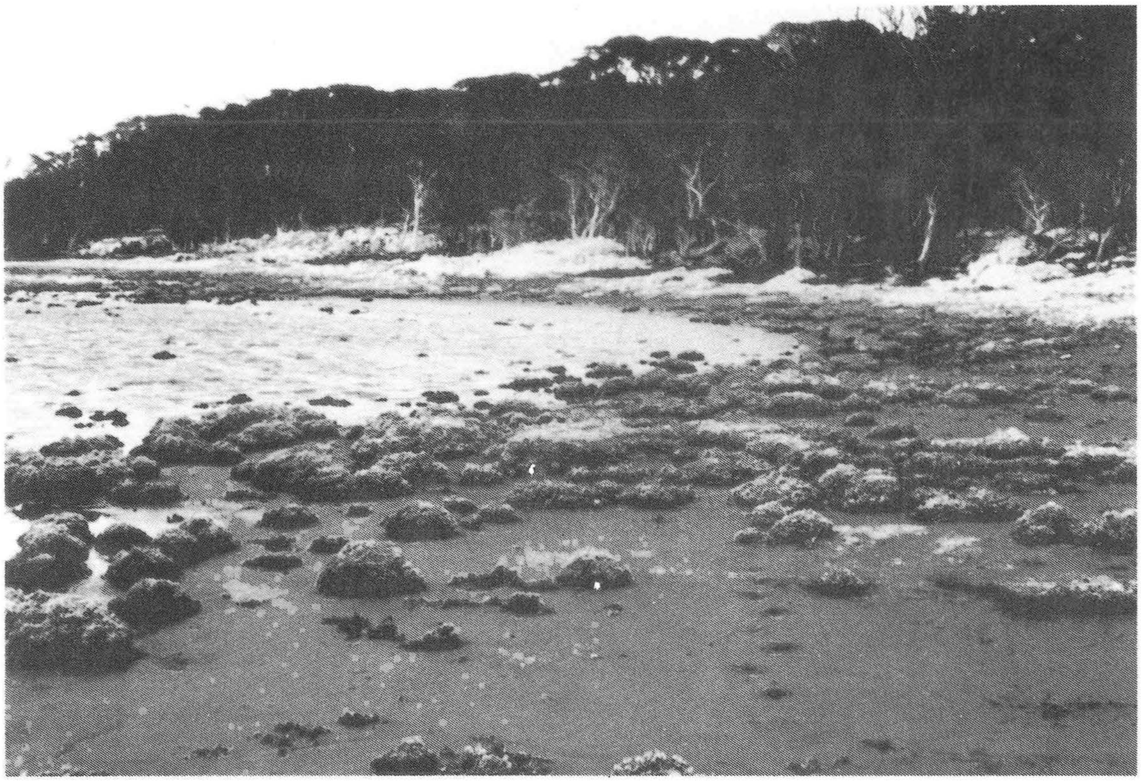
The high sea bar, which only opens briefly at intervals of several years, the infrequent floods, and the high evaporation rate result in great changes in water level in the estuary, from 2 m or more above sea level following heavy rain to below sea level at the end of summer. As a result the margins of the estuary are subject to alternate submergence and exposure, sometimes for prolonged periods. The lagoon is shallow throughout and the shallower parts may have little or no water in them in summer.

3.1 LANDFORMS

The estuary is 14 km long, running SE to NW perpendicular to the coast (Figure 3.11). The upper 8 km is riverine, in a deep valley incised through the spongolite rock to the granite bedrock (Figure 2.13). The valley then widens through a floodplain to the 3 km long lagoon. The steep slopes of the main and tributary valleys reflect the relatively soft nature of the spongolite rock. The estuary has an area of 7 km^2 and an estimated volume of 6.5×10^6 m^3 below mean sea level. Figure 3.12 shows landforms of the estuary.

UPPER ESTUARY Granite rock is exposed along the narrow upper reaches of the riverine part of the estuary and in the river bed upstream. Short creeks drain direct to the estuary at intervals along both shores and associated small embayments are filled by sediment and are swampy. There is shallow open water in two larger bays at about 6 km and 8 km upstream from the bar. Most of the channel is only 1-2 m deep and there are sand banks where it widens, but the river bed may be scoured to 5-7 m on the bends following floods.

MIDDLE ESTUARY Between about 6 km and 3 km from the bar the estuary is edged with small swamps and floodplains that are inundated during higher water levels. The bays are being enclosed by sand bars and ultimately by levees. This appears to indicate the rapid infilling of the estuary during periods of high river flow. The river delta on the southern shore (between 5 and 3 km) is mainly a samphire swamp subject to inundation and erosion by floods. A slightly higher sand ridge with paperbark and sheoak trees borders the swamp opposite Millers Point. On the northern shore, creeks enter two wide shallow bays bounded by sand spits. The bedrock is again exposed in places before the shore gives way to the sand flat on which Millers Point settlement is established above flood level. This is river sand and material eroded from spongolite.



A Beaufort Inlet shoreline following a dry summer (May 1983). In the foreground small rocks encrusted with masses of the tube worm - *Ficopomatus enigmatica*. In the background a granite shore with *Casuarina obesa* trees.

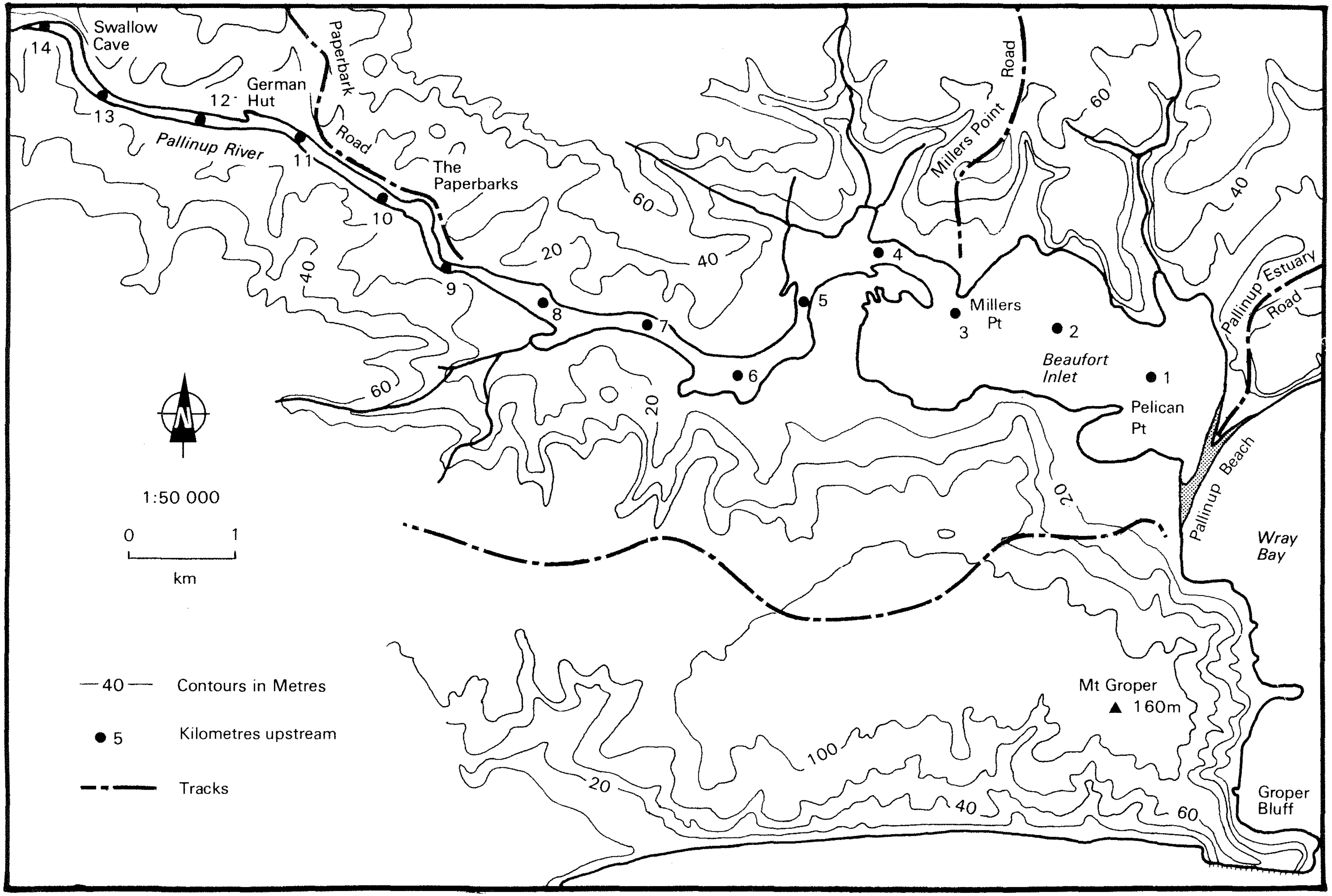


Figure 3.11 Beaufort Inlet.

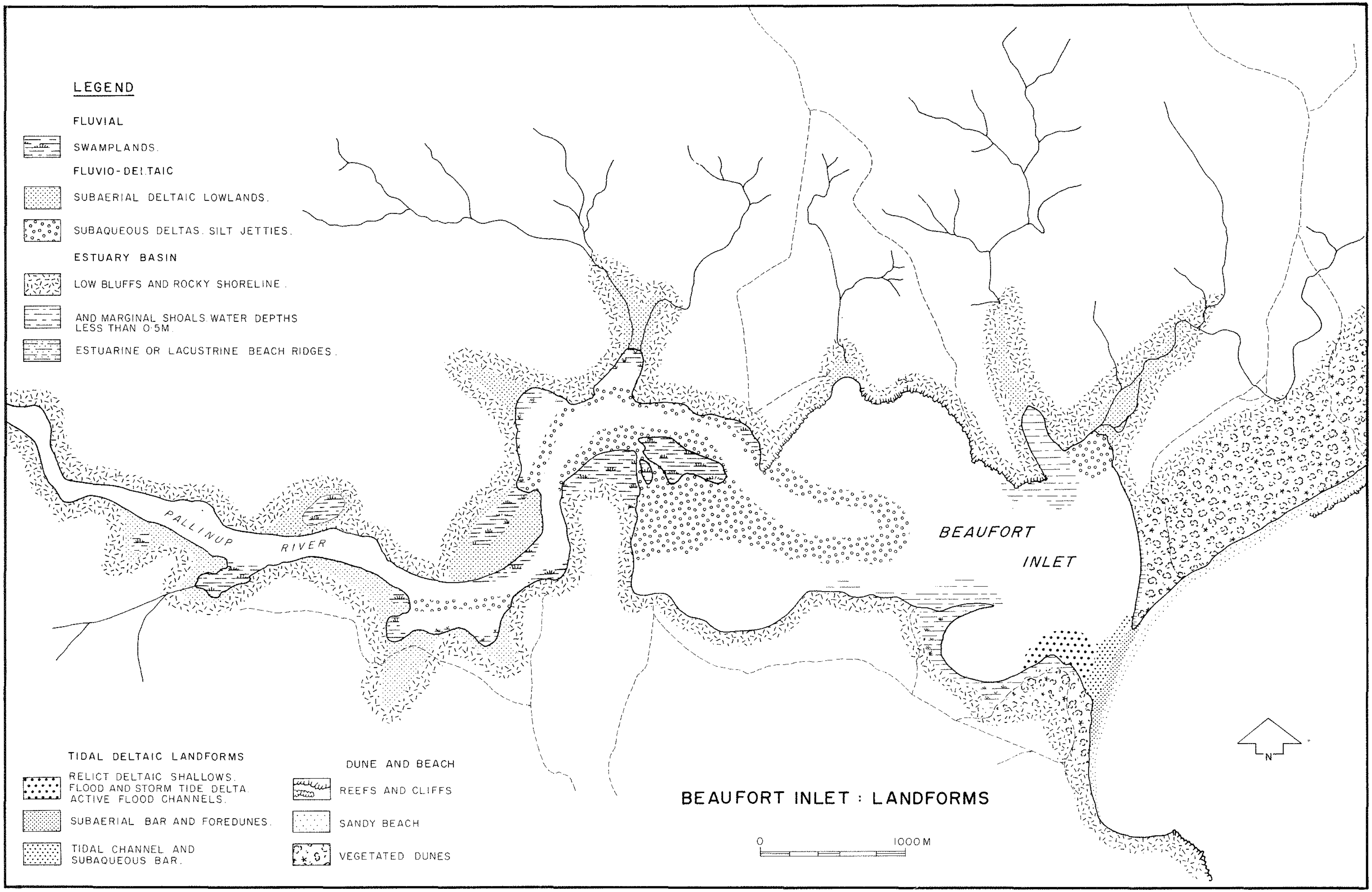


Figure 3.12 Landforms of Beaufort Inlet and surrounds. (I. Eliot)

LAGOON The lagoon is 3 km long and about 1.5 km wide, with an area of about 4.5 km^2. It is less than 1.5 m deep throughout and some areas are exposed under extreme low water conditions (Figure 3.13). Spits border both sides of the channel where it discharges to the lagoon, the southern spit partially encloses a very shallow bay. On the northern shore a 40 m high cliff is cut in the spongolite rock. Nearer the bar a creek cuts through the spongolite to Mullet Bay and, beyond a smaller bay, there is limestone and modern, well vegetated dune sand. The southern shore is mainly bordered by alluvial flats, but a low limestone cliff is exposed at one point. A sand spit partially encloses a small bay about 1 km from the bar. This spit contains abundant shells, predominantly of cockles (*Katelysia* spp.), probably sub-fossil material from 3000 to 4000 years ago. There is no evidence of a flood tide delta, but a small storm delta has formed from sand washed over the bar from the beach.

3.2 THE BAR

The mouth of the estuary is closed by a sand bar about 500 metres long and 100-150 m across, oriented NE-SW. It is a high bar, 3 - 3.5 m above sea level, built of poorly sorted, mainly coarse quartz sand and calcareous shell material (10%) (Figure 3.21). The dune tongue on the northern side is well vegetated beach and dune sand. On the southern side an outcrop of hard limestone in the beach (often covered by sand) reduces scouring when the bar breaks. This is cemented beach sand with mollusc shells embedded in it (*Katelysia*, *Fulvia*). Above and behind this, the dune has soft limestone that is reported to have been eroded when the bar broke in 1978. The bar usually breaks at the south side cutting a channel about 50 m wide; however a big flood can break across 200 m or more, as in 1955 and 1982. Waves and swell rapidly rebuild the bar so that it seldom stays open for more than a few weeks. The known dates of opening and closing of the bar since 1954 are shown in Figure 3.22.

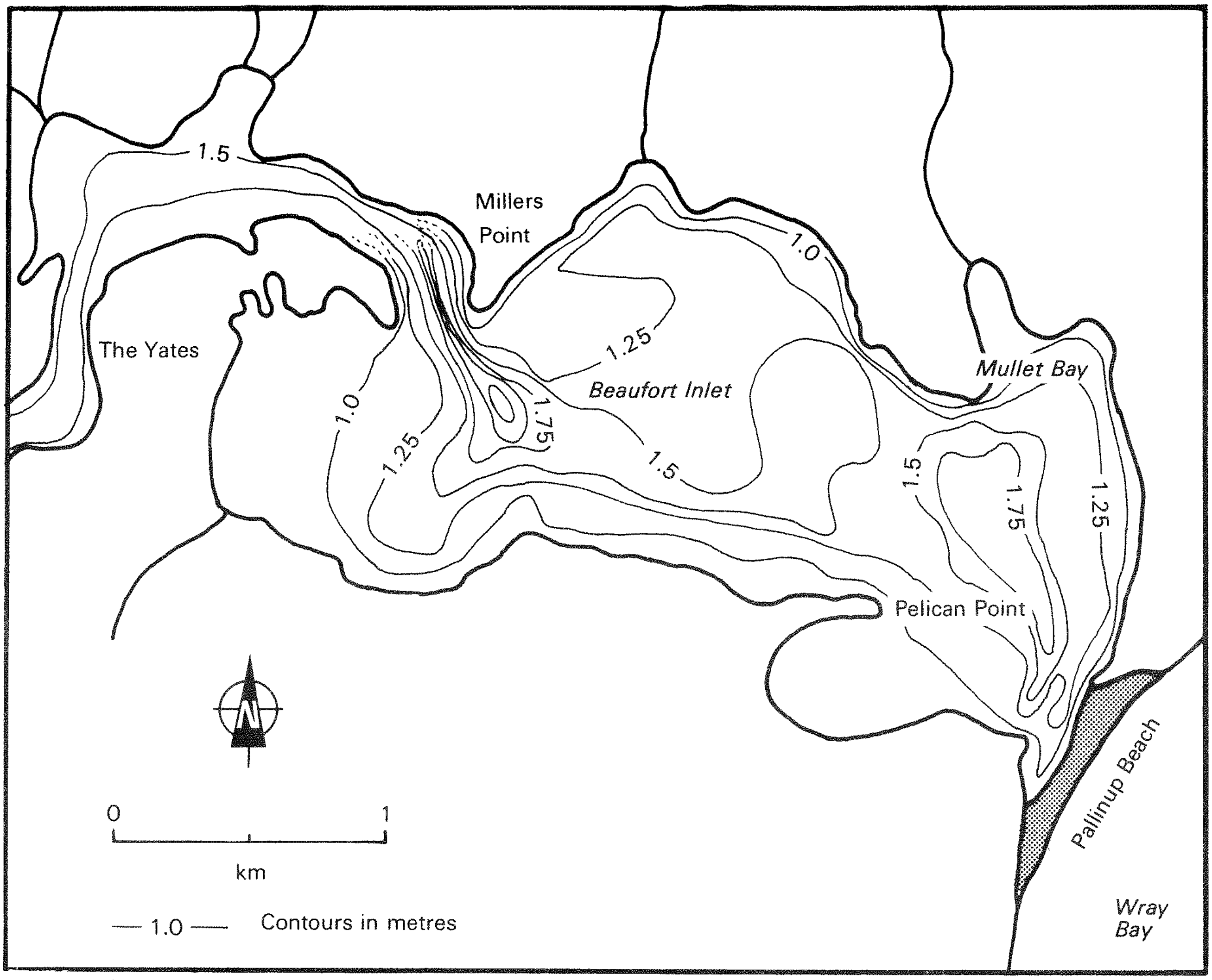


Figure 3.13 Beaufort Inlet. Bathymetry, 10 March 1987. Depths in metres below mean sea level. (J. Bowyer)

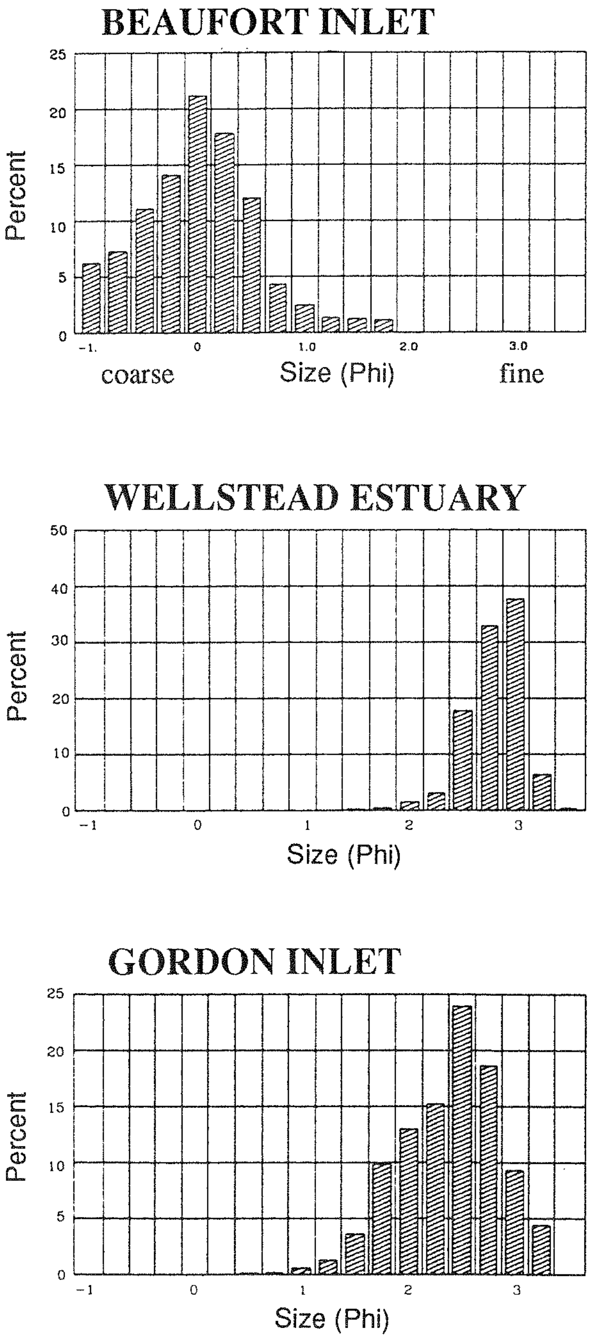


Figure 3.21 Sand size distributions from the bar crests at Beaufort, Wellstead and Gordon estuaries. Sizes are in phi units. Sand types and grain sizes in mm are shown below. (Bill Wilson)

Sand type	Grade limits phi units	mm
very coarse	-1.0 to 0	2-1
coarse	0 to 1.0	1-0.5
medium	1.0 to 2.0	0.5-0.25
fine	2.0 to 3.0	0.25-0.125
very fine	3.0 to 4.0	0.125-0.062

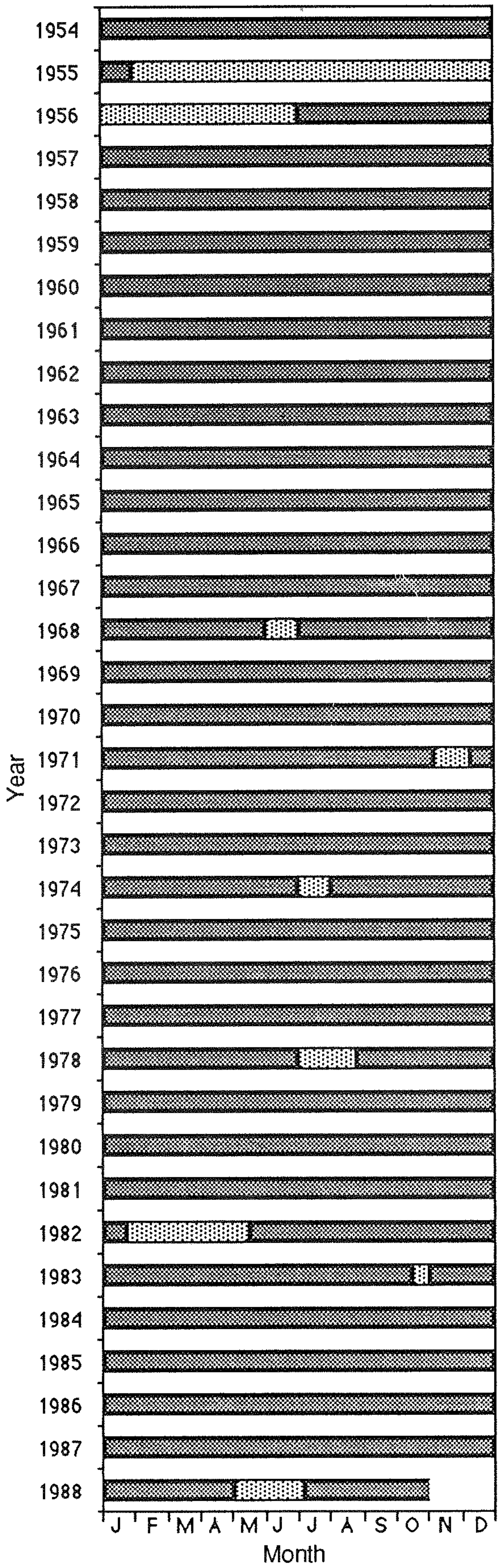


Figure 3.22 Beaufort Inlet. Reported opening and closing of the bar. open ▒, closed ▓.

It is possible to estimate the volume of flow required to break the bar by comparing these records with the volumes of river flow to the estuary, estimated from monthly rainfall data and the gauged flows since 1973 (Table 3.2). Winter rainfall of 200 mm over one or two months in winter, or a similar amount in a couple of days during summer can be expected to cause a flow of about 70 x $10^6 m^3$ from the whole catchment. The bar broke in the winter of 1978 after heavy rain in June and July (400 mm at Cape Riche) and an estimated flow of 68 x $10^6 m^3$ in July. It broke again following the heavy cyclonic rain of January 1982 (241 mm at Cape Riche) and an estimated flow of 67 x $10^6 m^3$ for that month. In 1974 the bar was breached artificially when estuary water neared the top of the bar, following an estimated flow of 30 x $10^6 m^3$. Thus it appears that a flow in excess of about 30 x $10^6 m^3$ is required to break the bar naturally.

Table 3.2 Total volumes from the catchment to the Beaufort estuary estimated from Water Authority gauging station 602 001 between 1973 and 1982. (Water Resources Branch, PWD, 1984)

Year	Volume to estuary ($10^6 m^3$)	Condition of the bar
1973	9.4	Closed
1974	30.6	Opened (artificial)
1975	6.4	Closed
1976	10.0	Closed
1977	8.5	Closed
1978	81.4	Opened (natural)
1979	7.2	Closed
1980	6.2	Closed
1981	7.0	Closed
1982	76.8	Opened (natural)

In October 1910 and April 1913 heavy rains which occurred over periods of a few days would have led to the bar breaking. In 1917 over 600 mm of rain fell near the coast in four winter months and probably opened the bar across its whole width. The bar broke in July in 1945, 1949 and February 1953. The floods of February 1955 broke the bar and the heavy rain of the following winter appears to have been sufficient to keep it open for the 18 months it is reported to have remained open. Thereafter the bar remained closed for 12 years, until 1968. Since 1968 it has broken six times, and has only stayed open for a few weeks each time, except January 1982 and May 1988. On two of these occasions it was breached artificially when the water level in the estuary rose extremely high but did not break the bar naturally. In January 1982 rainfall was 206 mm at Gnowangerup and 172 mm in 3 days at Millers Point. This flooded the estuary with a reported rise in water level of nearly 3 m and broke the bar which remained open for about 4 months. The heavy rain of early May 1988 again broke the bar across most of its length and it was open for 8 weeks.

3.3 BOTTOM SEDIMENTS

The few observations record mainly fine silt in surface sediment overlying mud within the lagoon and sand at the margins. Coarser sandy sediment has been deposited in the riverine reaches and the river delta and there are shelly sands in the bays and spits. A core taken in the lagoon by Treloar (1977) showed the following:

0-29 cm	pale to dark grey muddy sand, large molluscan skeletal debris prominent, mainly estuarine fauna.
29-66 cm	dark grey mud, fossiliferous, mainly estuarine fauna.
66-76 cm	transitional - intercalated sand and mud.
79-94 cm	pale to dark grey muddy sand, fossiliferous including abraded fragments of marine fauna (bryozoans, coralline algae, sponges, echinoids).

3.4 WATER CHARACTERISTICS

A noticeable feature of the lagoon water is that it is seldom clear. The turbidity is caused mainly by the abundant plant plankton and by fine sediment resuspended by wave action in the shallow water. Less obvious, but equally important for the life of the estuary, is the extreme range of salinity experienced.

SALINITY Records of salinity in the estuary are shown in Figure 3.4 and Table 3.41. The salinity of water in the lagoon is seldom less than 18 ppt (parts per thousand), half that of sea water (36 ppt), following river flow. Evaporation may raise salinity to 50-60 ppt before the winter rains. The figure of 65 ppt (April 1977) is nearly double that of sea water.

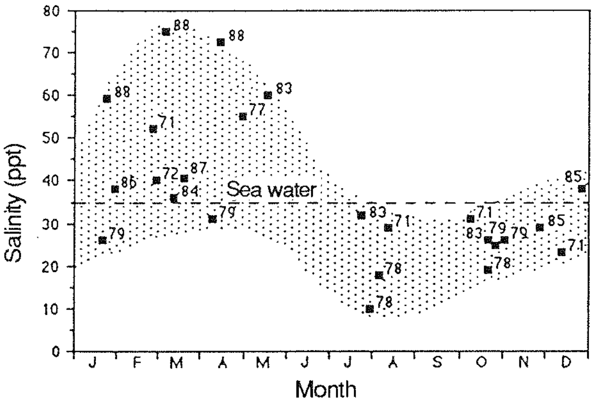


Figure 3.4 Surface salinities (ppt) in Beaufort Inlet near Millers Point between 1971 and 1988. Figures - dates of observations. Stippled area - envelope of observed surface salinity.

Table 3.41 Beaufort Inlet, records of salinity (ppt).

Date	S/B	At bar	3km	5km	bar O/C
14/1/71	S	43			C
21/2/71	S		52		C
8/8/71	S		29		C
2/10/71	S/B	31	31		C
13/12/71	S		23	21	C
	B		26	30	C
26/2/72	S/B	40	40	40	C
26/4/77	S	65	55		C
5/8/77	S	53			C
25/7/78	S	18	10		O
1/8/78	S	18	18	21	O
	B	21	25	35	O
17/10/78	S	20	19		C
14/1/79	S	26	26	26	C
3/4/79	S	36	31		C
5/8/79	S	53			C
24/10/79	S	25	25		C
12/5/83	S		60		C
19/7/83	S		32		C
16/10/83	S	33	26		O
7/3/84	S/B	35	36	34	C
19/10/85	S	34			C
23/11/85	S	33	29		C
30/12/85	S/B		38		C
25/1/86	S	38	38		C
	B	39	42		C
9/3/87	S/B	42	42	42	C
20/1/88	S	60	60	59	C
27/2/88	S		75		C
15/4/88	S		72		C
7/10/88	S		13		C

S - surface, B - bottom, O - open, C - closed

There may be a gradient of surface salinity along the estuary following recent river flow, e.g. from 31 ppt at the bar to 12 ppt at 10 km upstream (13 December 1971), or it may be uniform throughout the estuary when the bar has been closed for some time (40 ppt on 27 Feb. 1972). Significant stratification is unlikely to persist for long in the shallow lagoon, but some occurs in the riverine part while the river is flowing and the bar is open or recently closed, e.g. 21 ppt surface and 35 ppt bottom at 5 km on 1 August 1978. When the bar is closed and water level in the lagoon falls below sea level, sea water seeps through the bar into the estuary.

WATER TEMPERATURE Water temperature probably varies from about 12°C in winter to 25°C in summer. There may be some degree of stratification in the deeper water of the riverine part when the bar is open and there may be a temperature gradient along the estuary. On 13 December 1971 surface temperature ranged from 23° C near the bar to 26° C at 10 km from the bar, where the bottom water was 21° C.

LIGHT The basin water is frequently turbid; fine suspended sediment and phytoplankton reduce light penetration. The water of the riverine reaches is generally clearer.

OXYGEN The few available records indicate that oxygen concentration is generally high in the lagoon, as is to be expected in such a large shallow water body. Some deoxygenation may be expected in deeper water of the riverine reaches when it is stratified, but it is unlikely to persist for long.

NUTRIENTS Tables 3.42 & 3.43 record high nutrient levels, the highest of any estuary on the south coast sampled so far. These nutrients are believed to come from fertilizers applied to the catchment soils. High levels of chlorophyll were also observed in the water in January 1988: 6 µg/L near the bar, 23 µg/L at 8 km from the bar,18 µg/L at 14 km (J.Chambers pers. comm.).

POLLUTION There is no evidence of pollutants other than nutrients entering the estuary.

Table 3.42 Nutrient values (µg/L) in Beaufort Inlet (4 km from the bar), 30 August 1974 and 19 February 1975. (Lenanton and Edmonds pers. comm.)

		Phosphorus		Nitrogen	
Year	S/B	PO_4-P	Total P	NH_4-N	Total N
1974	S	20	80	20	760
	B	10	200	30	2000
1975	S	10	120	20	3400
	B	10	120	20	3600

Table 3.43 Nutrient values (µg/L) in Beaufort Inlet, 20 January 1988. (J.M. Chambers)

Distance	Phosphorus		Nitrogen		
from bar	PO_4-P	Total P	NH_4-N	NO_3-N	Total N
0	4	108	1	1	1419
2.5	3	177	4	3	2114
4.5	4	207	1	2	1206
8	5	229	1	1	1339
14	4	209	1	2	1171

4 GORDON INLET — PHYSICAL FEATURES

The Inlet should perhaps be called a 'transient estuary'. The bar is closed for long periods. The lagoon is so shallow from the accumulation of river and marine sediment and the bar is so low that it holds little water. River flow is so erratic and evaporation so high that often the little remaining water becomes brine. The water is then too saline for any marine or estuarine fauna to survive, though they do invade the lagoon when salinity is favourable. The riverine reaches hold water at all times and provide a more favourable environment for the fauna (including Sea mullet), although at times the salinity is 2 to 3 times that of sea water.

4.1 LANDFORMS

When the sea bar is open the estuary is tidal nearly to Quaalup, 13 km from the mouth. From there the riverine reaches meander across an 8 km wide coastal sandplain with the underlying spongolite rock to the lagoon (Figure 4.11). Within 1 km of the sea the estuary is again constricted by well vegetated dunes that border the inlet channel and the mouth. Figure 4.12 shows the landforms of the estuary.

UPPER ESTUARY The riverine reaches meander through a shallow valley cut into the spongolite rock with cliffs or steep slopes on the outsides of the bends and gentle slopes and deltaic sands on the insides of the bends, which are submerged during floods. There is a low rock bar at the head of the estuary, near the river flats at Quaalup. The sandy banks are 2 to 3 m high and pools in the river bed are scoured to 4 to 5 m on the bends, but there are sandy shallows less than 1 m deep. At 5 km from the mouth the river opens out into the lagoon between a spongolite cliff on the north shore and a samphire swamp on the south; here it is about 60 m wide and 2 m deep .

LAGOON This is very shallow, probably not more than 0.5 m below MSL anywhere in the wider parts, and seldom holds more than about 1 m of water. A shallow spit borders a bay on the south side where the river discharges into the lagoon and an emerged spit cuts off a smaller bay on the north side. At the eastern end of the lagoon a sand flat and swamp have filled a former bay in the higher ground. The shores are sandy with many sub-fossil shells.

INLET CHANNEL The channel to the sea is 800 m long and 200 m across and is bounded by coastal dune sands on each side. On the south side, 0.5 km from the bar, beds of sub-fossil marine shells (principally *Katelysia rhytiphora*, *K. scalarina* and *Nassarius* sp.) are up to about 2 m above sea level. The upper layers are water laid in sand and in the lower layers the shells are cemented into a soft rock. As noted by Hassell (1962), the channel is located opposite the centre of the lagoon, an unusual feature for south coast estuaries, probably reflecting the fact that it opens onto an east-facing beach sheltered from south-westerly swell and waves, where there is little net longshore drift.

The dunes are unconsolidated sand at the mouth, with areas of bare sand in small blowouts. The inlet channel is blocked over most of its width by a plug of sand (tidal and washover delta) which ends seawards in the bar. A narrow channel hugs the northern shore and may meander across to the south side when the bar is open.

4.2 THE BAR

The bar is part of the beach line and only builds up to 1 m to 1.5 m above MSL with sand drift from the beach, the height varying with the strength of the easterlies. It is about 300 m long and from its crest slopes gradually to the sand of the flood tide delta. Waves wash sand over the bar into the inlet channel and there is seldom much vegetation to reduce wind transport of sand. The sand is moderately well sorted, fine white quartz sand with 5% calcareous shell fragments, similar in composition to that of the Wellstead Estuary bar (Figure 3.21). Rock is patchily exposed in the beach and following storms a rock platform may be exposed in the beach. Unlike the limestone reef rock that borders many other estuaries of the south coast, this appears to be a duricrust with silcrete and lateritized material derived mainly from the spongolite rock upstream.

The bar breaks every 3-5 years following heavy rain in the upper catchment and generally only stays open for a few weeks or months while the river is flowing. It is reported to have remained open for two years following the 1955 flood. The 1973 or 1975 flood is reported to have broken across the whole width of the bar, scouring the banks and carrying away trees on the north bank of the inlet channel. The following is an incomplete record of bar opening from various sources.

1955	broke, probably in February
1957	was open in April
1960	was open in October, said to have remained open for three years continuously
1971	broke (? March, ? November)
1973 or 1975	bar reported to have broken (neither particularly wet winters)
1978	broke 3 July, closed mid March 1979
1984	broke 4 January, closed 5 August, opened 4 October, closed 20 October
1985	broke 3 October
1988	broke 4 May (still open 7 October)

The bar is reported to have been closed in March 1962, August and November 1974, August 1977.

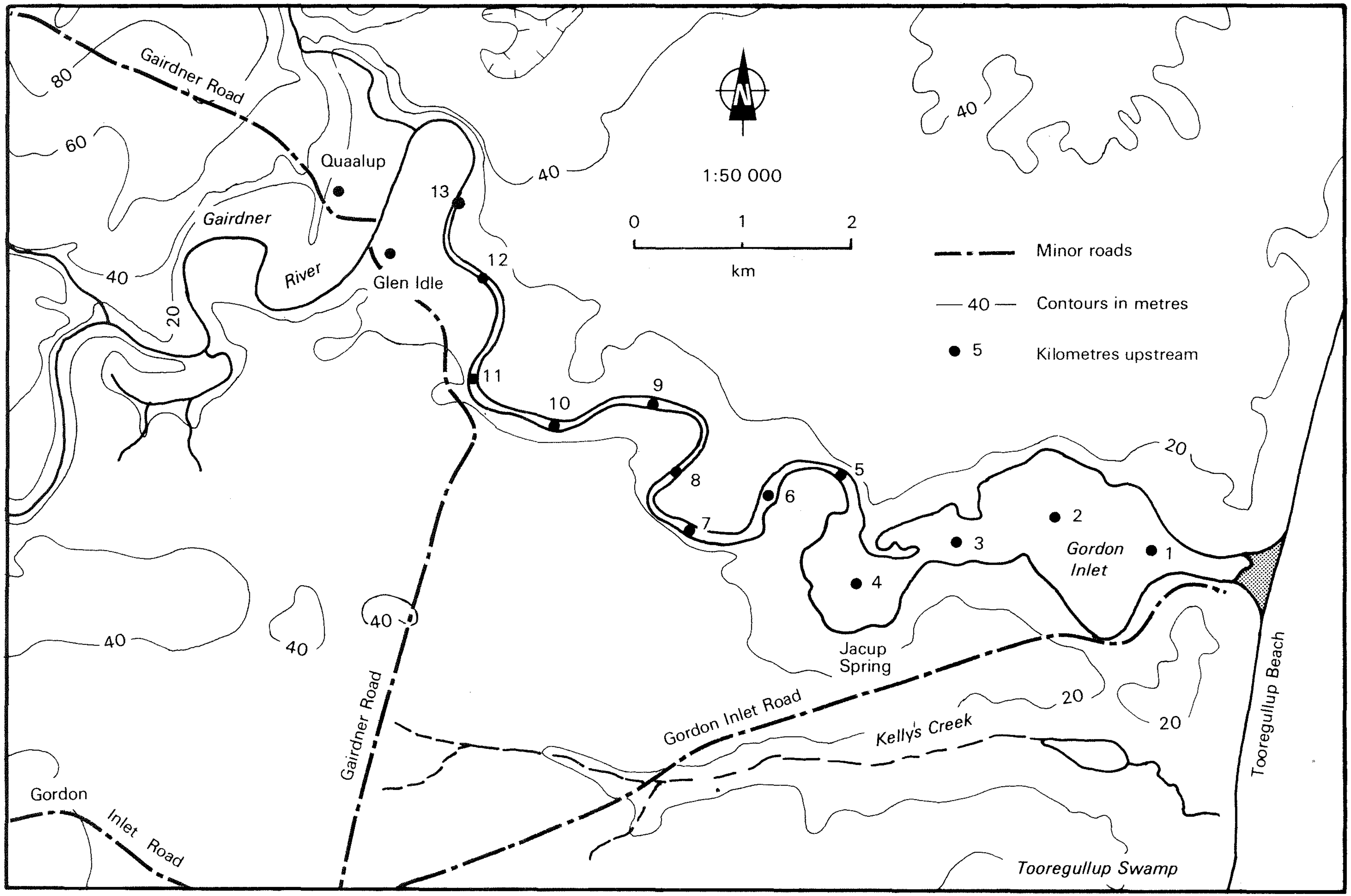


Figure 4.11 Gordon Inlet.

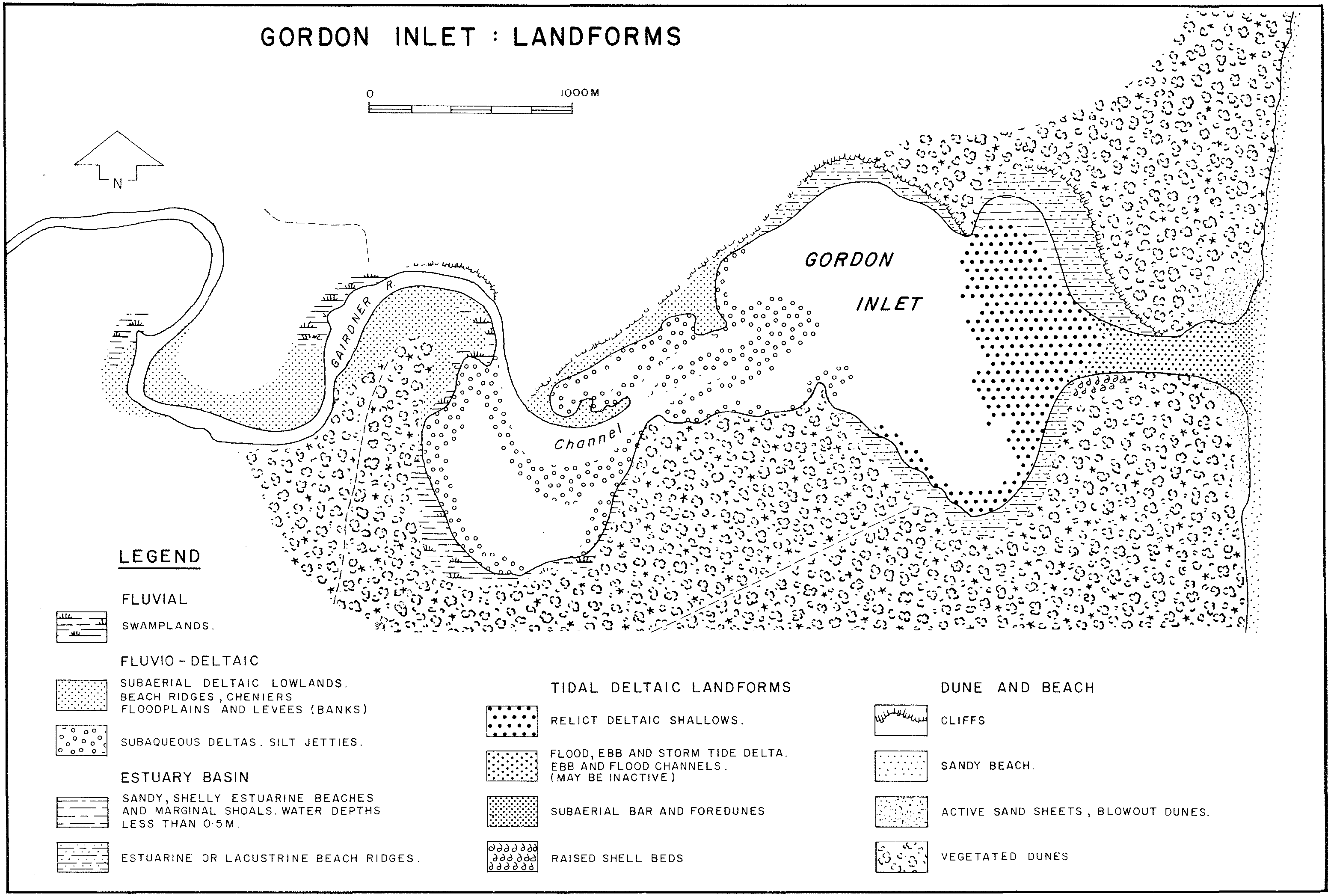


Figure 4.12 Landforms of Gordon Inlet and surrounds. (I. Eliot)

4.3 BOTTOM SEDIMENTS

Mud and sand alternate in the river reaches. Where sampled near the margin of the lagoon, the sediment is sand with a small silt fraction (Hassell, 1962). There are extensive surface deposits of water laid shells throughout the lagoon.

4.4 WATER CHARACTERISTICS

SALINITY Observed salinities in the lagoon range from slightly less than sea water to more than four times that of the sea. Sea water is reported to fill the lagoon when the bar is open and river flow slackens. Water in the riverine reaches may be less than 10 ppt when the river is flowing, but can be about 100 ppt when the bar is closed, sometimes with water of about 30 ppt overlying water of up to 160 ppt. A spring from the spongolite cliff at the head of the estuary, and probably other seepage, contributes some 'fresh' water. Sea water seeps through the bar into the estuary when the bar is closed and there is little water in the lagoon. However, as noted by Congdon and McComb (1986), fresh water from the dunes can dilute groundwater in the bar.

5 ESTUARINE VEGETATION

Surveys of the estuarine vegetation have been made by Congdon and McComb (1986) in August 1974 (Wellstead and Gordon), R.B. Humphries in May 1982 (Wellstead and Gordon), J.M. Chambers in January 1987 (Beaufort and Wellstead), and Clark and Hodgkin in October 1988 (Gordon). Chambers examined material from all the estuaries with the air photos and the following account and Figures are largely compiled from her report. Her account of the Wellstead Estuary vegetation is included in the study of that estuary (Hodgkin and Clark, 1987).

5.1 AQUATIC PLANTS

The sea grass *Ruppia maritima* and the stonewort *Lamprothamnium papulosum* which form extensive meadows in the shallow water of Wellstead Estuary also flourish in Gordon Inlet when salinity is favourable. Both were abundant in 1974 when salinity was 28 ppt, as was the small green alga *Polyphysa peniculus*. *Lamprothamnium* was again abundant in 1982 (42 ppt). *Ruppia* is also present in the riverine reaches of Gordon Inlet. The filamentous green alga *Enteromorpha paradoxa* was growing in shallow water at 6 km from the bar in 1988. There is reported to have been a bloom of blue-green algae near the head of the estuary (13 km) early in 1988.

In recent years dense blooms of phytoplankton in Beaufort Inlet have reduced light penetration, but *Ruppia* is still common there in shallow, protected areas and is often washed up on the shores. It was the only aquatic plant observed in the surveys.

5.2 SALT MARSH PLANTS

There are extensive salt marshes along the margins of the lagoons of all three estuaries. The wider low lying areas are generally dominated by samphire (*Sarcocornia* and other Chenopodiaceae) and many are almost a monoculture of *Sarcocornia quinqueflora*. But in other places dense stands of the salt water paperbark (*Melaleuca cuticularis*) largely replace the samphire, as on shores of southern bays of both Beaufort and Gordon Inlets. A variety of other species of salt tolerant plants were found at slightly higher levels behind the samphire swamps. The salt marsh plants found at these two Inlets are listed in Table 5.21. There were errors and omissions in the list of salt marsh plants found at Wellstead Estuary in Table 5.2 of Study No. 1. The corrected names are in Table 5.22.

Table 5.21 Salt marsh species found at Beaufort and Gordon Inlets (J.M. Chambers).

Gahnia trifida
Isolepis nodosa
Juncus kraussii
Atriplex cinerea
Halosarcia halocnemoides
Halosarcia indica subsp. *bidens*
Halosarcia pergranulata
Rhagodia crassifolia
Sarcocornia quinqueflora
Suaeda australis
Carpobrotus sp.
Disphyma crassifolium
Nitraria billardierei
Samolus repens
Centaurium spicatum
Wilsonia backhousei
Wilsonia humilis

Table 5.22 Plant species recorded in salt marshes throughout the Wellstead estuary. (Congdon and McComb, 1986; J.M. Chambers pers. comm.; R. Humphries pers. comm.)

Avena sp.*
*Ehrharta calycina**
Lagurus ovatus *
Lolium rigidum
Polypogon monspeliensis *
Sporobolus virginicus
Gahnia trifida
Isolepis nodosa
Juncus kraussii
Halosarcia halocnemoides sub *halocnemoides*
Sarcocornia blackiana
Suaeda australis
Threlkeldia diffusa
Carpobrotus sp.*
Disphyma crassifolium
Acacia eglandulosa
Acacia littorea
Medicago polymorpha *
Frankenia pauciflora
Agonis flexuosa
Samolus repens
Wilsonia humilis
Lycium ferocissimum *
Cotula australis
Cotula coronopifolia
Senecio glossanthus
Enteromorpha sp.
Vaucheria sp.*

* introduced species

The major difference between the salt marshes of Beaufort and Gordon Inlets is the dominance of the swamp sheoak *Casuarina obesa* which fringes the greater part of the Beaufort estuary, especially along its steeper, rocky shores. There are more extensive paperbark/samphire communities in sheltered coves, and the sheoak is also found on the landward side of this community (Figures 5.21 and 5.22).

5.3 FRINGING & TERRESTRIAL VEGETATION

The relatively steep slopes surrounding the greater part of Beaufort Inlet bring the terrestrial Eucalyptus communities described earlier (Section 2.2) close to the water's edge, particularly along the riverine stretches. There is a narrow fringing plant community such as the typical plant community found at the head of the estuary (Table 5.31). The many granite outcrops along the banks are colonised by the plants listed in Table 5.32. There has been no detailed survey of the terrestrial vegetation along Gordon Inlet, the shores of which are largely sandy and lack the granite outcrops of Beaufort Inlet.

Table 5.31 Fringing plant community 14 km from Beaufort Inlet mouth (J.M. Chambers).

*Pentaschistis airoides**
Lepidosperma drummondii
Casuarina obesa
Atriplex semibaccata
Enchylaena tomentosa var. *tomentosa*
Halosarcia lepidosperma
Rhagodia preissii subsp. *preissii*
Suaeda australis
Acacia harveyi
Labichea lanceolata subsp. *brevifolia*
Dodonaea ceratocarpa
Pimelea argentea
Calytrix acutifolia
Eucalyptus occidentalis
Eucalyptus rudis
Melaleuca hamulosa
Melaleuca pauperiflora
Melaleuca viminea
Verticordia densiflora
*Ursinia anthemoides**

* introduced species

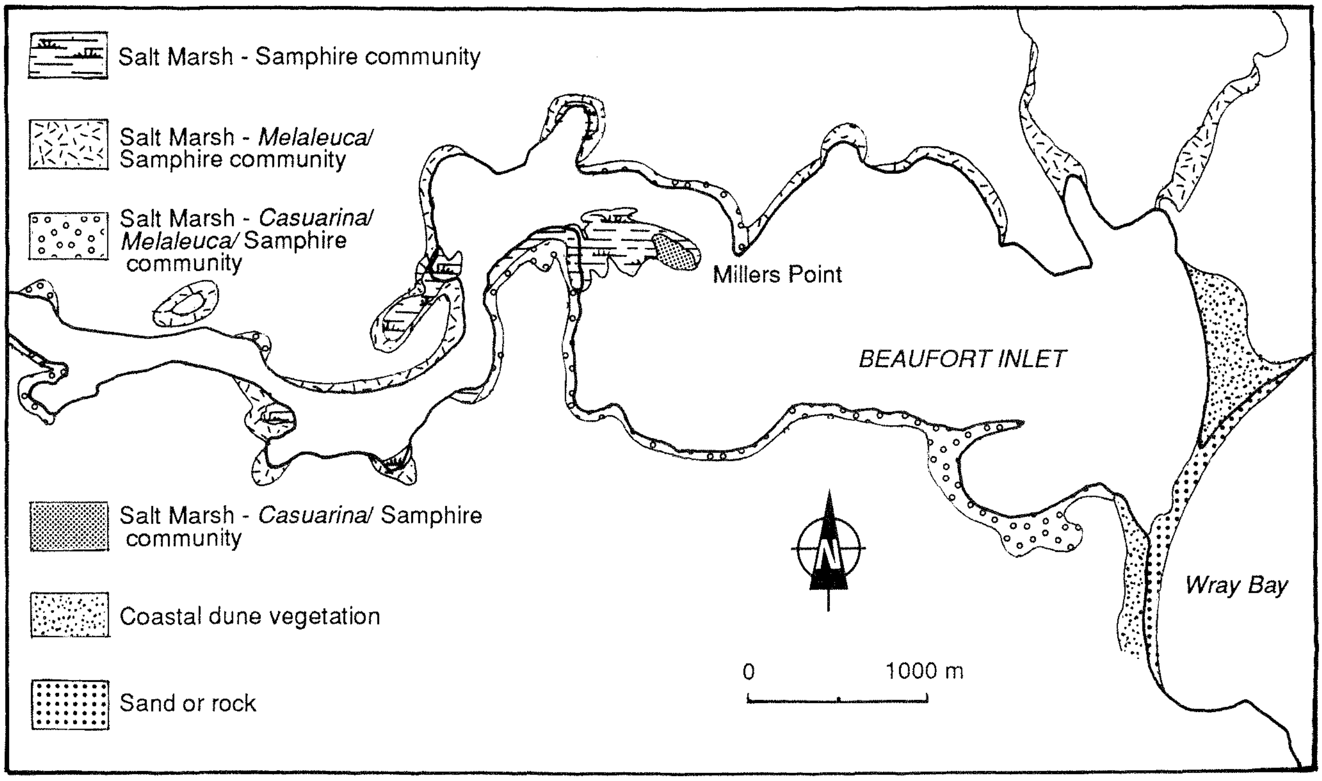


Figure 5.21 Beaufort Inlet. Vegetation (J.M. Chambers).

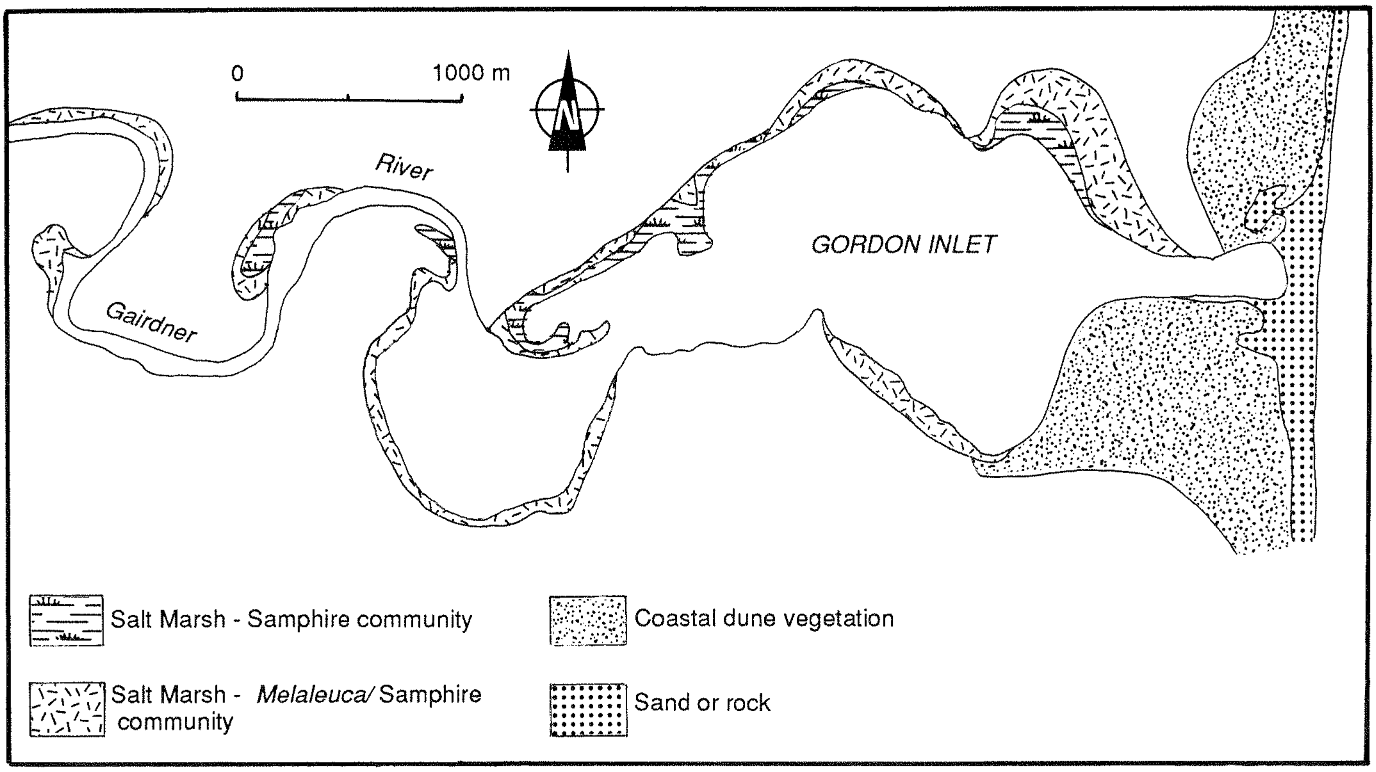


Figure 5.22 Gordon Inlet. Vegetation (J.M.Chambers).

Table 5.32 Plant species colonising rock outcrops at Beaufort Inlet (J.M. Chambers).

Spartochloa scirpoidea
Lepidosperma viscidum var. *viscidum*
Muehlenbeckia adpressa
Dodonaea ceratocarpa
Alyogyne huegelii
Thryptomene saxicola
Centaurium sp.
Eremophila sp.
Opercularia vaginata
Vittadinia gracilis

The coastal vegetation is similar at the two estuaries, except that *Melaleuca lanceolata* is common on the dunes and behind *M. cuticularis* inland to Millers Point at Beaufort Inlet but has not been collected at Gordon Inlet (Table 5.33). Hardy colonising species establish themselves on the beaches and on the bars. The more varied community on the dunes includes woody plants, Peppermint and wattles, and others which only grow further inland.

Table 5.33 Coastal dune vegetation at Beaufort and Gordon Inlets (J.M.Chambers).

Colonising species:
Ammophila arenaria *
*Festuca pubinervis**
Spinifex hirsutus
Isolepis nodosa
Atriplex isatidea
Carpobrotus sp.
*Cakile maritima**
*Euphorbia paralias**

Dune species:
Exocarpus sparteus
Olax phyllanthi
Cassytha sp.
Acacia cochlearis
Acacia eglandulosa
Spyridium globulosum
Hibbertia cuneiformis
Agonis flexuosa
Melaleuca lanceolata#
Leucopogon parviflorus
Olearia axillaris

Further inland:
Jacksonia horrida
Guichenotia ledifolia

only at Beaufort
* introduced species

6 ESTUARINE FAUNA

There are marked differences in the observed aquatic fauna of the three estuaries, as might be expected with their different hydrology. However it is difficult to know to what extent this is because as yet only limited surveys have been made. All have an impoverished permanent fauna, restricted to a few true estuarine species, which may be abundant, and an immigrant fauna recruited from the sea when the bars are open. Many of these more marine species survive and flourish while conditions are favourable, but few survive long once the bars close and salinities become extreme. There have been repeated reports of massive fish mortalities in Beaufort Inlet, preceded by salt burns on the fish and the deaths of shrimp and other invertebrates. The fauna of the Gordon Inlet lagoon is exposed to such extremes of salinity that it must depend on recruitment of estuarine species from the riverine reaches and of marine species from the sea.

6.1 PLANKTON

The few plankton samples taken in Beaufort Inlet and Wellstead Estuary have been dominated by the common copepods of south west estuaries: *Gladioferens imparipes*, *Acartia tranteri* , *Oithona* sp. and *Halicyclops* sp. Larvae of benthic polychaetes, mysids and other crustaceans were also present in the tows taken after dark (most planktonic animals retreat to deeper water or the bottom by day).

6.2 BOTTOM FAUNA

Table 6.21 lists the permanent bottom fauna recorded from Beaufort Inlet and Wellstead Estuary, these are the few estuarine species that tolerate the wide range of salinity normally experienced in the estuaries. Some of these species probably also live in the Gordon Inlet lagoon while salinity is favourable and permanently in the riverine reaches. Polychaete worms dominate the fauna in number of species (8) and may be very abundant. Large clumps of the tube worm *Ficopomatus* are conspicuous in the shallows of Beaufort Inlet and coat rocks in the upper estuary.

Table 6.21 Benthic estuarine fauna recorded from Beaufort Inlet (B) and Wellstead Estuary (W). Found + live, D recently dead, - not found.

		B	W
POLYCHAETA:			
Phyllodocidae:	*Phyllodoce* sp.	+	-
Nereididae:	*Ceratonereis aequisetes*	+	+
	Neanthes vaalii	+	-
Orbinidae:	*Scoloplos simplex*	+	+
Spionidae:	*Polydora* sp.	+	-
	Prionospio cf *cirrifera*	+	+
Capitellidae:	*Capitella capitata*	+	+
Serpulidae:	*Ficopomatus enigmatica*	+	+
MOLLUSCA:	Gastropoda		
Hydrobiidae:	*Hyobodia buccinoides*	+	-
Assimineidae:	*Assiminea* sp.	+	-
Hydrococcidae:	*Hydrococcus brazieri*	+	D
	Bivalvia		
Mactridae:	*Spisula trigonella*	D	+
Leptonidae:	*Arthritica semen*	+	+
CRUSTACEA:			
Amphipoda:	*Melita* sp.	+	+
Decapoda:	*Palaemonetes australis*	+	-
INSECTA:			
	Trichoptera larvae	-	+
Chironomidae:	*Pontomyia* sp.	+	+

A survey was made in Beaufort Inlet in May 1987 when the bar had been closed for over three years and the salinity was 44 ppt (Table 6.22). The difference in composition of the fauna at the four sites is

Table 6.22 Bottom fauna collected using cores in May 1987 at Beaufort Inlet. (J.L. Shaw)

		Bar	Mullet Bay	6 km	10 km
POLYCHAETA:					
Phyllodocidae:	*Phyllodoce* sp.	*	-	-	*
Nereididae:	*Ceratonereis aequisetes*	-	-	*	*
	Neanthes vaalii	*	-	**	***
Orbinidae:	*Scoloplos simplex*	***	-	*	*
Spionidae:	*Polydora* sp.	*	-	*	*
	Prionospio (*Minuspio*) cf *cirrifera*	-	-	-	*
Capitellidae:	*Capitella capitata*	***	**	**	**
Serpulidae:	*Ficopomatus enigmatica*	-	*	***	**
MOLLUSCA:	Gastropoda				
Hydrococcidae:	*Hydrococcus brazieri*	***	***	**	*
	Bivalvia				
	Arthritica semen	*	-	-	-
CRUSTACEA:					
Amphipoda:	*Melita* sp.	-	-	-	*
Decapoda:	*Palaemonetes australis*	-	-	*	*
	Depth (m)	0.5	1.5	0.2-3	0.2-5
	Bottom type	sand	mud	*Ruppia*	sand

probably related more to the type of bottom sampled than to location along the estuary. The eight polychaete species were widely distributed, with the opportunistic *Capitella* being found throughout the estuary. The molluscan fauna was reduced to the small gastropod *Hydrococcus brazieri*, the only abundant species, and the small bivalve *Arthritica semen*, both of which which have been shown to tolerate extreme fluctuations in salinity (Wells and Threlfall, 1982).

Table 6.23 lists immigrant mollusc species found alive near the bars in January 1979. The bars had broken in July/August 1978 and Wellstead and Gordon were still open. Some of these species survived in Wellstead Estuary over the following winter when the bar was closed and by October had shown normal growth, but there were also many recently dead. Similar settlements of marine species, in which the clam *Katelysia* is always conspicuous, have been observed on other occasions. However it is clear that these species do not form a significant component of the fauna even when conditions appear to be favourable. They are common in Princess Royal Harbour and Oyster Harbour which are probably the principal source of the spawn. The absence of all but two of these species from the Beaufort Inlet list is probably because the bar had only been open briefly in winter at which time the spawn was not present in the coastal water. On other occasions, recently dead shells of *Katelysia* and *Sanguinolaria* have been found there and live animals of the gastopods *Nassarius pauperatus* and *Diala* sp. and a barnacle (*Balanus* sp.).

Table 6.24 lists the species of Foraminifera found by Hassell (1962) in the surface sediment of the three estuaries.

Table 6.23 Mollusc species collected near the estuary mouths, 13 January 1979. (D. Roberts pers. comm.)

Bivalvia	B	W	G
Mytilus edulis planulatus	-	+	+
Fulvia tenuicostata	-	+	+
Spisula trigonella	-	+	+
Sanguinolaria biradiata	-	+	+
Katelysia scalarina	-	+	+
Katelysia rhytiphora	-	+	+
Laternula creccina	-	+	+
Irus crenatus	-	-	+
Electroma georgiana	-	+	-
Gastropoda	B	W	G
Adamnestia arachis	-	+	-
Bulla quoyii	-	+	-
Philine angasi	-	+	+
Salinator fragilis	+	-	-

Table 6.24 Foraminifera of Beaufort (B), Wellstead (W) and Gordon (G) estuaries. (Hassell, 1962)

	B	W	G
Halplophragmoides canariensis	-	+	-
Labrospira wiesneri	+	-	-
Quinqueloculina elongata	-	+	-
Quinqueloculina seminula	+	+	+
Quinqueloculina vulgaris	-	+	+
Quinqueloculina sp.	-	-	+
Sigmoilina schlumbergeri	-	-	+
Triloculina tricarinata	-	-	+
Vertebralina striata	-	-	+
Bolivina punctata	-	-	+
Discorbis araucana	-	+	-
Discorbis rosacea	-	+	-
Heronallenia translucens	-	+	+
Elphidium articulatum	-	-	+
Elphidium crispum	-	+	-
Elphidium macellum	-	+	+
Elphidium poeyanum	+	+	+
Elphidiella arctica	+	+	+
Robertina sp.	-	-	+
Rotalia beccarii	+	+	+

6.3 FISH

Only five estuarine species of fish are known to complete their life cycles in the estuaries; these estuarine species are listed in Table 6.31. But many marine species, fish which spawn at sea, enter when the bars are open and flourish while the salinity is favourable. Table 6.32 lists these immigrant species caught in the three estuaries. Recruitment of marine species to the estuarine populations depends on larvae and juveniles being present in nearby coastal waters when the bars are open, so that there is some selection of species by the season at which the bars are open and the duration of opening (Lenanton, 1984).

Table 6.31 Commercial and non-commercial estuarine species of fish caught in Beaufort (B), Wellstead (W) and Gordon (G) estuaries. (G.M. Cliff & J.L.Shaw - WA Fisheries Department)
+ caught, - not caught

Commercial		B	W	G
Sparidae:	Black bream *Acanthopagrus butcheri*	+	+	-
Non-commercial				
Galaxiidae:	Spotted minnow *Galaxias maculatus*	+	-	+
	Trout minnow *Galaxias truttaceus hesperius*	+	-	-
Atherinidae:	Hardyhead *Atherinosoma elongata*	+	+	-
	Wallace's hardyhead *Atherinosoma wallacei*	+	+	+
Gobiidae:	Blue spot goby *Pseudogobius olorum*	+	+	+

Most of the many marine species listed only survive while the bars are open and for a few months after they have closed, with the number declining progressively after the bars close. In April 1977 when the Beaufort Inlet bar had been closed for 3 years, and the salinity was about 60 ppt, only 6 species of fish were caught. The bar was open in July and August 1978 and eight months later (April 1979) 17 species were netted in it. By January 1981 (28 months after the bar had closed) only 8 species were caught, of which only Sea mullet was abundant (Lenanton, 1984).

Leatherjackets are said to be the first to die, within two weeks of closure, Yellow-eye mullet do not last long, but Sea mullet may live for years, be very abundant and grow to a large size. Fish survivors probably retreat to fresher and cooler water in the riverine reaches when conditions in the lagoons become extreme. Black bream also live in river pools upstream from the estuaries and Sea mullet enter the lower river pools such as that below South Coast Highway on the Pallinup River and in the Gairdner River above Quaalup.

The mass mortalities reported in Beaufort Inlet (1936, 1939, 1942, 1944, 1953, 1972 and 1988) have generally been preceded by a deterioration in fish condition (ulcers) and fish swimming at the surface with mouths gaping. They have been attributed to the combined effects of high salinity and temperature.

However there may be complicating factors; the eutrophic condition of Beaufort Inlet suggests that the water may be fouled by decomposing organic matter and become deoxygenated. Similar mass mortalities occur in Gordon Inlet, as is to be expected with the extreme salinities experienced there (1939, 1944, 1953, 1976).

Black bream and Sea mullet are taken in the small Kelly's Creek.

6.4 BIRDS

A wide range of habitats are available in the Beaufort area, including low woodlands, mallee shrublands, samphire flats, permanent water bodies, river and estuary, beach and sea. Some migratory birds stop-over at the estuary during summer. The number of species and individuals are thought to be lower than at Bremer Bay due to the lack of suitable mud flats and low sand patches at Beaufort Inlet.

In 1988 Gordon Inlet was found to be the most important wetland in the south west region for the Australian Shelduck. The Inlet was also found to be the second and third most important wetland for Chestnut Teal in 1987 and 1988 respectively. A pool up the Pallinup River recorded 150 Maned Duck whereas the estuary's highest recorded is 10. Table 6.4 lists the waterbirds and the highest numbers recorded at the three estuaries.

Table 6.32 Commercial and non-commercial marine species of fish caught in Beaufort (B), Wellstead (W) and Gordon (G) estuaries. (G.M. Cliff & J.L. Shaw - WA Fisheries Department) + caught, - not caught

Commercial		B	W	G
Clupeidae:	Sandy sprat *Hyperlophus vittatus*	+	-	-
Engraulidae:	Australian anchovy *Engraulis australis*	+	-	-
Plotosidae:	Cobbler *Cnidoglanis macrocephalus*	+	+	-
Platycephalidae:	Flathead *Platycephalus* sp.	+	-	-
	Southern sand flathead *Platycephalus bassensis*	-	+	-
	Blue-spotted flathead *Platycephalus speculator*	+	-	-
Sillaginidae:	King George whiting *Sillaginodes punctatus*	+	+	-
Pomatomidae:	Tailor *Pomatomus saltator*	+	-	-
Carangidae:	Silver trevally *Pseudocaranx dentex*	-	+	-
Arripidae:	Western Australian salmon *Arripis truttaceous*	+	+	-
	Australian herring *Arripis georgianus*	+	+	-
Sparidae:	Pink snapper *Chrysophrys auratus*	+	-	-
	Tarwhine *Rhabdosargus sarba*	+	+	-
Mugilidae:	Yelloweye mullet *Aldrichetta forsteri*	+	+	-
	Sea mullet *Mugil cephalus*	+	+	-
Labridae:	Western blue groper *Achoerodus gouldii*	-	+	-
Bothidae:	Small toothed flounder *Pseudorhombus jenynsii*	-	+	-
Pleuronectidae:	Elongate flounder *Ammotretis elongatus*	+	+	-

Commercial		B	W	G
Pleuronectidae:	Long snouted flounder *Ammotretis rostratus*	+	+	-
Monacanthidae:	Six-spined leatherjacket *Meuschenia freycineti*	-	+	-
Non-commercial				
Ophichthidae:	Serpent eel *Ophisurus serpens*	-	-	+
Peociliidae:	Mosquito fish *Gambusia affinis*	+	-	-
Gonorynchidae:	Beaked salmon *Gonorhynchus greyi*	+	-	-
Atherinidae:	Hardyhead Atherinid sp.	+	+	-
Scorpaenidae:	Soldier fish *Gymnapistes marmoratus*	+	+	-
Teraponidae:	Striped trumpeter *Pelates sexlineatus*	+	-	-
	Sea trumpeter *Pelsartia humeralis*	+	-	-
Scorpididae:	Banded sweep *Scorpis georgianus*	+	-	-
Enoplosidae:	Old wife *Enoplosus armatus*	+	-	-
Gobiidae:	Long finned goby *Favonigobius lateralis*	+	+	-
Cheilodactylidae:	Red lipped Morwong *Cheilodactylus rubrolabiatus*	+	-	-
Tetraodontidae:	Banded toadfish *Torquigener pleurogramma*	+	+	-
	Prickly pufferfish *Contusus brevicaudus*	-	+	-

Table 6.4 Waterbirds recorded at Beaufort (B), Wellstead (W) and Gordon (G) estuaries. (B. Newbey) Numbers indicate highest recorded.

Common name	Scientific name	B	W	G
Australasian Grebe	*Podiceps novaehollandiae*	#	—	—
Hoary-headed Grebe	*Podiceps poliocephalus*	#	1	200
Australian Pelican	*Pelecanus conspicillatus*	32	60	89
Little Black Cormorant	*Phalacrocorax sulcirostris*	2	12	500
Great Cormorant	*Phalacrocorax carbo*	#	6	10
Pied Cormorant	*Phalacrocorax varius*	#	—	20
Little Pied Cormorant	*Phalacrocorax melanoleucos*	1	32	11
Darter	*Anhinga melanogaster*	—	—	2
White-faced Heron	*Ardea novaehollandiae*	50	5	5
Great Egret	*Egretta alba*	8	8	7
Eastern Reef Heron	*Egretta sacra*	—	3	—
Black Swan	*Cygnus atratus*	136	905	49
Australian Shelduck	*Tadorna tadornoides*	1500	3460	1105
Pacific Black Duck	*Anas superciliosa*	40	58	12
Grey Teal	*Anas gibberifrons*	500	620	211
Chestnut Teal	*Anas castanea*	50	107	245
Australian Shoveler	*Anas rhynchotis*	5	—	—
Maned Duck	*Chenonetta jubata*	#	—	—
Musk Duck	*Biziura lobata*	1	—	40
Eurasian Coot	*Fulica atra*	#	9	2
Sooty Oystercatcher	*Haematopus fuliginosus*	#	2	3
Pied Oystercatcher	*Haematopus ostralegus*	#	2	4
Black-fronted Plover	*Charadrius melanops*	#	—	—
Pectoral Sandpiper	*Calidris melanotos**	—	#	—
Common Sandpiper	*Tringa hypoleucos**	#	1	2
Greenshank	*Tringa nebularia**	#	5	2
Silver Gull	*Larus novaehollandiae*	#	707	350
Caspian Tern	*Sterna caspia*	#	25	34
Crested Tern	*Sterna bergii*	40	476	264
Red-capped Plover	*Charadrius ruficapillus**	30	30	60
Red-necked Stint	*Calidris ruficollis**	8	100	594
Hooded Plover	*Charadrius cucullatus*	3	14	56
Bar-tailed Godwit	*Limosa lapponica*	1	3	—
White-breasted Sea Eagle	*Haliaeetus leucogaster*	1	—	1
Osprey	*Pandion haliaetus*	—	—	1
Peregrine Falcon	*Falco peregrinus*	—	—	1
Marsh Harrier	*Circus aeruginosus*	—	—	1
Banded Stilt	*Cladorhynchus leucocephalus*	—	—	200
Grey Plover	*Pluvialis squatarola*	—	—	1
Ruddy Turnstone	*Arenaria interpres**	—	—	3
Sanderling	*Calidris alba**	—	—	88
Great Knot	*Calidris tenuirostris**	—	—	1
Curlew Sandpiper	*Calidris ferruginea**	—	1	13
Broad-billed Sandpiper	*Limicola falcinellus**	—	—	2
Black-winged Stilt	*Himantopus himantopus*	5	18	16
Red-necked Avocet	*Recurvirostra novaehollandiae*	—	84	300
Pacific Gull	*Larus pacificus*	—	12	3
Whiskered Tern	*Sterna hybrida*	—	—	1
Fairy Tern	*Sterna nereis*	6	#	6
Blue-billed Duck	*Oxyura australis*	2	2	—
Wood Duck	*Chenonetta jubata*	#	—	—

* denotes migratory bird; present in greater numbers in spring and summer, most depart in autumn. All other birds are sedentary or vagrant. # denotes present but no numbers recorded.

7 MANAGEMENT

There are two outstanding environmental problems: sedimentation and shallowing of all three estuaries, and the eutrophic condition of Beaufort Inlet.

7.1 SEDIMENTATION The greatest threat to the estuaries comes from the accelerated rate of sediment accumulation consequent on clearing in the catchments. All three estuaries are already so shallow that the lagoons retain little water when the bars are closed. The area is one of low rainfall, saline river water, and high evaporation. Gordon Inlet is so shallow that when the bar closes the water soon evaporates, often leaving most of the lagoon dry. The Wellstead Estuary lagoon is also shallow and a large part of the flood tide delta and marginal shallows may be exposed at the end of summer. Beaufort Inlet is little deeper, but the high bar retains more water and only the shallowest parts dry out.

This progressive shallowing of the lagoons continues, but without more data it is not possible to give an accurate time scale for the process. The only data on which to base an estimate of the present rate of shallowing is the observation quoted above of 100 000 t of sediment being scoured from the Pallinup River channel in the 1982 flood. This represents a layer of sediment 25 mm thick spread over the bottom of the Beaufort Inlet lagoon. Much of the fine sediment will have gone out to sea with the flood waters and much coarse sediment may have been deposited in the river delta as well as on the under water bars and levees. Nevertheless this figure, crude as it is, highlights the potential for rapid shallowing of the Inlet and the damage done by a single storm carrying soil eroded from a cleared catchment. It is obvious that Beaufort Inlet is in danger of following Gordon Inlet and other estuaries to the east into the graveyard of estuaries.

There can be little doubt that clearing in the catchments has accelerated the natural processes of sediment transport and its accumulation in the lagoons. An indication of the potential rate of sedimentation is gained from ^{137}Caesium dating of cores taken from Stokes Inlet, 200 km to the east. There 50 to 60 cm of wet sediment (20-25 cm dry) has accumulated in the last 30 years (K-H Wyrwoll, pers. comm.). That is one metre in 50 to 100 years. Partial reafforestation of the catchments is needed urgently to reduce the rate of sediment loss to the streams. This is particularly necessary along the water courses, where there is reported to have been increased clearing recently.

Beach sand is also filling the estuaries from the seaward end; it has almost blocked the inlet channels of both Gordon Inlet and Wellstead Estuary and extends into the lagoons. Wind blows sand in from the beaches and bars which lack vegetation to bind it. Waves wash sand over the bars and when they are open inflowing currents carry sand in. Floods flush some sand out again, but there is no measure of the rate at which the bars and deltas are increasing, or decreasing. There appears to be much less infilling with marine sand at Beaufort Inlet, probably mainly because the bar is only open briefly but also because it is higher and of coarser sand. Premature breaking of the bars, before they are ready to break naturally, may be expected to accelerate this process. However, it is not possible to make responsible recommendations for management of the bars until the dynamics of the systems are studied.

7.2 EUTROPHICATION Clearing, cultivation and the application of fertilizers in the catchments has caused another problem. Nutrient input is high and Beaufort Inlet is now seriously eutrophic, as evidenced by the high total phosphorus and total nitrogen levels in Tables 3.42 and 3.43 and the high level of chlorophyll. This is in contrast to the situation in Wellstead Estuary where the water is generally clear and there is a rich growth of water weeds (*Ruppia* and *Lamprothamnium*), plants which combine with the sediment to maintain low nutrient levels, as in the water of Wilson Inlet (Hodgkin and Clark, 1988). These plants are present but not abundant in the murky water of Beaufort Inlet.

This high level of eutrophication in the Beaufort Inlet is comparable to that in the Swan River estuary (Lukatelich *et al.*, 1984, Table 5). It is much higher than in estuaries of the south coast with largely forested catchments, where nutrient levels are generally low (they are oligotrophic). As suggested above, it may well be a contributory cause of the periodic mass mortalities of fish. Nutrient levels in river and estuary water should be monitored in order to detect any worsening of the present condition.

Gordon Inlet is probably also eutrophic. A bloom of blue green algae in the upper reaches of the Gairdner River estuary in April 1988, and associated fish mortality, may also have been caused by excess nutrients in the stagnant water. The few data on nutrients in Wellstead Estuary show relatively low levels, but again it would be wise to monitor nutrients in both estuary and river water.

Sediment and nutrient transport are linked because most of the phosphorus is probably attached to eroded soil particles

7.3 FISH AND THE FISHERY The success of fish, and hence of the fishery, depends greatly on the frequency, time and duration of the bar openings. Some fishermen advocate breaking the bars when they have been closed for three years or more, to allow access of marine fish to the estuaries. While more frequent opening of the bars would undoubtedly allow more frequent recruitment to the estuaries, a short term gain to the fishery, the conditions under which this would be of long term benefit to the estuaries require careful investigation. All three estuaries are fished by professional fishermen two to three years after the bars have been open, when legal size fish are abundant. Beaufort Inlet and Wellstead Estuary are particularly popular with amateur (recreational) fishermen and the riverine reaches of Gordon Inlet are sometimes heavily fished. There are restrictions on net fishing, relating to mesh size, location and time (see Recreational Fishing, issued by Fisheries Department , W.A.).

Water remaining in the lagoons in summer becomes more hypersaline than most fish species tolerate, and this causes periodical mass mortality in Beaufort and Gordon Inlets. The riverine reaches are deeper and retain more water but this may also become hypersaline. In Gordon Inlet it is often twice sea water salinity and it is surprising that any fish survive.

7.4 GREENHOUSE EFFECT In view of the recent extensive publicity on the Greenhouse Effect it is appropriate to comment on how this may affect the estuaries. The expected rise in sea level of between 0.2 and 1.4 m in the next 40 to 50 years is only one of many factors which will influence them and the results will be complex. The nature of the changes will depend greatly on rate of sea level rise and the time over which the environments can accommodate.

Water level will rise, but sedimentation may keep pace and the estuaries not be deeper. Salt marshes could be inundated, but sediment accretion and plant growth may keep pace with the rise. Unprotected shorelines will be eroded and low lying areas will be flooded periodically, probably with the loss of woodlands such as those of the Bremer Bay caravan park. Much will depend on the behaviour of the bars. There is probably sufficient sand available on the sea shores for them to grow in height as sea level rises, and any change to the aquatic environment will depend more on rainfall in the catchments. If rainfall increases, the estuaries could revert to the more marine conditions of 4000 years ago. But the more likely decrease in rainfall in the south west would accelerate the trend to extinction of the estuaries.

In the present state of knowledge it would be folly to try to predict what changes there will be to any particular estuary, there are too many uncertainties. There are several relevant articles in the recent publication 'Greenhouse' (Pearman, 1988).

7.5 GENERAL The Beaufort and Gordon estuaries and the greater part of Wellstead Estuary are surrounded by bush, most but not all in National Park and Shire reserves, with a wealth of native plants and animals. It is important to preserve the bush in the vicinity of the estuaries, for the sake of the estuaries themselves and for the pleasure it gives those who use them, also to encourage visitors to show more concern for the environment and the enjoyment of others than has sometimes been shown in the past. Unsightly piles of bottles and cans at picnic spots are no credit to the community, nor is thoughtless damage to the vegetation. The destruction of Paperbark woodland a short distance upstream from Millers Point appears to have been caused by cutting for firewood. The trees are slow to regenerate and such damage to the bush degrades the environment and may increase erosion of the shoreline during floods.

There are other problems for management which although marginal for the estuaries themselves are nevertheless important to their surroundings. The rare Newbey's Mallett (*Eucalyptus newbeyi*) is confined to Miller's Point where it forms a dense, shady grove. However the understorey has suffered by trampling and there is unlikely to be regeneration. A recent report by Newbey (1986) deals with the main aspects of land use and management in the Beaufort Inlet area.

8 FURTHER INVESTIGATION

The information reported in this Study is based largely on the recollections of local residents and fishermen and limited observations made by the authors and other scientists on sporadic visits to the estuaries. There have been no continuing, coordinated studies such as are essential to a proper understanding of the ecology and the problems for management. It will be obvious that there are still many gaps in our knowledge of the estuaries.

The most important gaps at the present time relate to the input of sediment and nutrients to the estuaries. It would be valuable to establish the long term history of the estuaries by deep coring, as has been done in New South Wales (Roy, 1984), but the more urgent need is to determine the present rate of sediment accumulation. This can be done by the ^{137}Caesium technique. Sediment input to estuaries represents sediment lost from the catchments, much of it soil that agricultural land can ill afford to lose. Catchment management investigations now being made in higher rainfall areas further west will provide valuable information about both soil and nutrient loss, but the limited evidence available from the present studies suggests that soil loss, and the unwanted gain to the estuaries, is much greater in the lower rainfall areas east of Albany. Valuable efforts are being made to conserve the soil by farmers and others in the Soil Conservation Districts Advisory Committees, in the present instance especially the Jerramungup SCDAC, but more still needs to be done.

The limited observations reported here indicate that the level of nutrient input to Beaufort Inlet is unacceptably high. The nature and extent of the nutrient enrichment can only be identified by more extended sampling of both river and estuary water for nutrients, and an assessment of the effect on the estuarine ecosystem. The problem does not appear to be so pressing in Wellstead Estuary and Gordon Inlet, but it is clear that both are potentially, if not actually, eutrophic, and also need to be monitored.

It is essential that the Water Authority streamflow gauging stations east of Albany be maintained and if possible extended, so that quantitative estimates of Accurate estimates of the long term behaviour of the catchments, rivers and estuaries of the area can only be made on the basis of statistical analysis of continuous river flow records.

The Wellstead Estuary Study discussed the management of the bar and stressed the need for further careful investigation. There is no obvious simple and relatively inexpensive method of managing the bar so as to ensure that the estuary remains in a healthy condition, without the extremes of salinity and low water levels that are now experienced with the sometimes prolonged closure of the bar.

There is much controversy on the subject of bar opening generally, with little factual information on which to base rational decisions for management. As noted earlier, fishermen often advocate breaching the bars after long closure in order to flush stale estuary water out to sea and allow fish stocks to be recruited. This may be of immediate benefit to the fishery, but there is no basis for judging what the long term effect will be on the estuaries. Premature breaching is likely to be followed by a shorter open time than if the bars are allowed to open naturally so scouring a better channel and flushing more estuary water to sea. On the other hand prolonged opening of the bars, without continued strong river flow, may allow an increased net input of beach sand, further shallowing the estuaries. What may be wise management for one estuary may be inappropriate for another. The high Beaufort bar closes rapidly allowing little time for beach sand to wash in, but the Wellstead bar may remain open to tidal flow and sand transport for many months.

Gordon Inlet is no longer an estuary in the usual sense of the word. Both Beaufort and Wellstead are nearing the end of their lives as estuaries through normal environmental processes, now accelerated by human activities. They can continue to be healthy systems for many years to come if properly managed, but rational management decisions can only be made on the basis of reliable information. This is to advocate a study of the dynamics of the estuarine systems. Data relevant to such a study include: records of river flow, water level changes in the estuaries relative to sea level (especially when the bars are closed), salinity of the estuary water, plant nutrients in estuary and river water, the condition of the aquatic plants. These records and samples should be taken regularly, preferably over a number of years.

The three estuaries are a most interesting series biologically and geomorphologically. They are typical estuaries of the low rainfall area of the south coast, but show significant individual features. They are highly productive in spite of the extreme hydrological conditions, even though the plant and animal life is to a large extent dependent on recruitment from external sources. They offer a fascinating field for further study and are easy of access.

9 ACKNOWLEDGEMENTS

The data in this series of studies have been gleaned from a variety of sources - published reports, unpublished records of government departments, and personal observations. Much valuable information has come from fishermen and other local residents who have lived and worked in the area for many years and it has been a privilege to learn from their memories and experience. There are obvious gaps in our knowledge of these and other estuaries of the south coast, 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 in any way to these studies and of anyone else who has relevant information on the estuaries.

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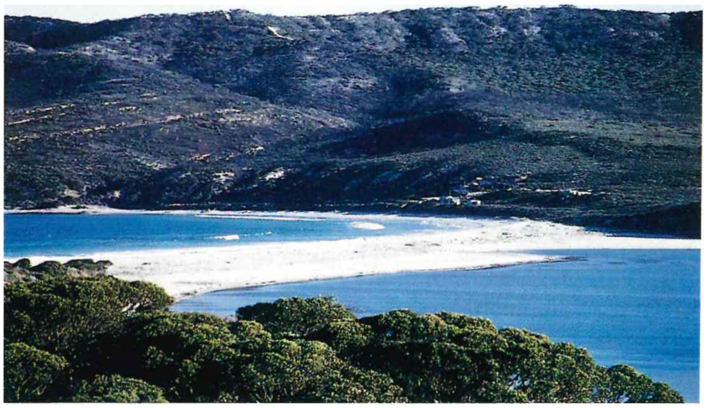
GORDON INLET
October 1988

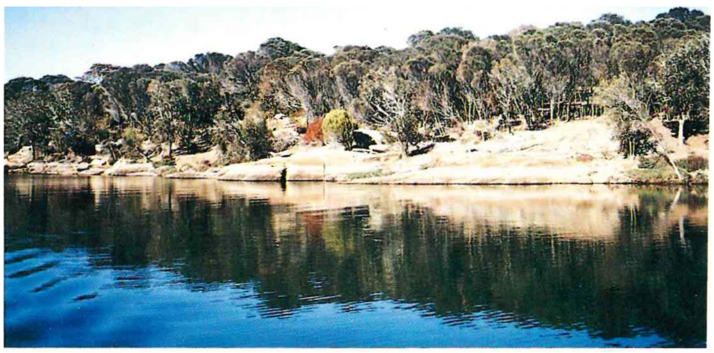
BEAUFORT INLET

Spongolite cliff
from Millers Point



The bar and Mount Groper

South end of the bar with limestone rocks



The river shoreline

Paperbarks, *Melaleuca cuticularis*.