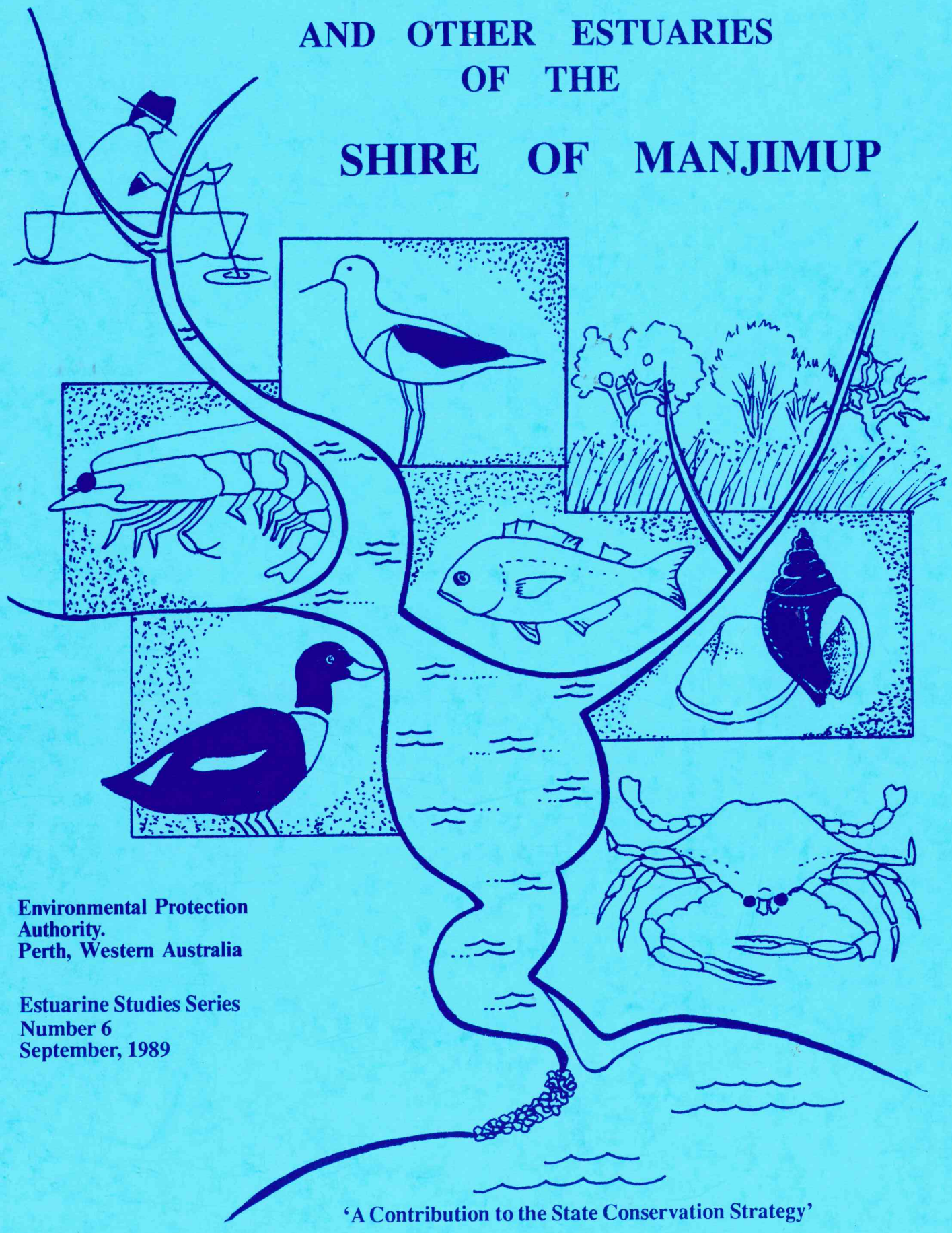
ESTUARIES AND COASTAL LAGOONS OF SOUTH WESTERN AUSTRALIA

BROKE INLET

AND OTHER ESTUARIES OF THE

SHIRE OF MANJIMUP



Environmental Protection Authority.
Perth, Western Australia

Estuarine Studies Series
Number 6
September, 1989

'A Contribution to the State Conservation Strategy'

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By E. P. Hodgkin and R. Clark

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Estuaries of the Shire of Esperance No. **5**

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An Inventory of Information on the

Estuaries and Coastal Lagoons of South Western Australia

ESTUARIES OF THE SHIRE OF MANJIMUP

BROKE INLET

DONNELLY, WARREN AND GARDNER RIVERS

By Ernest P. Hodgkin and Ruth Clark

Broke Inlet December 1988 Photo: Land Administration, WA.

Environmental Protection Authority

Perth, Western Australia

Estuarine Studies Series No. 6

September 1989

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

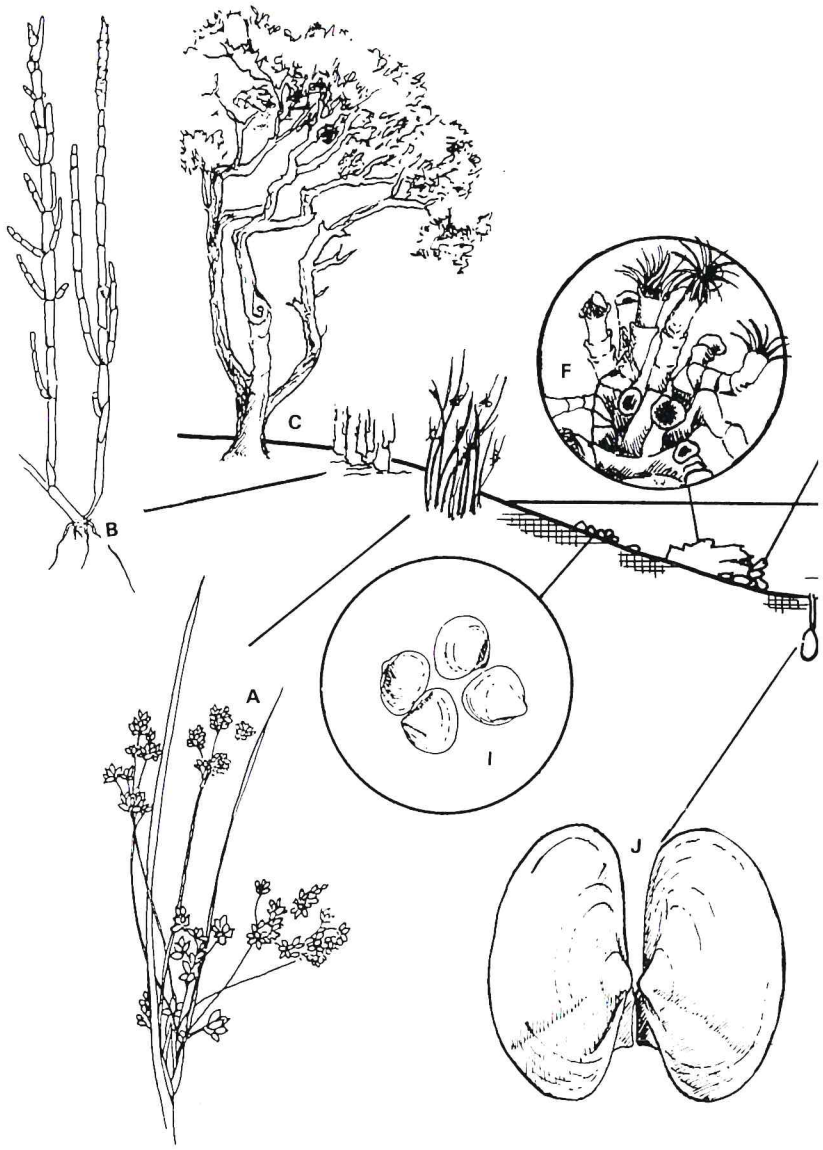
F Tubeworms - *Ficopomatos enigmaticus* 20

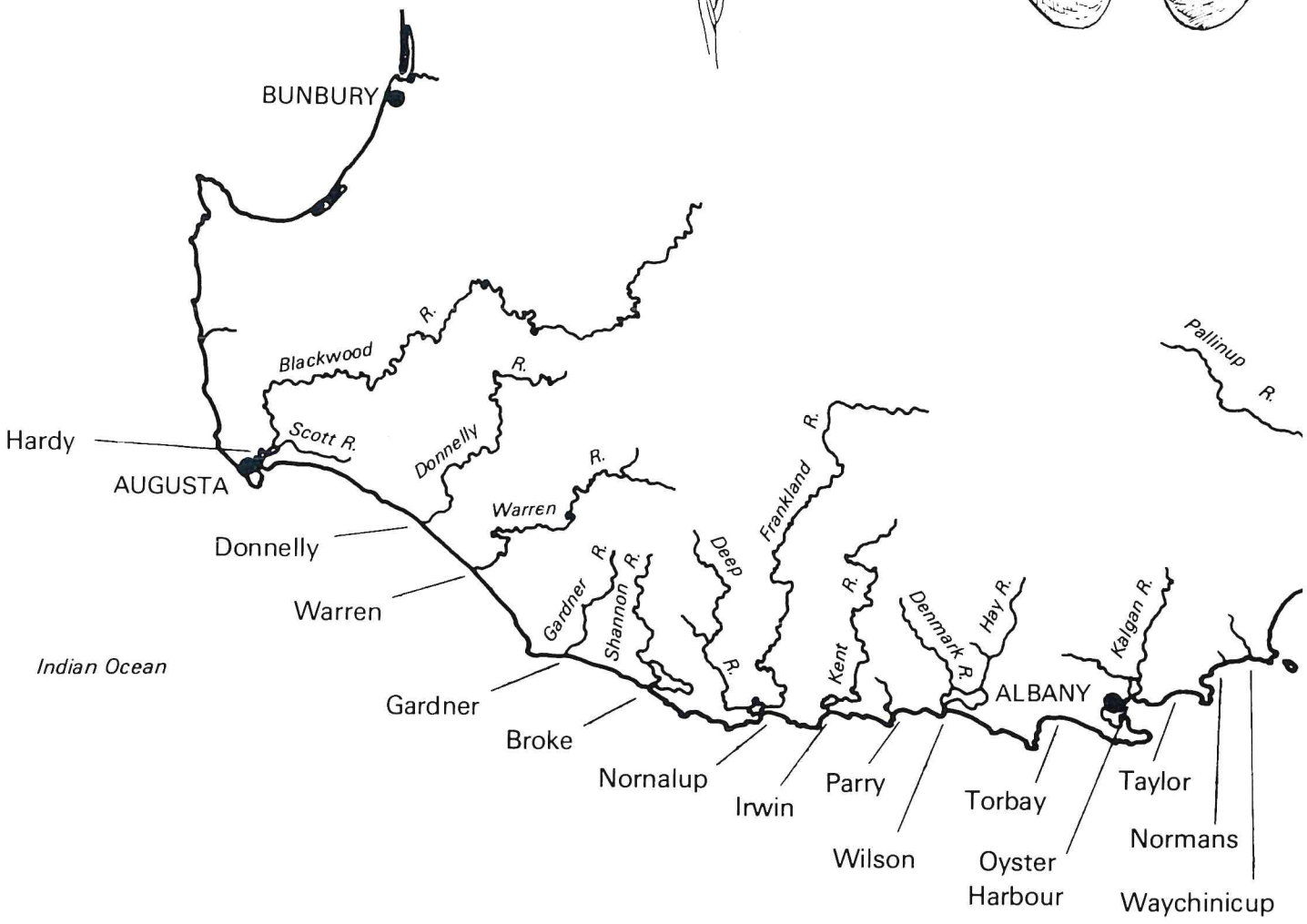
Bivalve molluscs
- G Estuarine mussel - *Xenostrobus securis* 30
- H Edible mussel - *Mytilus edulis* 100
- I *Arthritica semen* 3
- J *Sanguinolaria biradiata* 50
- K Cockle - *Katelysia* 3 spp. 40
- L *Spisula trigonella* 20

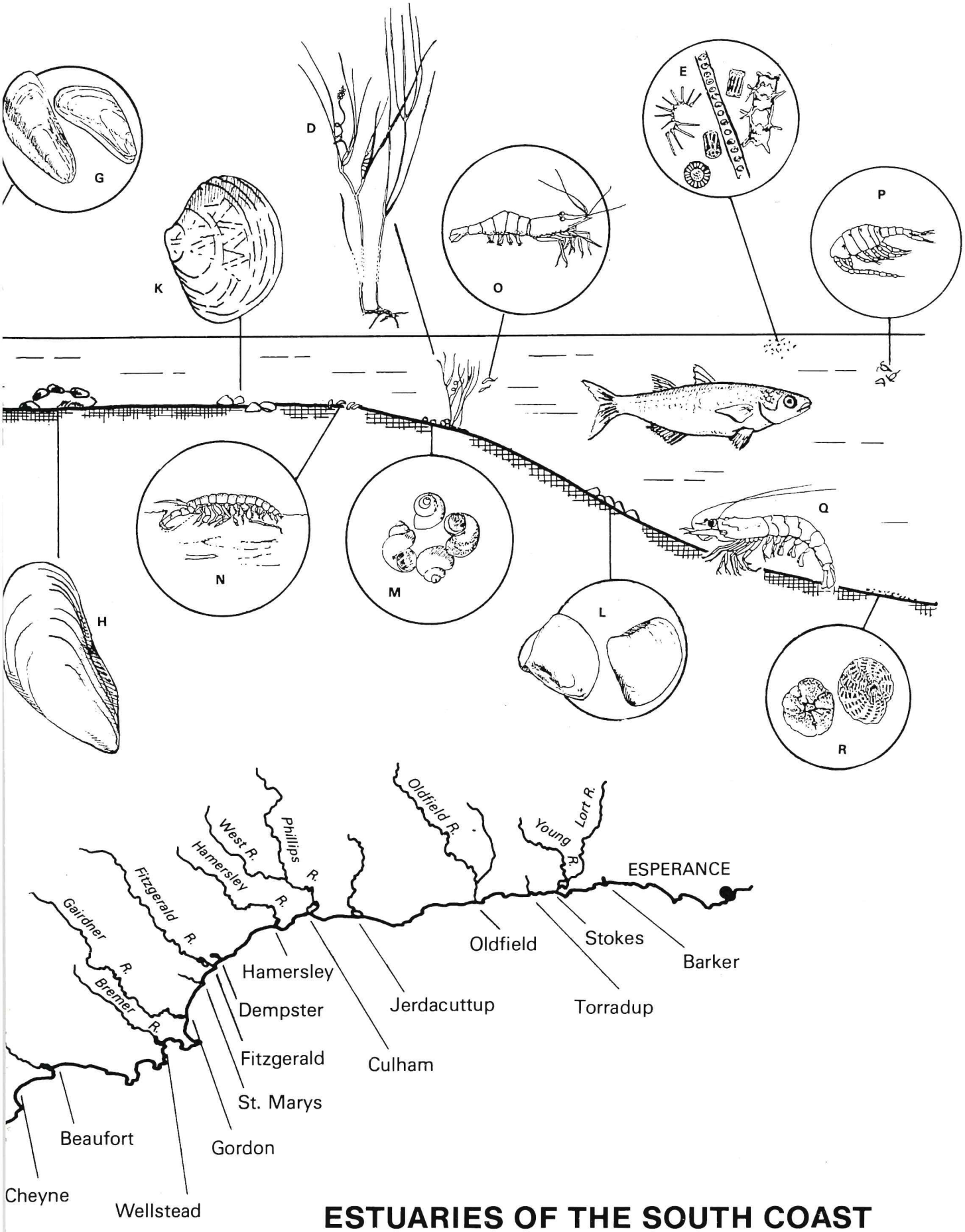
Gastropod molluscs
- M Snail - *Hydrococcus brazieri* 4

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

0 100

Kilometres

Hon R J Pearce, MLA
Minister for Environment

FOREWORD

This series of studies of the estuaries of the south west is a link in the State Conservation Strategy initiated by the Government in 1987.

The estuaries of our south coast are a part of the national estate and their welfare is an important concern for management authorities which often face difficult conflicts of interest.

The studies aim to provide information on which rational decisions can be made about the future of the estuaries, and to make this available to local and other management authorities. They will also be of value to conservation groups and to individuals interested in the estuaries for recreation and study.

I hope that the data in this study and their interpretation will help to resolve management problems and hence protect the estuaries.

I welcome the interest shown by local people and local authorities in these waterways and commend this report to all who are concerned with their future.

This sixth study discusses a group of estuaries in the Shire of Manjimup, all of which are in the D'Entrecasteaux National Park . They are in the highest rainfall part of the State and their tributary rivers flow strongly from largely forested land.

The estuaries have been little affected by human activities and as such are of especial interest for their near pristine condition. They provide a useful basis for comparison with other estuaries where local developments and indirect pressures from clearing and cultivation in the catchments have already considerably modified the environments.

They are strung along 100 km of the most exposed coastline of the south west where waves and swell pound onto the open beaches and the winds have blown up massive dunes. Their unspoilt condition has a special appeal. I encourage all who know the estuaries to do all in their power to ensure the conservation of these beautiful natural environments.

CONTENTS

1 INTRODUCTION

There are five estuaries in the Shire of Manjimup: the lower reaches of the Donnelly, Warren and Gardner rivers, the large Broke Inlet, and the Nornalup and Walpole Inlet system. Two other streams flow to the coast, the Meerup River and Doggerup Creek, but they are not estuarine. Nornalup Inlet and Walpole Inlet were the subject of Study 2 in this series and are not considered here. Nornalup Inlet and the Frankland River are the eastern border of the Shire, with the Shire of Denmark, and the western shore of the Donnelly River estuary is the boundary with the Nannup Shire (Figure 1).

Broke Inlet has a large lagoon, 48 km^2, the same size as Wilson Inlet, these two being the largest on the south coast. It is connected to the sea by a long narrow channel through the coastal dunes and its main tributary, the Shannon River, is also estuarine for some distance. Broke Inlet water is nearly fresh in winter before the bar opens, but sea water flows back into it while the bar is open, and mixing and evaporation make the water brackish through summer. It is seldom more than about half sea water salinity except in deep water in the inlet channel. By contrast the estuaries of the Donnelly, Warren and Gardner rivers are riverine throughout, with only a small 'Broadwater' in the Donnelly. The bar at the mouth of the Donnelly River opens and closes several times each year and sea water flows back in under the outflowing river water. The Warren River flows out over the high beach most of the time and it is probably rarely or ever tidal or saline. A rock bar at the mouth of the Gardner River keeps it open and sea water flows back in under the fresh water when river flow slackens; it is occasionally closed briefly by sand and seaweed.

All four estuaries open onto long sandy beaches and the mouths lack the protection of the projecting hard rock headlands which shelter the mouth of Nornalup Inlet and of most estuaries further east. However there is coastal limestone on either side of the mouth of Broke Inlet and granite in the Gardner River bar. The beaches face south west into the prevailing winds and swell, except at the Gardner River where the beach faces south. This NW-SE orientation of the coast is reflected in the high coastal dunes that line its whole length from Black Point to Point D'Entrecasteaux and along much of the coast from there to Cliffy Head and beyond to Nornalup Inlet. The dunes have a core of limestone rock that is exposed as high cliffs at Cape D'Entrecasteaux and along the coast near Broke Inlet. They also dictate the predominantly WSW-ENE orientation and character of the river channels and the channel to Broke Inlet.

Rainfall is high near the coast, about 1400 mm a year, decreasing inland to 700 to 880 mm. This is mainly winter rain with the heaviest falls generally in June and July (Figure 1). The major river flow is from June to November, but some flow continues from coastal areas throughout summer. Most of the flow is from the southern, high rainfall areas which are largely forested, and river water entering the estuaries is fresh. It is only in the low rainfall catchments of the Tone, Perup and Wilgarup River tributaries of the Warren River that there has been extensive clearing for agriculture and river water is saline.

Pastoralists came to the area in the 1850s and 1860s and cleared small areas for subsistence farming. They grazed their stock through the forests and drove them to the coast to agist them in summer. The forests then had a relatively clear forest floor with abundant native grasses and a closed canopy of tall trees. It was not until the early years of the 20th century that timber mills were established and settlement began in the high rainfall areas, mainly around Manjimup, Pemberton and Northcliffe, and land was cleared and fenced for pasture and orchards. In the Tone River catchment land was taken up by wheat and cereal farmers. An attempt was made to establish a dairy industry in southern areas by the Group Settlement Schemes of the 1920s, with limited success. Remnants of the Groups were used in the 1945 War Service Settlement Schemes, many in the short lived tobacco growing project between Manjimup and Northcliffe.

There are the remains of a number of Aboriginal rock wall fish traps along the northern shore of Broke Inlet between Camfield and Inlet River and it would be informative to know when these were last in use, how they were operated, and what species of fish were caught. There is abundant evidence of Aboriginal occupation of the area with many artefacts having been found (C. Dortch, pers comm).

The estuaries are all within the D'Entrecasteaux National Park and there is much valuable information about the area in the park management plan (Walker, 1987). The only habitations near the estuaries are two houses in the small townsite of Camfield on Broke Inlet, holiday cottages along the lower reaches of the Donnelly River, and fishermen's huts at Camfield and at the mouths of the Warren and Gardner rivers. Park Rangers are stationed at Pemberton, Northcliffe, Crystal Springs and Walpole. As yet the estuaries, and the coastal zone generally, have been little affected by human activities since European settlement, apart from grazing and burning the coastal vegetation. The hinterland and the towns are increasingly popular with tourists, but the estuaries attract few visitors. Broke Inlet is popular with fishermen, the Donnelly River is used by the owners of the cottages and by other local residents, but the Warren and Gardner are difficult of access and hidden from all except beach fishermen and canoeists who come down the rivers.

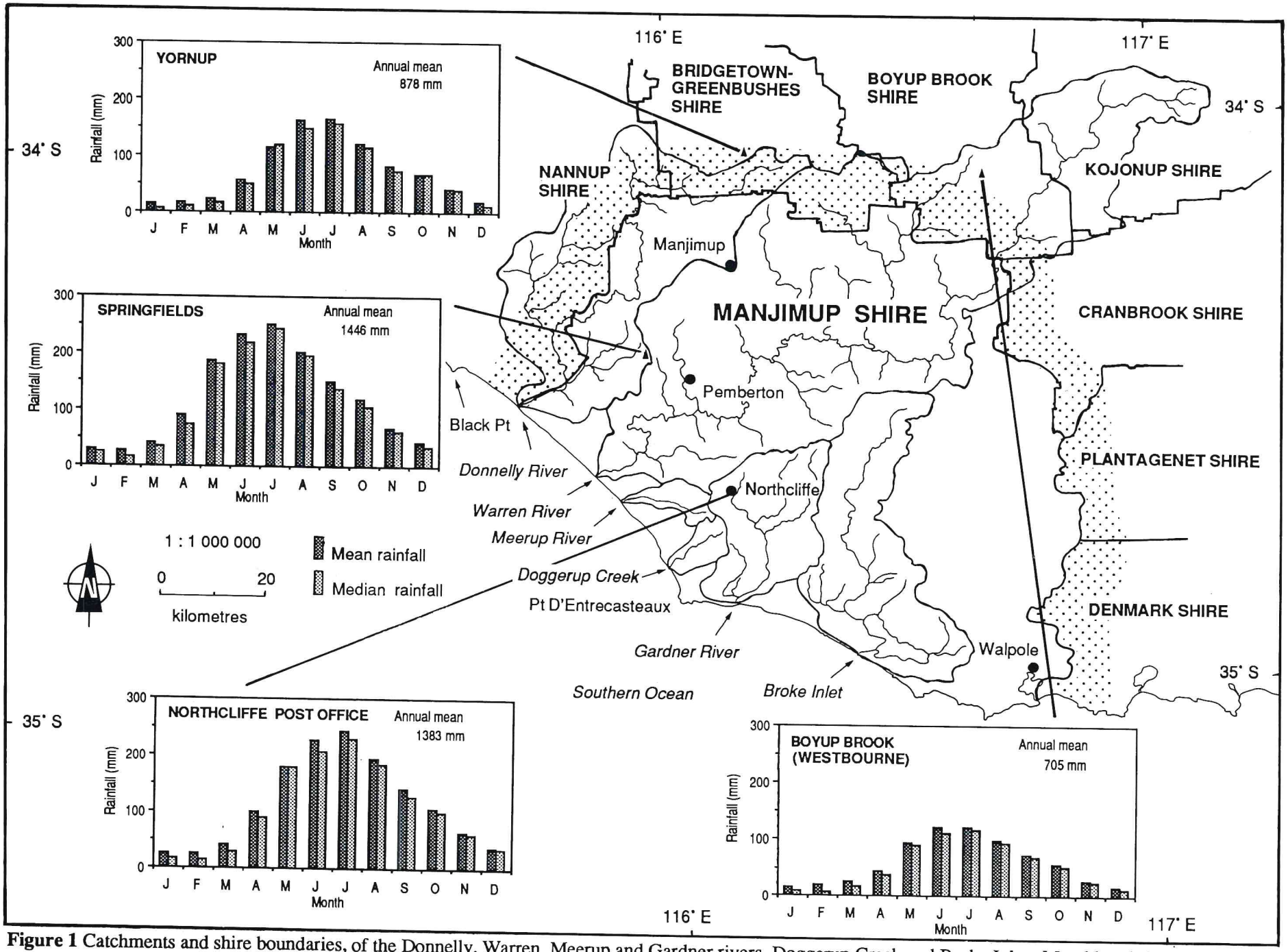


Figure 1 Catchments and shire boundaries, of the Donnelly, Warren, Meerup and Gardner rivers, Doggerup Creek and Broke Inlet. Monthly rainfall. (Commonwealth Bureau of Meteorology)

1.1 LOCATION AND ACCESS

The main roads cross the tributary rivers well inland from the coast. Broke Inlet is reached by a gravel road from South Western Highway, the Donnelly River estuary by gravel road off Vasse Highway, the Warren and Gardner rivers by bush tracks from the Pemberton Northcliffe and Windy Harbour roads. Grid references given below are to maps 2028 Meerup, 2029 Donnelly and 2128 Northcliffe on the 1:100 000 topographic map series published by Natmap.

Broke Inlet lies between 116°22' and 116°32' East and 34°52' and 34°58' South. The mouth is at grid reference 430338. Broke Inlet Road (gravel, 11 km) leaves South Western Highway 25 km west of Walpole and 100 km south east of Manjimup. It leads to Camfield townsite at Signal Point midway along the northern shore of the Inlet, where boats can be launched. The eastern shore of the inlet channel can be reached along a tangle of bush tracks through National Park and private property from Crystal Springs 11 km west of Walpole on South Western Highway. The estuarine part of the Shannon River is accessible from Springbreak Road, off Chesapeake Road, about 3 km upstream from the Inlet.

Donnelly River lies between 115° 40' and 115° 47' East and 34° 27' and 34° 29' South. The mouth is at grid reference 780832. The only access to the estuary is off Vasse Highway 20 km west of Pemberton along Boat Landing Road (gravel, 8 km) to the boat launching ramp on the eastern shore. This is 12 km upstream from the bar near the head of the estuary.

Warren River lies between 115° 50' and 115° 53' East and 34° 36' and 34° 37' South. The mouth is at grid reference 930695. Access to the river mouth is from the Pemberton Northcliffe Road 10 km from Pemberton, thence along Plantation Road and Lewis Road (both gravel) to Warren Beach Road. Alternatively access is from Northcliffe, west along Richardson Road, thence along Lewis Road to Warren Beach Road. Warren Beach Road is a bush track with loose sand in places to Callcup Hill from where it descends 200 m down a steep dune to a track across low hummocky dunes to the beach, and then 3 km along the beach to the south side of the mouth. Warren Beach Road was originally built by fishermen with railway sleepers which still form parts of the track. A track across the Yeagerup dunes also gives access to the beach north of the river mouth.

Gardner River lies between 116° 07' and 116° 08' East and 34° 50' and 34° 51' South. The mouth is at grid reference 198438. Access to the estuary is via Lower Gardner Road which leaves Chesapeake Road (gravel) 16 km from Northcliffe. Alternatively from Windy Harbour Road 22 km south of Northcliffe and then along Tragedy Track. Both the Lower Gardner Road and Tragedy Track are bush tracks which may be impassable in winter, even for 4 wheel drive vehicles. They finish on the western shore of the estuary 300 m from the mouth.

The two major towns in the Donnelly and Warren catchments are popular with tourists. Manjimup has hotel, boarding house and caravan park accommodation for approximately 600 and Pemberton for roughly 1600. Northcliffe, in the Gardner catchment, can accommodate up to 140 people (RAC, 1989). Camping is permitted at Camfield (Broke Inlet) and at the Donnelly River boat landing site, but there are no facilities. There are camping facilities in the Warren National Park, but none near the estuary. The camping area at Windy Harbour, 10 km west of the Gardner River mouth, accommodates 360 people at the camping area (cold showers and toilets but no power).

1.2 GEOLOGICAL HISTORY OF THE ESTUARIES

The coastal dunes of this area were formed during interglacial epochs of the Pleistocene period (the last 2 million years) when sea level was about the same as at present. They were subsequently hardened to Coastal Limestone, particularly near the coast. But during the last major glaciation, and only 20 000 years ago, sea level was more than 100 m lower than it is now and the rivers flowed through deep valleys and out across a wide plain to the sea. Broke Inlet was probably an open swampy valley or perhaps a freshwater lake.

Today's estuaries are therefore of very recent origin geologically. The river valleys were only flooded to form the estuaries during the Holocene (the last 10 000 years) when the ice caps melted and sea level rose rapidly, coming to its present level about 6000 years ago. For some time sea level may have been about 2 m higher than it is now. Swamps adjacent to Broke Inlet were probably part of it and there may have been open water surrounding the upper reaches of the Donnelly estuary. At first the estuaries were probably wide open to the sea, deep and tidal. Sea water would have penetrated far into them and the hydrological regimes would have been very different from those experienced today.

During and following this rise in sea level wave action built the ocean beaches with sand eroded from the wide coastal shelf; it moved sand onshore, offshore and alongshore and built the bars at the mouths of the estuaries. When the bars were open, tidal currents carried sand into the estuaries to form the flood tide deltas which obstruct water flow. For a time the channels would have continued to be open to the sea, but neither the river floods nor the small tides of the south coast could prevent the bars closing seasonally. The Gardner River alone of the four estuaries is always open to the sea, it has a rock bar and its mouth is the least exposed to south westerly swell.

Where rivers do not flow continuously there must be shelter from wave action if the channels are to remain permanently open (as at Nornalup Inlet and Oyster Harbour). Where sand is abundant and wave action is heavy, the bars close seasonally and it is only the river floods that break them, and so prevent them closing permanently, as has happened at Culham Inlet. Further east the bars probably first closed seasonally about 3000 years ago and the estuary water became brackish to hypersaline, with the present seasonal hydrological extremes, but there is no evidence as to when these western estuaries first closed.

A considerable depth of river sediment has accumulated in the estuaries and swamps during the last 6000 years. This, and much organic material, has been redistributed to make their relatively flat bottoms. The extensive shoals so conspicuous in Broke Inlet have been formed by erosion of the shore lines and redistribution of the river sediments. The river deltas have been formed from sediment brought down by the rivers and the estuarine beach ridges by sand built up by wave action and stabilised by vegetation. Sand has spilled in from the encroaching dunes, in some places with steep slopes to the water. The meanders in the riverine estuaries, especially the Warren River, show how the rivers have cut into the dunes on one bank and built river flats on the other.

These processes of erosion and sedimentation are active today; the estuarine environments are not static, they are constantly changing. The estuaries are filling from both ends, from the sea and from the land, natural processes that can be accelerated by clearing in the catchments and destruction of vegetation along the banks. Though the rate of change appears slow in human terms it is rapid on the geological time scale. At present there is no evidence on which to base reliable estimates of the rate of sedimentation in these four estuaries or the quantities of sediment involved, nor on the effect that human activities have had on them.

2 CATCHMENT CHARACTERISTICS

The catchments of the four estuaries and their tributaries are in the highest rainfall area of the south west, but rainfall decreases greatly in the upper catchments of the Donnelly and Warren rivers. They are still largely forested, except in the northern catchments and around Manjimup. River flow to the estuaries is mainly from the southern, high rainfall area. The catchments are mainly in the Manjimup Shire, but the western part of the Donnelly River catchment is in the Nannup and Bridgetown-Greenbushes Shire and the Perup River and Tone River tributaries of the Warren River extend into the Bridgetown-Greenbushes, Boyup Brook, Kojonup and Cranbrook Shires. The smaller Gardner and Broke catchments are entirely within the Manjimup Shire (Figure 1).

2.1 LANDFORMS, GEOLOGY AND SOILS

Figure 2.11 shows the catchments of Broke Inlet, Gardner and Meerup rivers and Doggerup Creek and Figure 2.12 shows the catchments of the Donnelly and Warren rivers. The upper parts of the Donnelly and Warren river catchments are on the gently undulating land of the plateau (the Yilgarn Block) with broad valleys at about 300 m above sea level. The higher ground has deeply weathered laterite over the hard Archaean rock (mainly gneiss) which is exposed in the deeper valleys. Some is agricultural land used mainly for grazing on improved pastures. The tributary valleys are often broad and swampy and are not generally prone to erosion. However the soil erosion hazard is considerable in saline country in the upper Tone River.

The middle part of these catchments and the Gardner and Broke catchments lie on the southern slopes of the plateau where the hills are steeper and the valleys deeper. This is the Albany-Frazer geological province the basement rocks of which are Proterozoic granitic rocks (more than 1600 million years old), overlain in the broader valleys by alluvial Tertiary and Quaternary sands and laterite. The land is deeply dissected by the river valleys with steep slopes and rounded hills the laterite cover of which thins towards the south. It is mainly forested but there are considerable areas of cultivation around Manjimup, Pemberton and Northcliffe. Under intensive cultivation or where there are logging operations the red Karri loams are prone to erosion and the rivers carry suspended clay after heavy rain. Most soils have some ferruginous gravel in the surface which reduces the risk of erosion.

The Darling Fault lies along the western side of the Donnelly River catchment and the lower reaches of the river and its western tributary (Barlee Brook) are on younger rocks (Tertiary) west of the fault, at about 100 m. Basalt outcrops along the Donnelly River within 3 km of the mouth and there are spectacular columnar basalt cliffs and shore rocks at Black Point (Cape Beaufort) 14 km to the west.

A belt of low lying wetlands lies between the hills and the coastal dunes, about 5 km wide in the west but twice that between Doggerup Creek and the Gardner River and north of Broke Inlet. Here the soils are sand and clay of estuarine origin (Tertiary) and the swamp water has a high humic content and is very acid (pH 4.5). There are two larger freshwater lakes, Lake Jasper and Lake Maringup, and a number of smaller lakes with deep organic sediments on their bottoms. Many small granite hills outcrop in the swamps west of the Gardner River; Mount Chudalup (188 m) on Windy Harbour Road is the highest of these.

The coastal dunes form a broad belt up to 9 km wide in places and encroach over the wetlands. The Donnelly, Warren and Meerup rivers are confined to the narrow valleys between these high parabolic

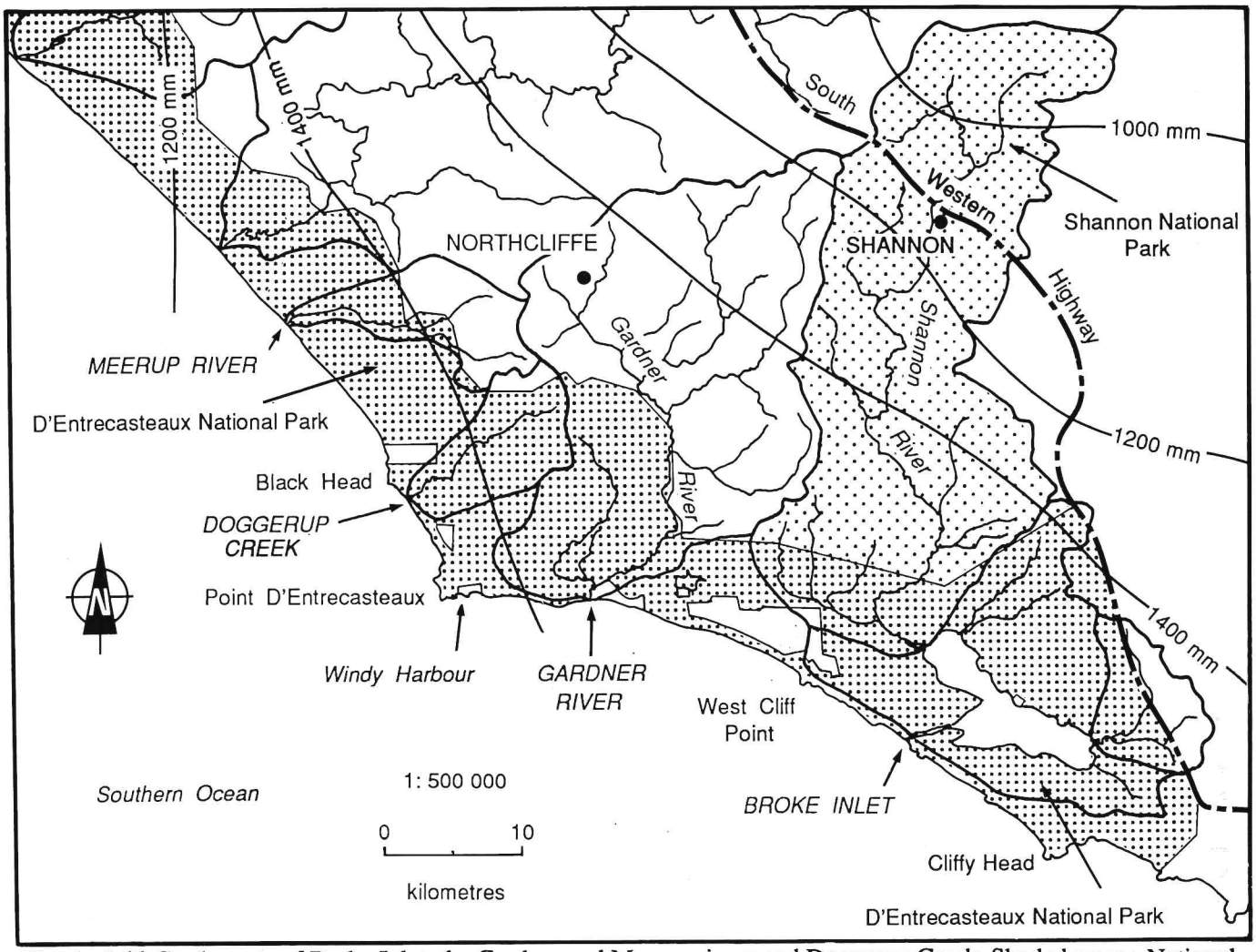


Figure 2.11 Catchments of Broke Inlet, the Gardner and Meerup rivers and Doggerup Creek. Shaded areas: National Parks. Mean annual rainfall isohyets.

dunes which dictate their riverine character. The dune sands are a variable mix of carbonate and silica sand and along much of the coast have been cemented to dune limestone (calcarenite) during the Pleistocene. The rock is overlain by sand that is only bound by the vegetation and there are extensive mobile dunes, especially the Yeagerup and Meerup dunes, and along the steep face of the old coastline between the Donnelly River and Black Head. Where the rock is exposed at the shore it has been eroded into onshore reefs and cliffs especially the cliffs at Point D'Entrecasteaux and between West Cliff Point and Cliffy Head which are over 100 m high; also at the mouth of Donnelly River.

The soils of the area are described in detail by McArthur and Clifton (1975); Collins and Barrett (1980) describe the landforms of the river catchments, and the geology is detailed by Wilde and Walker (1984). These aspects are also summarised in the park management plan (Walker, 1987).

2.2 COASTAL FEATURES

The coastline of the Shire is of two radically different types. From Cliffy Head to Nornalup Inlet the coast is dominated by granite headlands, limestone cliffs and small bays, it is a jagged coastline carved into an ancient landscape. But the four estuaries discussed here discharge onto two long open coasts where the generally NW-SE orientation exposes them to the south westerly waves and swell from the Southern Ocean, except near the Gardner River (Figures 2.11 and 2.12). This is a very high energy coast, as can be seen from the breakers on the offshore sand bars, and many of the coastal features reflect this, eg: the high coastal dunes, the narrow 'coastal plain' from which the sand has been blown up to the extensive blowouts, the eroding limestone cliffs near Broke Inlet, the instability of the river mouths and their diversion along the high beaches from the mouths.

From Cliffy Head the sweep of the coast first faces south west, where Broke Inlet opens, then curves west to where the Gardner River opens and to Point D'Entrecasteaux. Inland there is a belt of dunes and

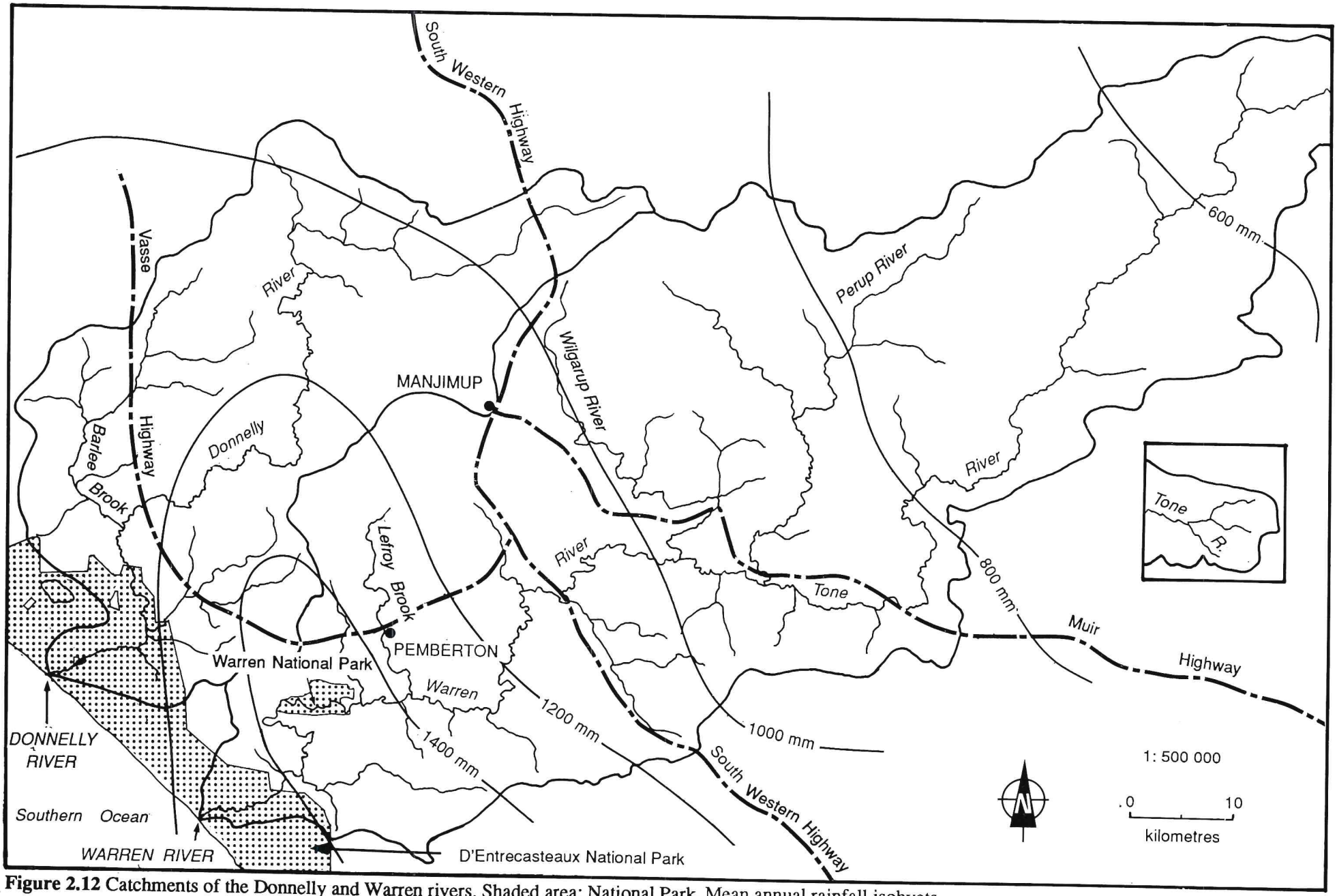


Figure 2.12 Catchments of the Donnelly and Warren rivers. Shaded area: National Park. Mean annual rainfall isohyets.

swamps 3 to 8 km wide between the coast and the Precambrian granitic hills. The orientation of the dunes is predominantly W-E, as is the Broke Inlet channel through them to the sea. A few small granite outcrops, notably at the mouth of the Gardner River, scarcely interrupt the curve of the nearly 50 km long coastline. Between Cliffy Head and West Cliff Point the coast is dune limestone with cliffs along much of it and only small narrow beaches. Then from West Cliff Point to the Gardner River there is a narrow sandy beach. From the Gardner River to Point D'Entrecasteaux a 500 m wide band of high dunes parallel to the coast separates the beach from the older (Tertiary) estuarine and lagoonal deposits of the swamps behind.

From the granite rocks of Black Head to the basalt of Black Point the 50 km long coastline is almost straight, facing south west across the wide, shallow coastal shelf from which the beach and dune sands have come. The beach is high and steep and there are sand bars about 200 m offshore and rips along most of it. The Pleistocene dunes form a belt up to 9 km wide between the coast and the granite hills inland east of the Darling Fault, and the only hard rocks are small basalt outcrops near the mouth of the Donnelly River. The river channels are orientated ENE-WSW in the valleys through the dunes, reflecting the direction of the prevailing winds, as do the modern blowouts. For 17 km along the coast SE of the Warren River and 8 km NW of it there is a narrow coastal plain up to 1 km wide between the beach and foredunes and the high dunes of the older Pleistocene coastline. This has hummocks of calcareous sand stabilised by marram grass and other coastal plants, and has small freshwater swamps and peat; it is a deflation area from which much of the sand has been lost, down to the water table.

2.3 RAINFALL

Rainfall is high near the coast, with an annual average of more than 1350 mm, but with as little as 1000 mm or up to 2000 mm in a single year (Table 2.3). It decreases inland with less than 800 mm in the Tone and Perup river catchments. This is mainly winter rainfall peaking in June and July when there may be heavy falls (Figure 1), but there are also occasional summer storms, eg 183 mm in November 1946 and 174 mm in November 1984 at Northcliffe. In the last 30 years rainfall near the coast has decreased by about 200 mm, as shown by the annual means at Walpole Post Office and Springfields (near Pemberton):

Decades	Walpole P.O.	Springfields
1956-1965	1465 mm	1434 mm
1966-1975	1319 mm	1340 mm
1976-1985	1265 mm	1204 mm

2.4 RIVERS

The character of the rivers, and of river flow to the estuaries, is dictated by their location in the highest rainfall part of the south west with predominantly winter runoff from hilly, forested country. The whole of the Broke and Gardner catchments, and most of the Donnelly catchment receive more than 1000 mm rainfall, but only half of the Warren catchment (Figures 2.11 & 2.12). Although the major river flow is in winter and spring some flow generally continues through summer and autumn. The only dams are on tributaries to the rivers, they supply the small water demands of local townships or individual farm schemes.

Broke Inlet. The major flow to the Inlet is from the Shannon River, which is 47 km long and rises in forested hills at about 200 m above sea level, most of it within the Shannon National Park. Two small rivers flow to the Inlet from the Pingerup Plains, mostly at less than 20 m rising to 60 m: the Forth River (10 km) to the north west end of the Inlet and Inlet River (14 km) to the east end.

The **Donnelly River** is the only river flowing to the estuary. It rises near Yornup 60 km from the coast and drains mainly forested hill country over 200 m above sea level. It has carved a deep valley where it cuts through the Darling Scarp onto the Scott Coastal Plain at 80 m above sea level. Barlee Brook joins it from the west, 23 km from the mouth of the estuary.

The **Warren River** meanders through forests for about 150 km from the confluence of the Tone and

Table 2.3 Highest and lowest, monthly and annual rainfalls (mm) for rainfall stations, Boyup Brook (Westbourne) - 009 616, Yornup - 009 627, Northcliffe Post Office - 009 590, and Springfields - 009 512. (Commonwealth Bureau of Meteorology)

	BOYUP BROOK (WESTBOURNE) 1903-1984 009 616	YORNUP 1946-1984 009 627	NORTHCLIFFE POST OFFICE 1925-1985 009 590	SPRINGFIELDS 1912-1985 009 512
Average annual	705 mm	878 mm	1383 mm	1446 mm
Highest annual	936 mm (1945)	1239 mm (1963)	2116 mm (1945)	2159 mm (1917)
Lowest annual	344 mm (1936)	633 mm (1954)	999 mm (1940)	944 mm (1969)
Highest monthly	259 mm (Jly 1926)	302 mm (Jly 1946)	592 mm (Jun 1945)	430 mm (Jly 1958)
Highest two mthly	397 mm (Jun/Jly 1964)	509 mm (My/Jun 1947)	838 mm (Jun/Jly 1945)	750 mm (Jun/Jly 1964)

Table 2.4 Catchments of Broke Inlet, the Donnelly, Warren, Gardner and Meerup rivers and Doggerup Creek. Total and cleared areas. Estimated runoff and flow to the estuaries.

	Broke	Donnelly	Warren	Gardner	Meerup	Doggerup
Total catchment (km^2)	928	1591	4093	539	76	82
Total area cleared up to Feb 1988 (km^2)	40	296	1304	105	5.5	12
Percent cleared	4.5%	19%	32%	19.5%	7%	14%
Runoff (mm)	187	206	100	188	-	-
Flow to estuary ($X10^6\ m^3$)	157	319	421	114	-	-
Gauging station No.	606185	608151	607220	606218	-	-

Perup rivers just south of the Muir Highway to the sea. It has cut a deep valley through the hills to where it flows out onto the coastal plain 10 km from the sea. The Tone River is 110 km long to its source near Kojonup on the edge of the wheatbelt in open undulating country at 300 m. There is also cleared land along the Perup River, but the greater part of the catchment is forested.

The **Gardner River** rises in low undulating country near Northcliffe, much of it farmed, at less than 100 m above sea level. It is about 35 km long. Its eastern tributary, the Canterbury River (about 27 km long) traverses higher, steeper, mainly forested country to join it 20 km from the coast. From there the Gardner meanders across the coastal plain and is joined near the mouth by Blackwater Creek. This flows from an extensive area of poorly drained swamp land to the west of the Gardner River.

The **Meerup River** and **Doggerup Creek** flow to the sea between the Warren River and Point D'Entrecasteaux. Neither is estuarine. The Meerup River is a small version of the Warren River; it rises in swampy land, some of it cultivated, west of Northcliffe and flows in a deep, narrow valley through the dunes to spread out in braided channels over the narrow coastal plain to the high beach. There it may be confined to a channel NW or SE along the shore. It is unlikely that any sea water penetrates into the river.

Doggerup Creek rises in swampy country between Northcliffe and Windy Harbour. It flows to the sea over a mobile dune between the granite shore of Black Head and the limestone cliffs of Point D'Entrecasteaux. As at the Meerup, the flow may be confined to a narrow channel behind the beach after flowing off the dune and an air photo of July 1977 shows it flowing SE for 80 m before breaking through to the sea.

RUNOFF AND RIVER FLOW The water resources of the Shannon, Warren and Donnelly rivers were investigated by Collins and Barrett (1980). The estimates of runoff and river flow to the four estuaries in Table 2.4 are from analysis of their data and Western Australian Water Authority records from gauging and sampling stations (Water Resources Branch, PWD, 1984). Monthly runoff distributions in the Donnelly, Warren and Shannon rivers are shown in Figure 2.41. Runoff is over 20% of rainfall from the high rainfall areas within about 50 km of the coast, but is only 5% from the low rainfall area of the upper half of the Warren River catchment, the Tone and Perup catchments (Figure 2.42). The great variability in monthly runoff is shown by the percentiles in Figure 2.43 (millimetres per month likely to be equalled or exceeded 1,5 and 9 years in 10).

SEDIMENT TRANSPORT We have no data on sediment transport by the rivers. With the strong seasonal nature of flow and the extemes of flow rate it is to be expected that considerable amounts of fine suspended sediment and organic matter will be transported to the estuaries. Clearing increases both the volume of runoff and flow rates in rivers and with them the amount of sediment eroded from cleared areas. Coarser bed load sediment, sand, may come from the lower reaches of the rivers under flood flow conditions.

WATER CHEMISTRY The water of the Shannon, Donnelly and Gardner rivers is fresh (less than 500 mg/L TSS). However there has been a progressive increase in salinity of the Warren River water, from less than 400 mg/L in the 1940s to 700 to 800 mg/L in the 1970s. Collins and Barrett (1980) correlate this increase with land alienation and clearing in the 1920s and 60s to 70s. River water becomes progressively saltier upstream with more than 6000 mg/L (6 ppt) in the headwaters of the Tone River, but this high salinity water is diluted by the greater volume of freshwater runoff from the southern high rainfall area.

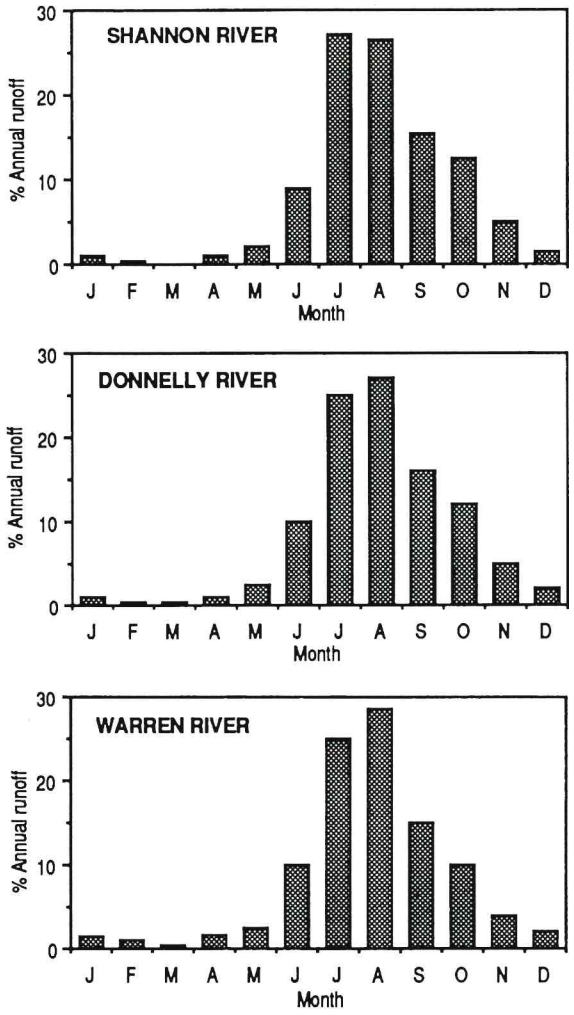


Figure 2.41 Average monthly runoff, as a percentage of annual runoff for the Shannon, Donnelly and Warren rivers. (WA Water Resources Branch, PWD, 1984)

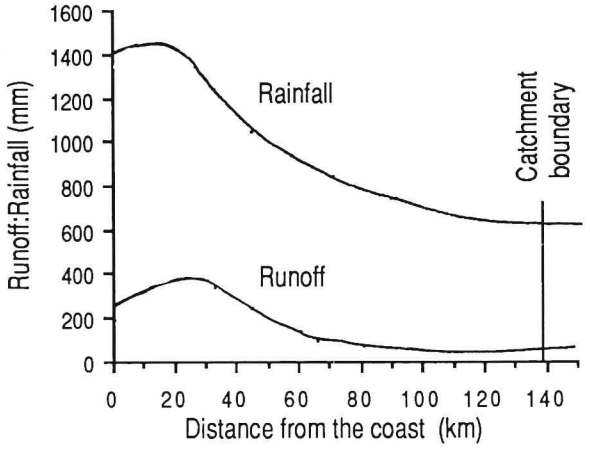


Figure 2.42 Profile of rainfall and runoff distribution in the Warren River catchment. (Collins and Fowlie, 1981)

NUTRIENTS Water in the Tone River is thought to be enriched with nutrients from farm land and the trout hatcheries on Lefroy and Treen brooks also make a small nutrient contribution to Warren River water. However, this is unlikely to affect the estuary because of the small volume of flow. The few water samples taken from the rivers near where they flow into the estuaries show low levels of total phosphorus in river water, generally less than 0.03 mg/L.

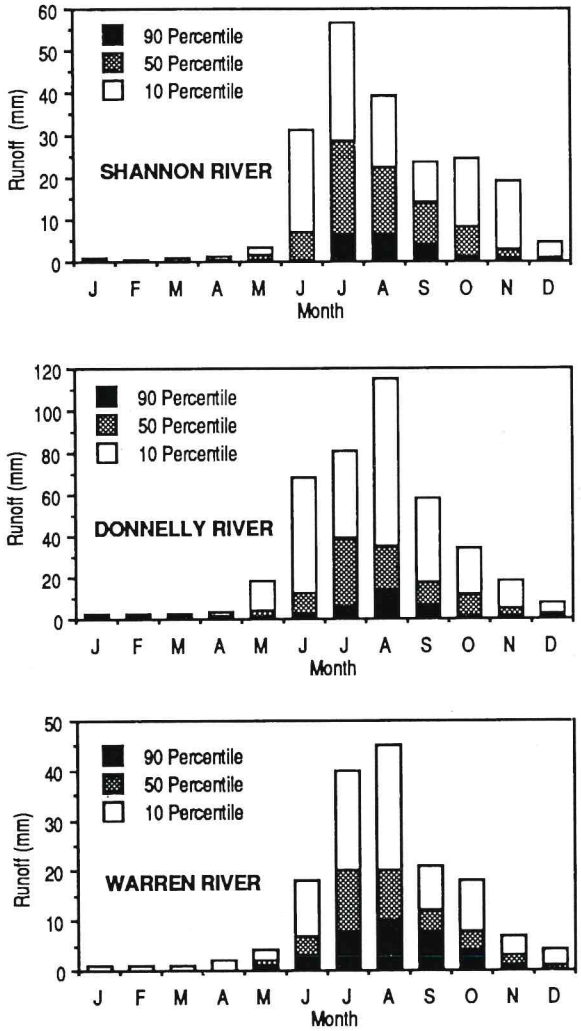


Figure 2.43 Mean monthly percentiles of runoff (mm) for the Shannon, Donnelly and Warren rivers. (WA Water Resources Branch, PWD, 1984)

2.5 LAND OWNERSHIP AND USE

The D'Entrecasteaux National Park now extends along the coast from west of the Donnelly River to east of **Broke Inlet**, covering the dunes and swampy plains for about 9 km inland (Figures 2.11 & 2.12). Broke Inlet is surrounded by the park, except for the Camfield townsite. An old pastoral lease borders the southern shore of the Inlet within the park and is still grazed. The catchment of the Shannon River is in the Shannon National Park. Most of the **Donnelly River** catchment is in forest

reserve, except near Manjimup, Palgarup and Yornup in the north east where about 300 km^2 has been cleared for a variety of agriculture. More of the headwaters of the **Warren River** has been cleared along the Wilgarup and Perup rivers and in the upper Tone River catchment, much of which is now alienated land. There is also agricultural land around Manjimup and Pemberton but the southern part of the catchment is still largely forested. Much of the upper **Gardner River** catchment near Northcliffe is alienated land, half cleared for small farms, but the rest is in forest reserve and national park. Catchment areas and areas of cleared land are shown in Table 2.4. Two Shire reserves border the estuaries: Camfield townsite (40.5 ha) on the northern shore of Broke Inlet; a 283 ha area on the east bank of the Gardner River, where there is no development.

Farming activities in the area are largely dictated by the soil patterns and rainfall distribution. The red earths of the Karri country are commonly used for fruit orchards, potato growing and vegetables, also for dairy and beef production where perennial or summer growing pastures have been sown. The yellow podzolic soils are used mainly for beef production on winter pastures and some fruit orchards. The gravelly lateritic upland soils and the broad sandy flats are only used for low intensity grazing. Hilly dissected lateritic country in the lower rainfall zone is used for extensive grazing of beef cattle and sheep on winter pastures, although some fodder crops of oats and barley are grown.

The area is the major source of Karri, Jarrah and Marri timber and State Forests cover the greater part of the catchments. There are 11 saw mills and one woodchip mill in the Manjimup Shire. Residue Karri and Marri is used for woodchipping. Logging activity has been widespread throughout the forests, but current integrated logging for sawlogs and chiplogs is mainly concentrated in the Karri-Marri forest. A pine plantation has been established 10 km upstream from the mouth of the Warren River. The two major towns, Manjimup and Pemberton are centres of the timber industry and are also popular with tourists.

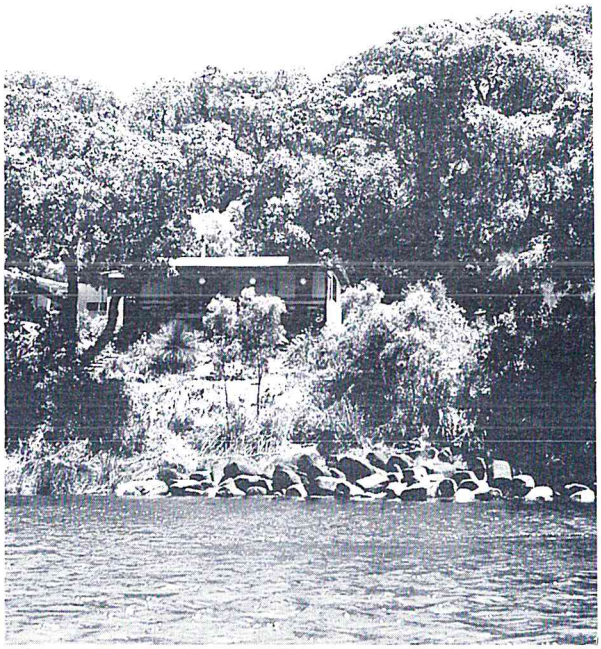
At Broke Inlet (Camfield) there are 13 fishermen's huts, 3 holiday cottages and one private home and camping is usually permitted there. There are 43 holiday cottages built along the steep banks of the Donnelly River within 3 km of the mouth, most of them on the north bank. There are two fishermen's huts near the mouth of the Warren River and four at the Gardner River. Tracks to the mouths of the estuaries give access to the beaches for beach fishing, 'undoubtedly the most popular recreational activity in the D'Entrecasteaux National Park' (Walker, 1987).

2.6 VEGETATION

Karri (*Eucalyptus diversicolor*) forest dominates hilly country with loamy soils in the southern part of the forest, interspersed with Jarrah and Jarrah-Marri forest northwards. Jarrah reaches its best development in the hilly, dissected laterites with a mean annual rainfall above 900 mm, becoming more open and depauperate as rainfall decreases. Blackbutt (*Eucalyptus patens*) and Bullich (*E. megacarpa*) occur in the damper valley floors and along streamlines. Throughout the forest, broad swampy drainage lines and open sandy flats subject to seasonal inundation carry a low open woodland of *Melaleuca*, *Banksia* and *Agonis*, with an understorey of heaths and sedges. The Tone and Perup river catchments extend into Wandoo (*Eucalyptus wandoo*) country.

Much of the coastal sand dune country is covered by Peppermint (*Agonis flexuosa*) scrub or woodland with some open heath. Inland from the dunes, stands of Jarrah (*E. marginata*) and Marri (*E. calophylla*) dominate higher ground, depending on the soils, and lower sandy ridges carry Banksia woodland. Paperbark (*Melaleuca*) woodland and sedge swamps occupy the extensive peaty swamps where the low lying Tertiary sands and clays border the estuarine reaches of the Shannon River, on the Chudalup Plains near Windy Harbour, and along the middle estuarine reaches of the Donnelly River. The coastal vegetation has all been burnt, most of it several times in the last 50 years.

Smith (1972) and Beard (1981) have surveyed and mapped the vegetation of the area. The vegetation of the Parks is summarised by Walker (1987) from these surveys and from McArthur and Clifton (1975) and Muir (1981).



Basalt outcrop on the north bank of the Donnelly River.Photo: R. Clark.

3 BROKE INLET - PHYSICAL FEATURES

This estuary is similar to Wilson Inlet in many respects; it is the same size, it is elongate behind the Pleistocene coastal dunes, the sea bar is closed for half the year, and the water is brackish. But there are important differences between them; the Broke lagoon is shallower with extensive sandy shallows, the inlet channel is long and narrow, and the tidal delta is much smaller than that at the mouth of Wilson Inlet (Hodgkin and Clark, 1988b). The catchment is in the highest rainfall part of the south west, 95% is forested, and river water is fresh and low in nutrients. Though estuary water is brackish it is seldom much more than half sea water salinity. Although hard rock outcrops at intervals along the north shore and on the islands, much of the lagoon is surrounded by extensive swamps. Equally important for the future of the estuary is that it is entirely within a national park, with the few houses confined to one restricted location.

3.1 LANDFORMS

The estuarine system includes not only the lagoon and inlet channel but also short stretches of the Shannon, Forth and Inlet rivers (Figures 3.11 and 3.12). Major river flow to the estuary is from the Shannon River the greater part of the catchment of which is in upland forest. The Forth and Inlet rivers, and several small creeks, drain mainly swampy, virgin land surrounding the Inlet.

RIVERS The Shannon River is estuarine (tidal when the bar is open) at Springbreak Road, 3 km from the river mouth, and perhaps beyond. It meanders through swampy lowlands and discharges through a triangular delta built from beach ridges and trapped swamps on either side of the river (Figure 3.13). The beach ridges are well vegetated. The Forth River (10 km) is estuarine for about 300 m. The Inlet River (14 km) has a meandering estuarine channel for about 2 km through swamp and dune.

LAGOON Broke Inlet is a large, shallow lagoon with an area of 48 km^2. It is elongate, parallel to the coast behind the dunes in a NW-SE direction, 15 km long and 2 to 3 km wide except in the middle where it widens towards the inlet channel. Assuming an average depth of 1.5 m below mean sea level (MSL) the volume is approximately 72 x 10^6 m^3. Within the lagoon three main basins are separated by shallow sand bars which may be exposed in summer. These bars and the marginal shallows appear to have been formed mainly from sand eroded from the beaches and transported by waves and wind-driven currents. A tongue of dune projects into the lagoon, narrowing the shallow channel between the western and middle basins. Two large islands, Clarke Island and Shannon Island, and a number of small, low islands, are granitic, indicating that the Precambrian rock is probably nowhere at great depth.

Along the north eastern shore there are low rocky outcrops at intervals with sandy bays between. The beaches rise to narrow, densely vegetated dunes between the beaches and the swamps behind. There are sandy lignites and clays near the surface along the shoreline, also in the banks of the Shannon River, and at Coal Point (McWhae et al, 1958). The sheltered, south western shore is of different character, with a wide or narrow fringe of paperbark swamp along much of its length, or a narrow sandy

Dune and limestone shore of the Broke Inlet channel. Photo: E.P. Hodgkin.

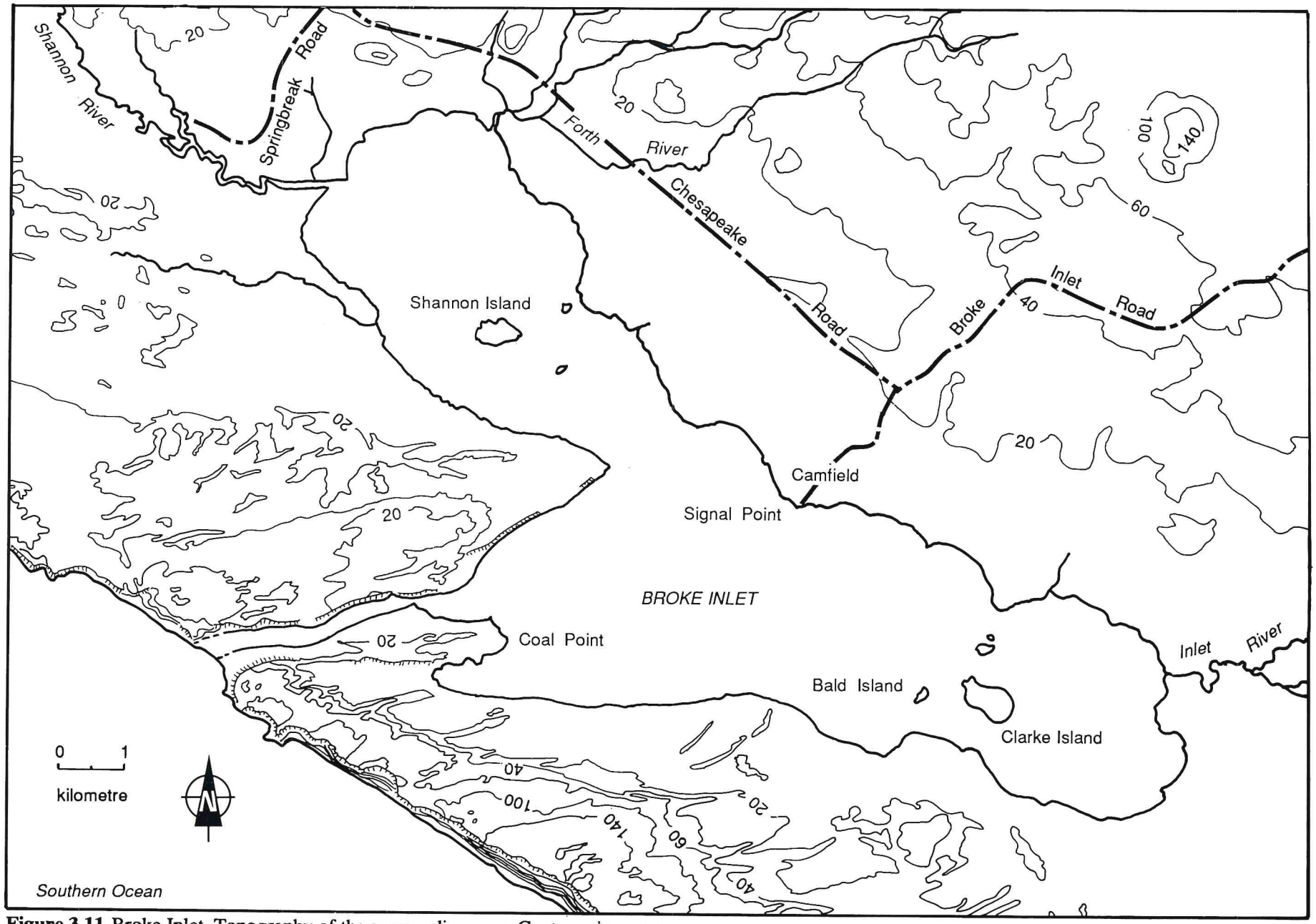


Figure 3.11 Broke Inlet. Topography of the surrounding area. Contours in metres.

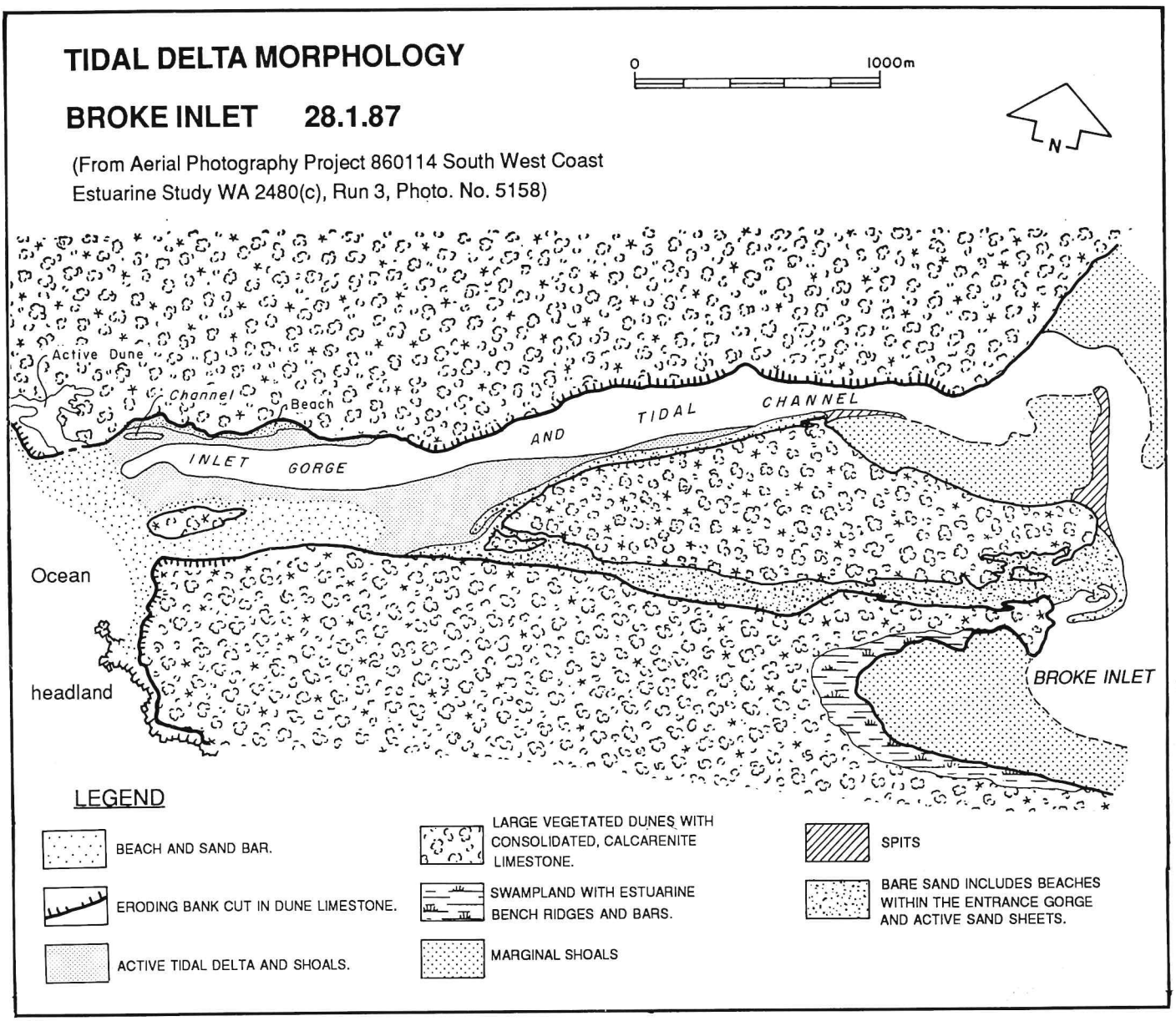


Figure 3.12 Broke Inlet. Morphology of the inlet channel. (I. Eliot & D. Milton)

beach generally with a fringe of vegetation at the water's edge. There is only one outcrop of granite along the southern shore, opposite Clarke Island.

INLET CHANNEL and MOUTH The inlet channel is 3.5 km long trending nearly due west through the parabolic coastal dunes (Figure 3.12). It is nowhere more than 250 m wide, but is the deepest part of the estuary with 5-6 m of water. The northern shore is steep and cliffed in places, with the Pleistocene dune rock exposed at the mouth and along the shoreline in several places. This is in contrast to the wide sandy beach of the southern shore. The northern shore is eroding and the southern accreting and the whole channel appears to be migrating slowly northwards. A limestone 'island' in the bare sand at the mouth separates the present channel from what may have been an earlier, southern channel. The bar now breaks north of this island, but is reported to have broken through south of it in the 1920s. The mouth is 300 m wide between the island and the northern rock wall. The active channel is constricted to less than 100 m by deltaic and washover sand, but its form varies greatly from season to season.

3.2 THE BAR

The overall width of the bar is 500 m and it builds up to about 1.8 m above MSL, the height varying with the amount of sand contributed from the beach. Even at this height waves may break across the bar. It is composed of clean white fine to coarse grained sand with minor shell grit (Figure 3.21).

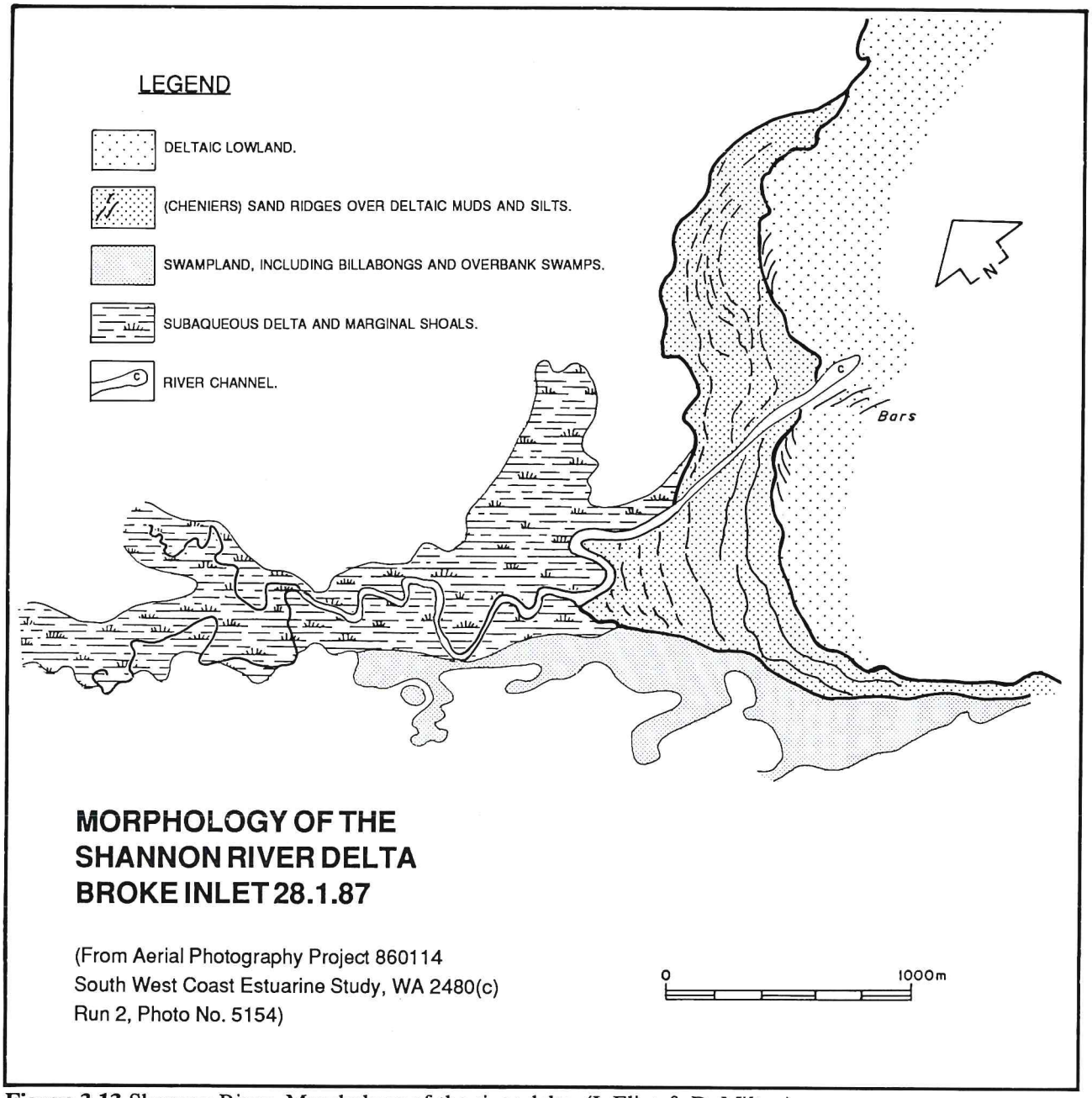


Figure 3.13 Shannon River. Morphology of the river delta. (I. Eliot & D. Milton)

The bar is closed for the first half of the year and breaks, or is broken, in June to September (Figure 3.22). It has opened every year from 1964 to 1989 except in 1969 and 1986, years of low rainfall. The date of opening and the time the bar stays open depend mainly on the time and volume of river flow, both of which vary greatly, as shown in Figure 2.43. It closes again in October to January, never remaining open for more than six months and sometimes for as little as one month. In 1969 the total year's flow in the Shannon River (at gauging station 606185) was only 26 x 10^6 m^3, 30% of mean annual flow (86 x 10^6 m^3). In the following year (1970) the June flow alone was 31 x 10^6 m^3, and the bar broke at the end of that month.

The bar breaks naturally or is broken by fishermen when Inlet water reaches the top of the bar. It is breached in the middle but often breaks across its whole width. When it did not break in 1969 the Inlet water only rose to within about 80 cm of the top of the bar.

3.3 WATER DEPTHS

Water level in the estuary can vary by nearly 3 m, from 2 m above MSL before the bar breaks to 1 m below at the end of summer. Sandbanks border much of the shoreline and extend out from both shores and divide the lagoon into three main basins that are 2 to 3 m deep. It has sometimes been possible to drive across the Inlet on these banks at the end of summer.

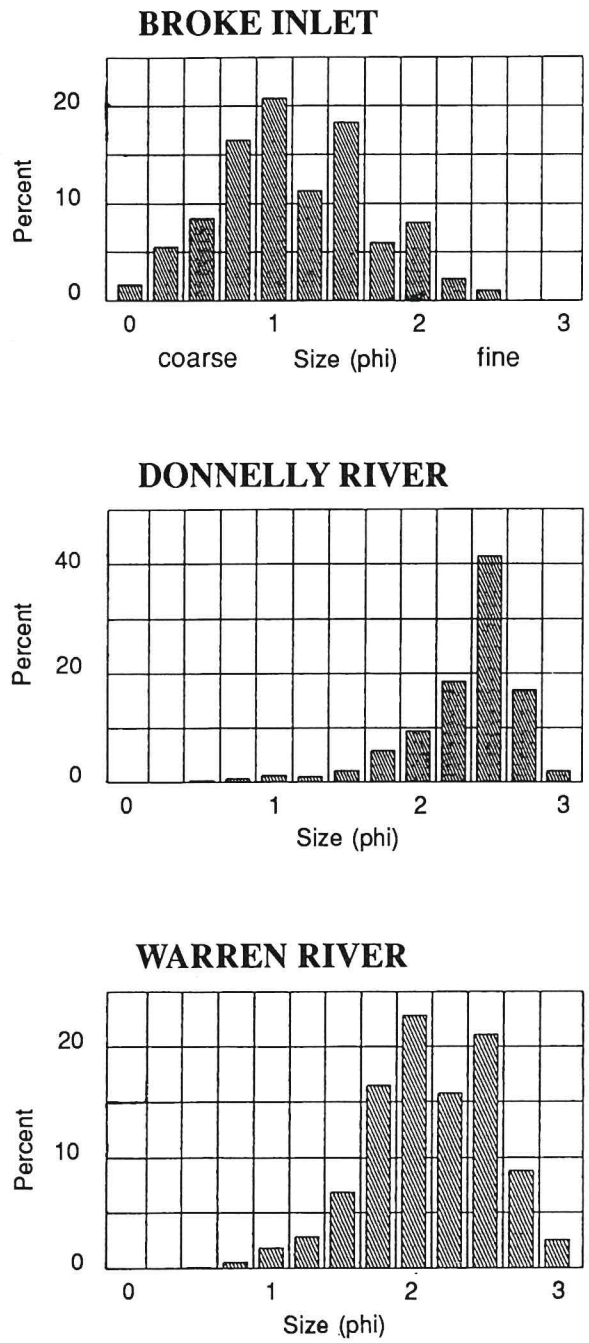


Figure 3.21 Sand size distributions from the bar crests at Broke Inlet, Donnelly and Warren rivers. Sizes are in phi units. Sand types and grain sizes in mm are shown below. (Bill Wilson)

Sand type	Grade limits	
	phi units	mm
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

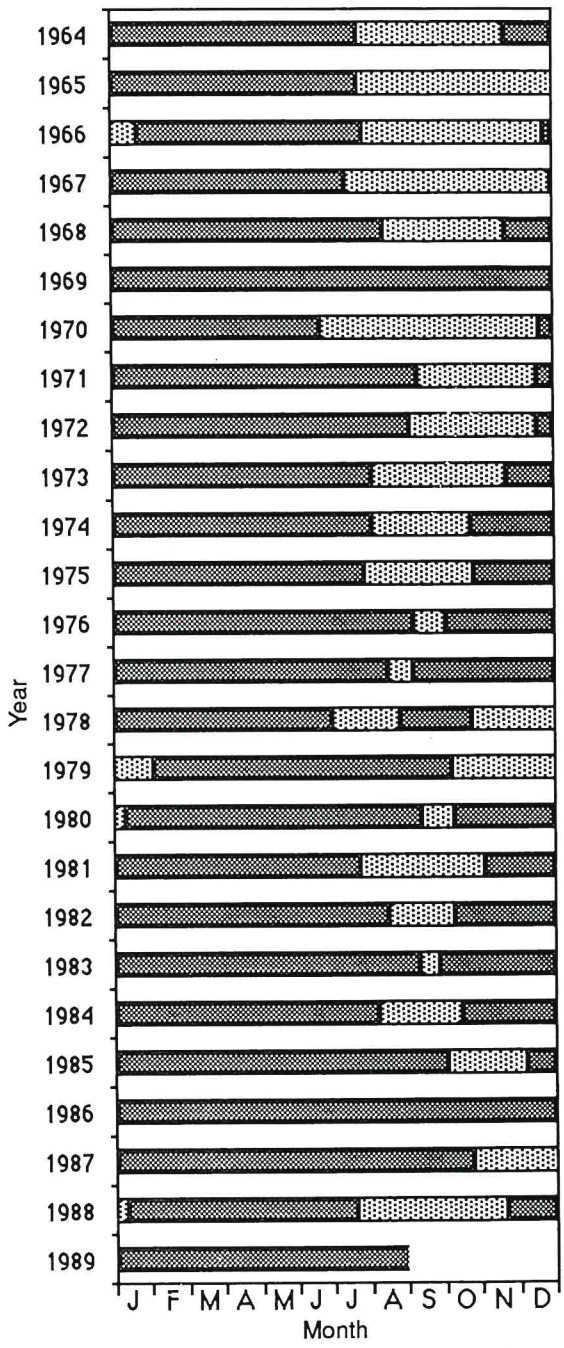


Figure 3.22 Broke Inlet. Reported opening and closing of the bar. Closed , open .(K & C.T. Jorgensen)

Sandbanks also bar the mouths of the rivers, but the river channels are deeper. The air photo mosaic (Figure 3.31) shows the sandbanks dramatically, as seen in 1988, however the sand is mobile and the contours of the banks are always changing. There has been no bathymetric survey of the Inlet, but Figure 3.32 shows the bottom contours (drawn from spot plumbing). The Shannon is about 3 m deep and deepens to 10 m where it is scoured on a bend. The inlet channel is up to 6 m with steep slopes on either side.

Figure 3.31 Broke Inlet. Photo mosaic, April 1988. (WA Department of Land Administration)

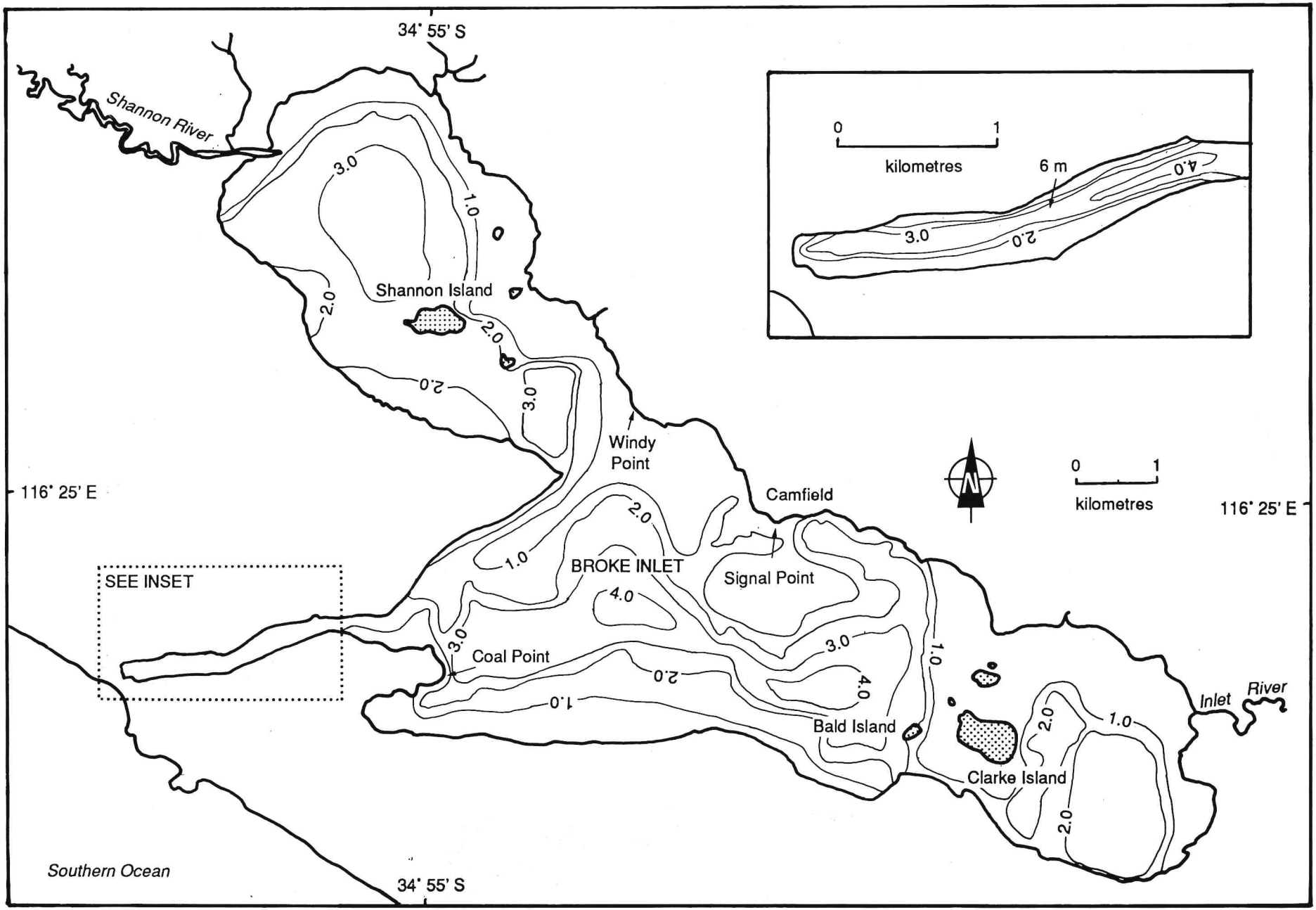


Figure 3.32 Broke Inlet bathymetry. Depths in metres below mean sea level. (R. Clark & G.M. Cliff, 5-8 January 1989)

When the bar is open the estuary is tidal, however tidal exchange is so restricted by the bar that daily astronomic tides in the Inlet are probably less than 10 cm, 10% of the ocean tide. When river flow slackens the greatest changes in water level, and consequent greatest exchange of water with the ocean, are caused by variation in barometric pressure. Water level probably rises and falls about 30 cm with the passage of high and low pressure systems as at Wilson Inlet.

3.4 BOTTOM SEDIMENTS

The sandbanks and marginal shoals of the lagoon are of yellow siliceous sand. The inlet channel has medium to coarse, clean, marine sand. Sediment in the deep water of the basins is fine sand, sandy mud, and black gelatinous mud in the deepest parts.

3.5 WATER CHARACTERISTICS

The only data on the hydrology of the estuary are from surveys by Fisheries Department staff in 1971, 1972, 1976 and 1989 and sporadic sampling by them and other workers.

SALINITY The available records are summarised in Figure 3.51. It will be seen that the general pattern is for surface salinity to vary from about 5 ppt when the river is flowing in winter to 30 ppt or more at the end of summer, but both lower (2 ppt) and higher, to sea water salinity (35 ppt), have been observed.There is great variation from year to year depending on the volume and timing of river flow and the time and duration of bar opening. Mixing is rapid in the open water of the lagoon and the salinity is generally uniform throughout the lagoon and from top to bottom, except when the river is flowing strongly as in October 1976 when surface salinity ranged from 1 ppt in the western part to 13 ppt near the inlet channel. Also when the river was flowing and the bar was open on 11 August 1974 the surface water was 6 ppt over 29 ppt at 3 m depth; the bar had broken on 1st August. High salinity water flows from the lagoon into the Shannon River under the river water causing strong stratification; in January 1989 near Springbreak Road surface water was 2 ppt, from 1 to 7 m it was 10.5 to 11 ppt, and below 8 m was 19 to 26 ppt (Figure 3.52).

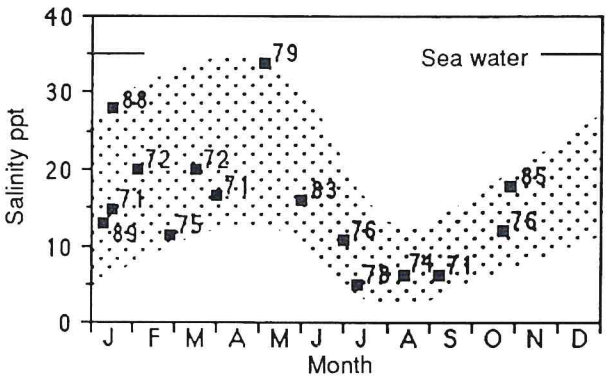


Figure 3.51 Broke Inlet. Surface water salinities (ppt) in the basin. Figures - dates of observations. Stippled area - envelope of observed surface salinity.

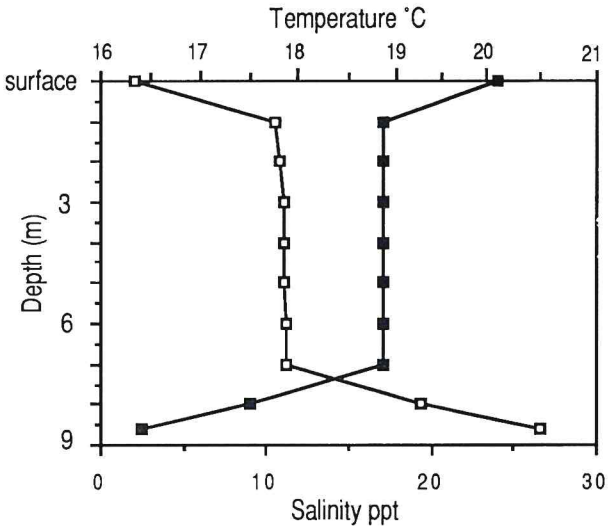


Figure 3.52 Shannon River. Profile of salinity and temperature, 6 January 1989. Salinity -□- , temperature -■- . (R. Clark & G.M. Cliff)

The picture is somewhat different in the deeper water of the inlet channel. Surface salinity is within 1 or 2 ppt the same as in the lagoon, but when river flow slackens sea water flows back into the estuary under the outflowing fresh water while the bar is open. Then, and for a time after it closes, there can be marked stratification between surface and deep water. Figure 3.53 shows the stratification in the channel in October 1976 (the bar had been closed for 3 weeks). In January 1989 surface water was 14 ppt, almost the same as that of the lagoon, and water below 2.5 m was 31 ppt (the bar had been closed for 6 weeks).

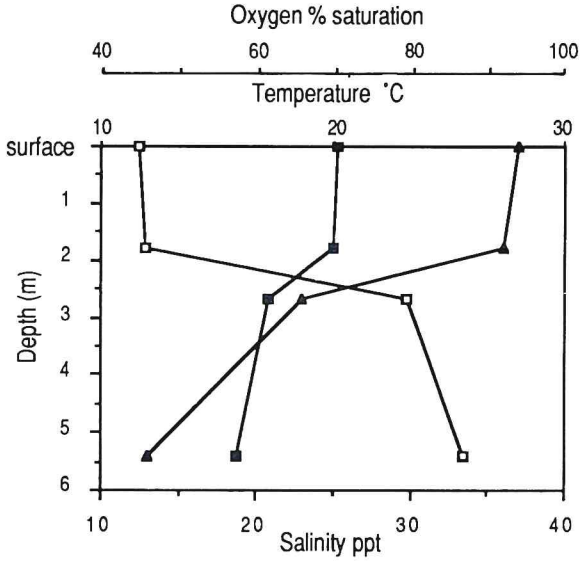


Figure 3.53 Broke Inlet. Profile of salinity, temperature and oxygen at the lagoon end of the channel, 20 October 1976. Salinity -□- , temperature -■- and oxygen -▲- . (J. Wallace)

WATER TEMPERATURE Observed temperatures vary from 11 to 22°C, but probably range from 10 to 24°C as in Wilson Inlet.

LIGHT The clarity of the water varies greatly. In calm weather the water may be clear to the bottom, but wind stirring can reduce secchi depths to 0.5 m. River water is tannin stained but clear.

OXYGEN Surface water is well oxygenated, as is to be expected in such a large body of water, and is probably generally well oxygenated throughout. Some deoxygenation (58% saturation) was observed when there was stratification in the lagoon in August 1974, a condition that is not likely to persist for long. When the deep water in the inlet channel is stratified the deeper water becomes deoxygenated (Figure 3.52). In January 1989 it was anoxic (0.5 mg/L at 5.5 m deep). There was also oxygen depletion of the deeper water of the Shannon River (3.7 mg/L).

NUTRIENTS AND POLLUTION Samples (14) from the estuary have shown uniformly low levels of total phosphorus, most 0.01 mg/L or less (a single sample of 0.06 mg/L). Four samples in 1974 and 1975 showed low nitrogen levels (<0.6 mg/L Total N, 0.02 mg/L NO_3). A report of abundant growth of green algae in deep water of the inlet channel and of a red alga throughout the estuary in May 1988 is not of itself evidence of nutrient enrichment, but does merit further investigation if repeated.

A beach on the north shore of Broke Inlet with granite rock and paperbark trees. Photo: E.P. Hodgkin.

4 DONNELLY RIVER - PHYSICAL FEATURES

The Donnelly River is tidal for about 12 km from the mouth to the boat ramp at Boat Landing Road and a little beyond, when the bar is open. Hydrologically and biologically it is an atypical estuary. When the bar is open and river flow slackens seawater flows in and intrudes beneath the freshwater. There is little mixing between seawater and freshwater except within 3-4 km of the mouth and the resultant brackish water may penetrate along the bottom, the whole length of the estuary with little further mixing. Some estuarine animals and plants live in the lower reaches, but are replaced by a predominantly freshwater biota upstream. A few marine fish enter the estuary.

4.1 LANDFORMS

The estuary is riverine throughout and only widens near the bar and in the Broadwater (Figure 4.11). The Broadwater and low lying land nearby appear to be the remnant of a former estuarine basin. At the boat ramp the banks are sandy and 1-2 m above water level. From there to 3 km from the mouth the river winds through a freshwater swamp that is often inundated. The last 3 km meanders between the steep slopes of Pleistocene dunes which rise to 40 m and are cliffed in places, especially along the south bank (Figure 4.12). There are steep, narrow sandy shores that are densely vegetated in places. Rounded blocks of basalt outcrop to about 2 m above water level on the northern shore at a sharp bend 2 km from the bar and there is another small outcrop on the southern shore at 1 km. Basalt also forms a bar in the river channel at 2.5 km; this may be submerged or exposed depending on the water level.

Within 1 km of the ocean beach the estuary widens between low dunes on the north shore and limestone cliffs on the southern shore, with rock to the water's edge. Between them there is a wide sandflat (the 'subaerial bar' in Figure 4.11) which is submerged when the water level is high and through which the river has cut different channels to the sea. The dunes have been stabilised by planting marram grass, but there is still much bare sand.

4.2 THE BAR

The bar is part of the general beach line which faces south west into the direction of the prevailing swell and a linear sand bar builds up about 250 m offshore. The beach is only 2.5 km long between limestone outcrops on either side of the mouth and the bar is about 1 km long between the two alternative flow channels to the sea. The bar is only about 2 m high above sea level and waves wash over it into the estuary carrying sand into the mouth and at times almost blocking the flow channels. It is built of well sorted, fine, mainly silica sand with 10% carbonate content (Figure 3.21). Sparse vegetation establishes on the bar and washover delta, and recent growth of marram grass has trapped sand and built small dunes to about 3 m above the general level. There is some calcarenite rock in the beach west of the mouth.

The bar breaks with the first heavy rains, sometimes as early as March, and may close and open again several times before closing in December or January, only staying open for a few days at a time. It may break at either end, at the south east against the cliff or at the north western end against the foredune, and flow channels persist to both locations. The channels are only about 50 m wide. In 1976 and 1978 the bar opened at the SE end and in 1984 and 1985 at the NW end. It has sometimes been broken prematurely when the water level reached the top of the bar.

4.3 WATER DEPTHS

The estuary is tidal when open but the tide range is considerably attenuated by the bar. When the bar is closed the water level rises to about 2 m above sea level and drops rapidly to sea level when it breaks. There has been no detailed survey of the bathymetry. The results of two line surveys (see Figure 4.5) show that the estuary is generally only about 2 m below mean sea level with deeper parts to 4 m and sandy shallows upstream of the Broadwater. A 9 m deep hole occurs near the basalt rocks at 2 km. The Broadwater is less than 1 m deep but there is 4 m at its mouth.

4.4 BOTTOM SEDIMENTS

The marginal shoals have fine to coarse sand and there is mud in deeper water.

4.5 WATER CHARACTERISTICS

SALINITY Two surveys of the hydrology of the estuary were made during summer when the bar was closed and there was little river flow (Figure 4.5). These show stratified conditions with a layer of fresh or low salinity water 1.5 to 2 m deep overlying brackish water that has penetrated the whole length of the estuary. There was limited mixing between surface and bottom water in the first 3 km from the mouth. It must be assumed that all the brackish water is flushed out of the estuary when the river flows strongly, leaving it fresh throughout. When the flow slackens sea water flows back in and is reported to flow several kilometres up the estuary before sinking under the lighter fresh water. Some sea water is also added by waves overtopping the bar. The generally fresh condition of the surface water is reflected in the marginal vegetation, salt tolerant species being confined to the proximity of the mouth.

WATER TEMPERATURE Temperatures are likely to be similar to those experienced in Wilson Inlet, 10°C in winter to 22°C in summer. In January 1989 surface water varied from 19.6° C to 22.6° C and the bottom high salinity water from18.5° C to 22.0° C, always warmer at the surface. Under similar stratified conditions in other estuaries of the south

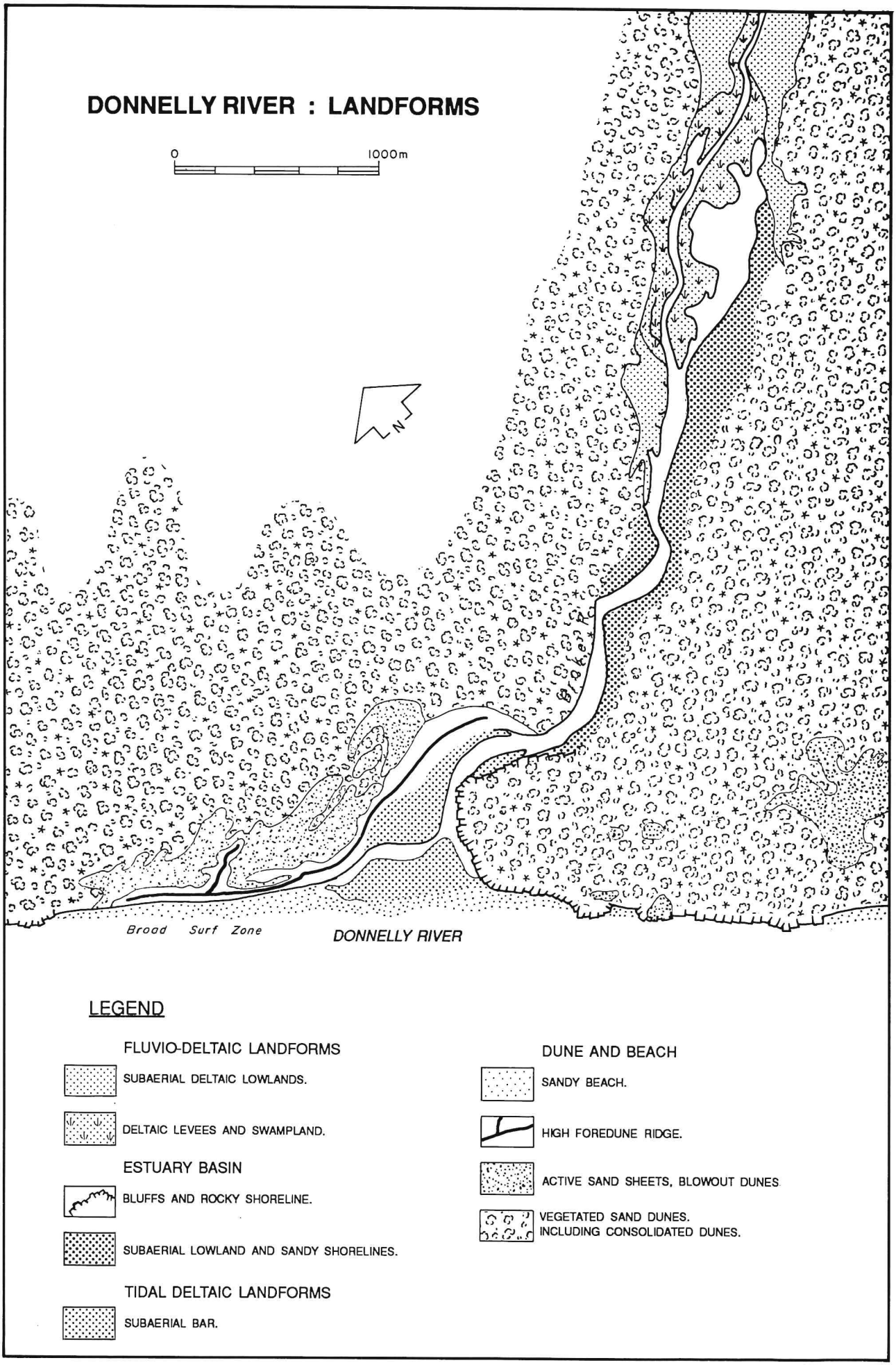


Figure 4.11 Donnelly River. Landforms. (I. Eliot & D. Milton)

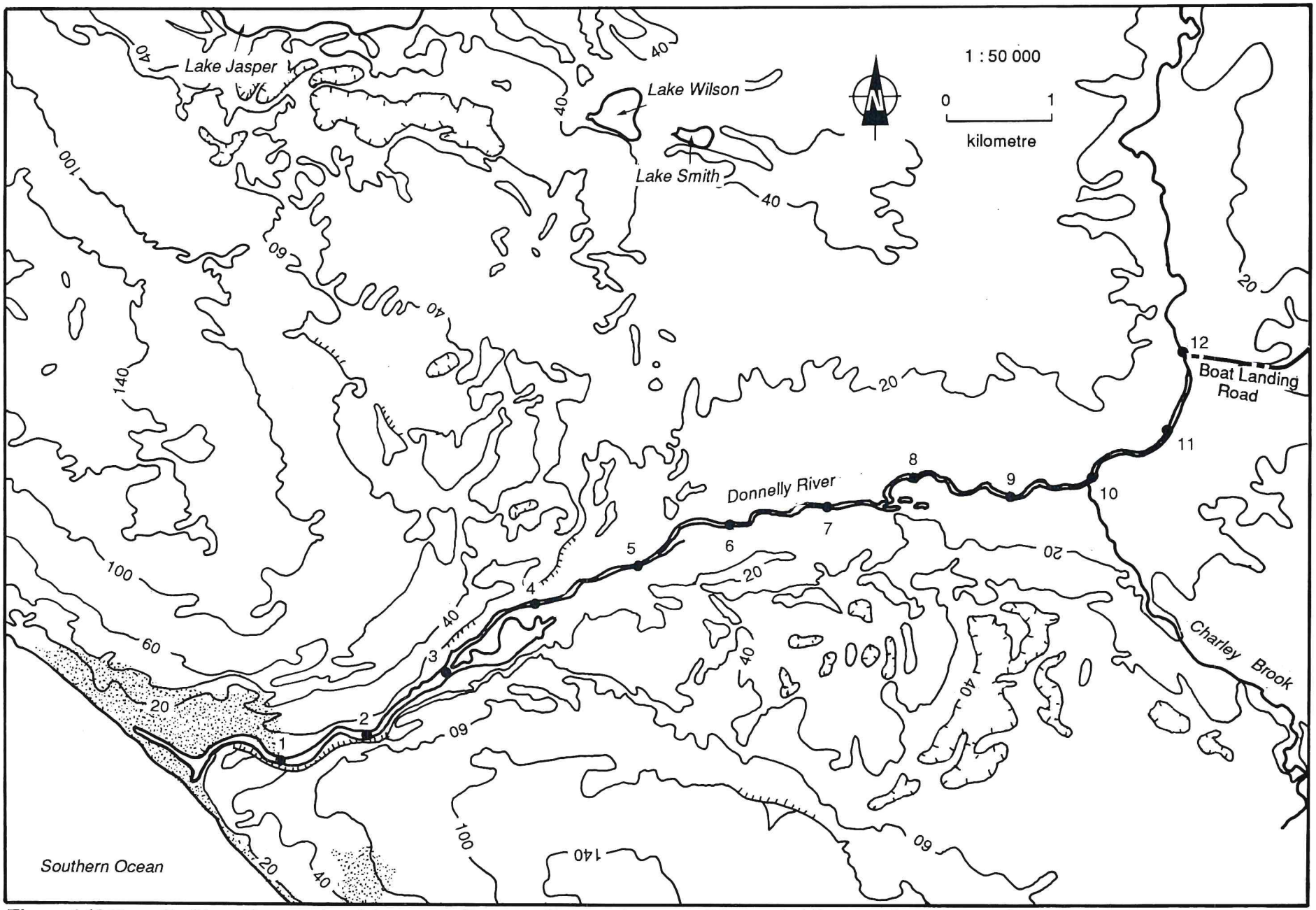


Figure 4.12 Donnelly River. Topography of the surrounding area. Contours in metres. Distance in kilometres from the mouth.

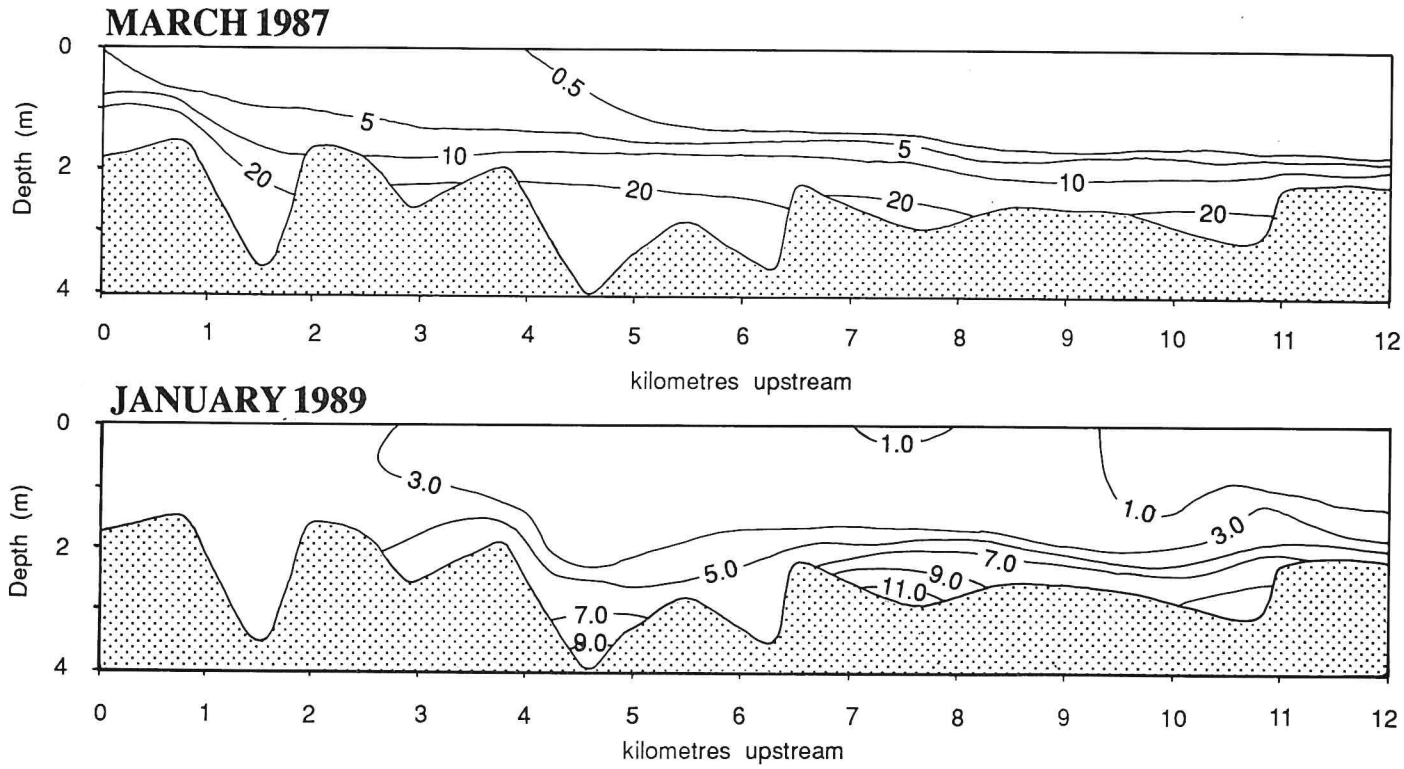


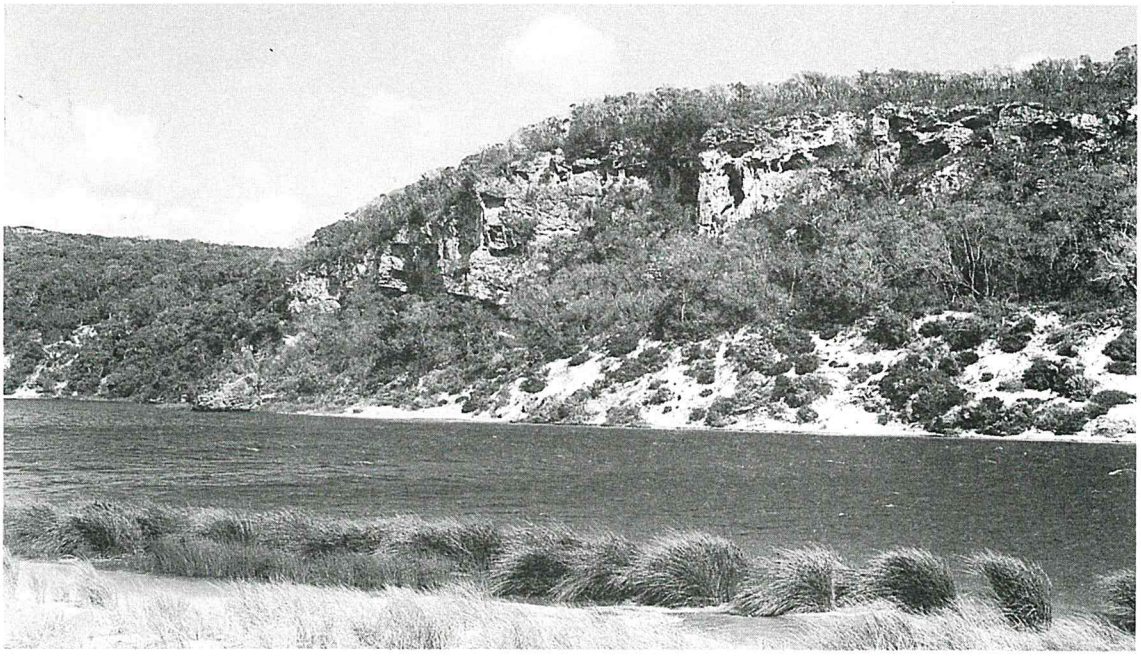
Figure 4.5 Donnelly River. Salinity profiles along the estuary, 12 March 1987 (J. Bowyer) and 9 January 1989 (R. Clark & G.M. Cliff).

west the bottom water is warmer than surface water in Autumn/Winter and the reverse in Spring/Summer, sometimes by several degrees, as in the Deep and Frankland rivers (Hodgkin and Clark, 1988a).

LIGHT River water is tannin stained and this brown water continues into the estuary, where visibility was 1m. Clear sea water may penetrate a kilometre or more up the estuary and visibility was to the bottom.

OXYGEN In the January 1989 survey the surface fresh water was to 2 m well oxygenated throughout the estuary (5.1 - 6.1 mg/L) and the isolated high salinity bottom water deeper than 2 m was deoxygenated (0.5 -1.7 mg/L). From Broadwater to the mouth the water was well oxygenated from surface to bottom.

NUTRIENTS and POLLUTION There are no data on nutrient concentrations in estuary water and no evidence of pollution.



Limestone cliff near the mouth of the Donnelly River. Photo: E.P. Hodgkin.

5 WARREN RIVER - PHYSICAL FEATURES

It is questionable whether this should be regarded as an estuary at all or only the mouth of a river that is probably never tidal. The river is narrow and shallow to where it flows out over the beach, apparently without ever cutting a tidal channel through it. It flows to the sea most of the time and little or no seawater washes back into it. Flow only ceases briefly when river flow slackens and the beach builds up and closes the mouth. A small salt water rush (*Juncus kraussii*) swamp forms on the beach, but from where the river channel narrows between the dunes the marginal vegetation is of predominantly freshwater species. The bullrush, *Typha*, grows within 0.5 km of the beach.

5.1 LANDFORMS

RIVER The river meanders between high Pleistocene dunes for about 8 km to where it discharges onto the narrow coastal plain (Figure 5.11). The dunes and the river valley are oriented WSW to ENE and the coastline NW-SE. Close to the coast the dunes are hardened to limestone and this is exposed along the river banks near the mouth. Further upstream the river meanders have cut steep slopes in the poorly consolidated dunes and built narrow alluvial floodplains (Figure 5.12). The river is only 50 m

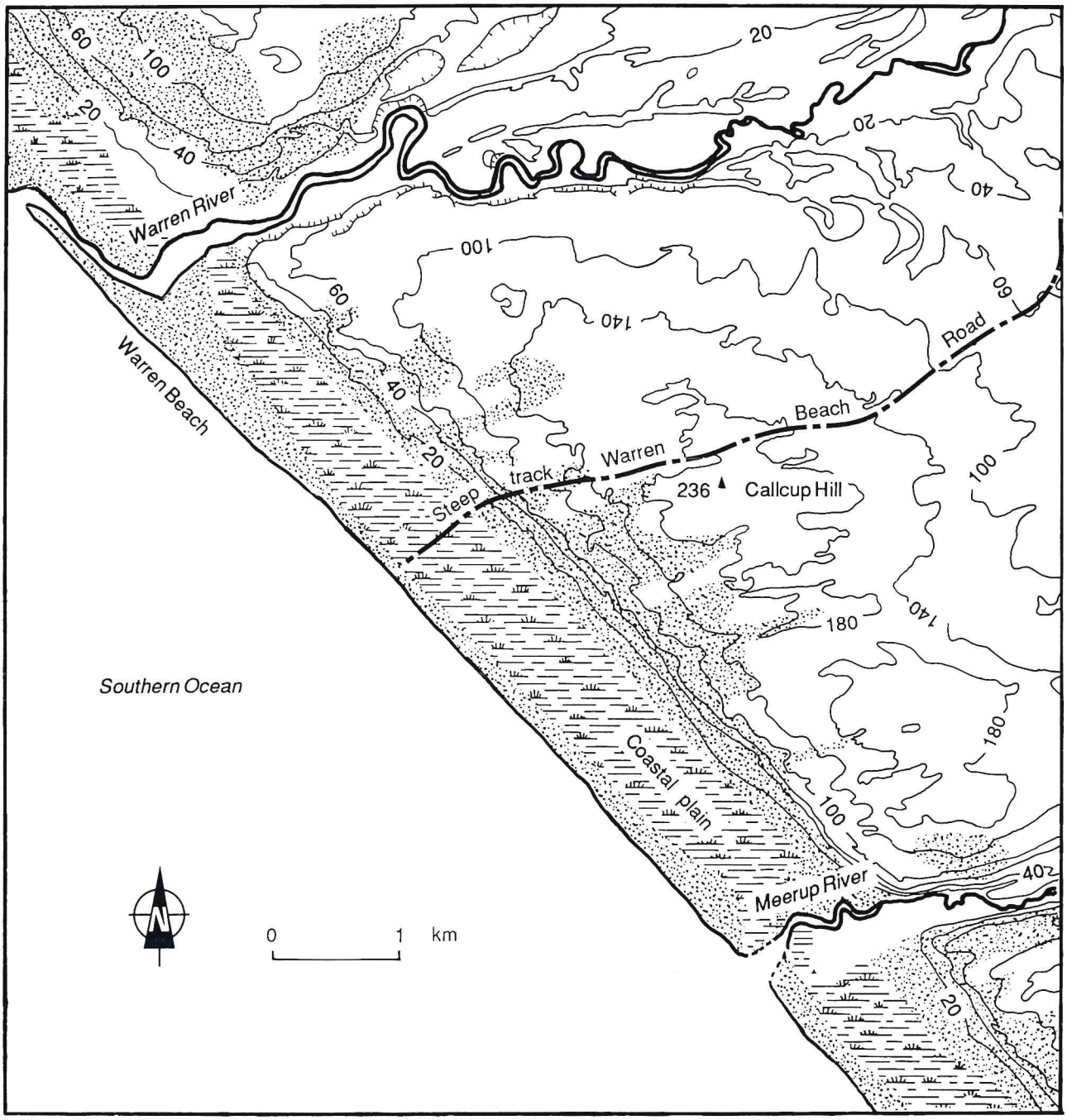


Figure 5.11 Warren and Meerup rivers. Topography of the surrounding area. Contours in metres.

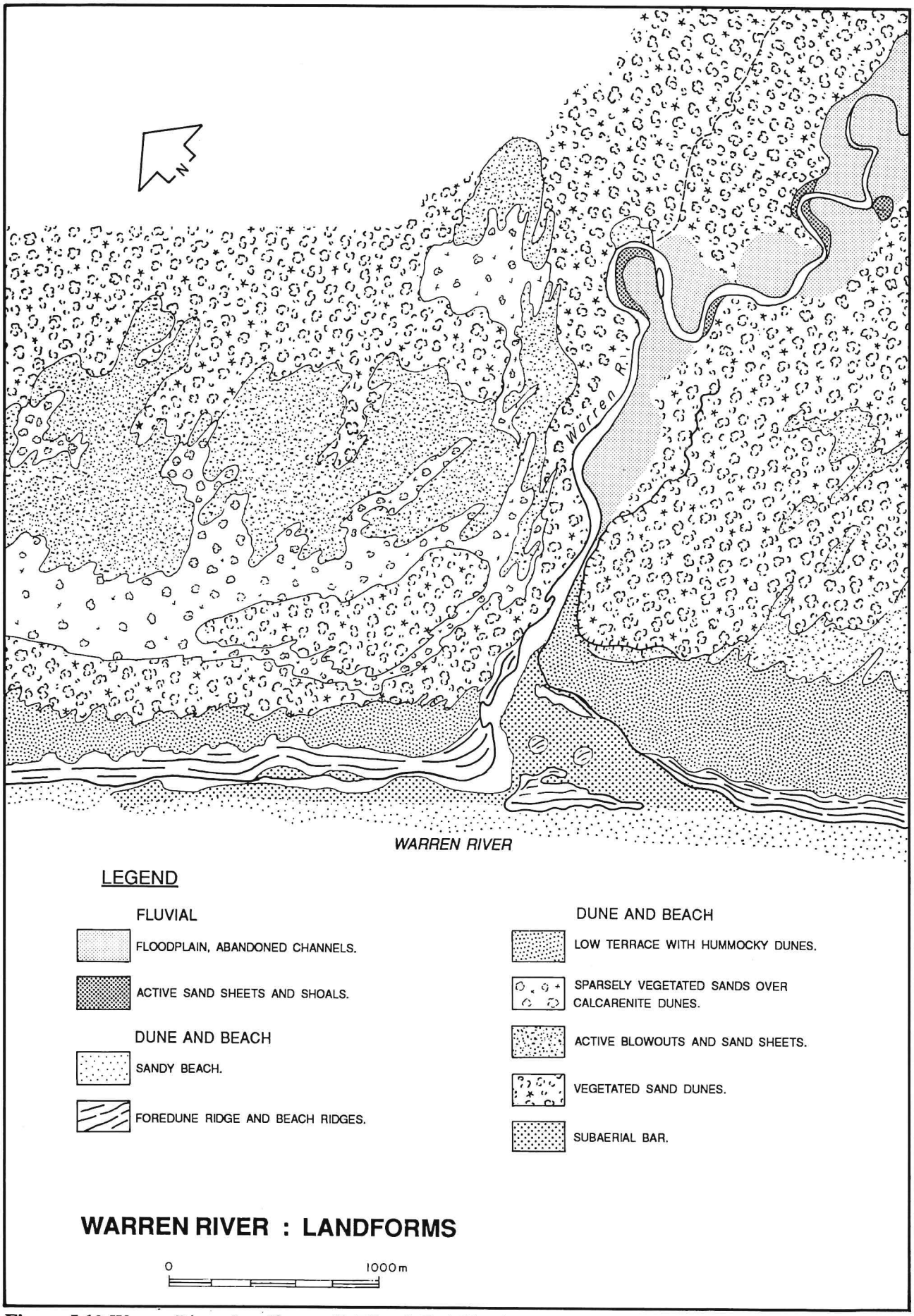


Figure 5.12 Warren River. Landforms. (I. Eliot & D. Milton)

wide or less and there are shallows across its width in several places, with deeper stretches between. The banks are densely vegetated to the water's edge except where sand is exposed in the eroded slopes or where sandbanks have built up above normal water level. In some places there is a narrow fringe of sedges. A large blowout approaches within 100 m of the northern shore near the mouth, but does not reach the river.

5.2 THE MOUTH

The river discharges onto the narrow coastal plain, here 300 m to 600 m wide, with a foredune and low

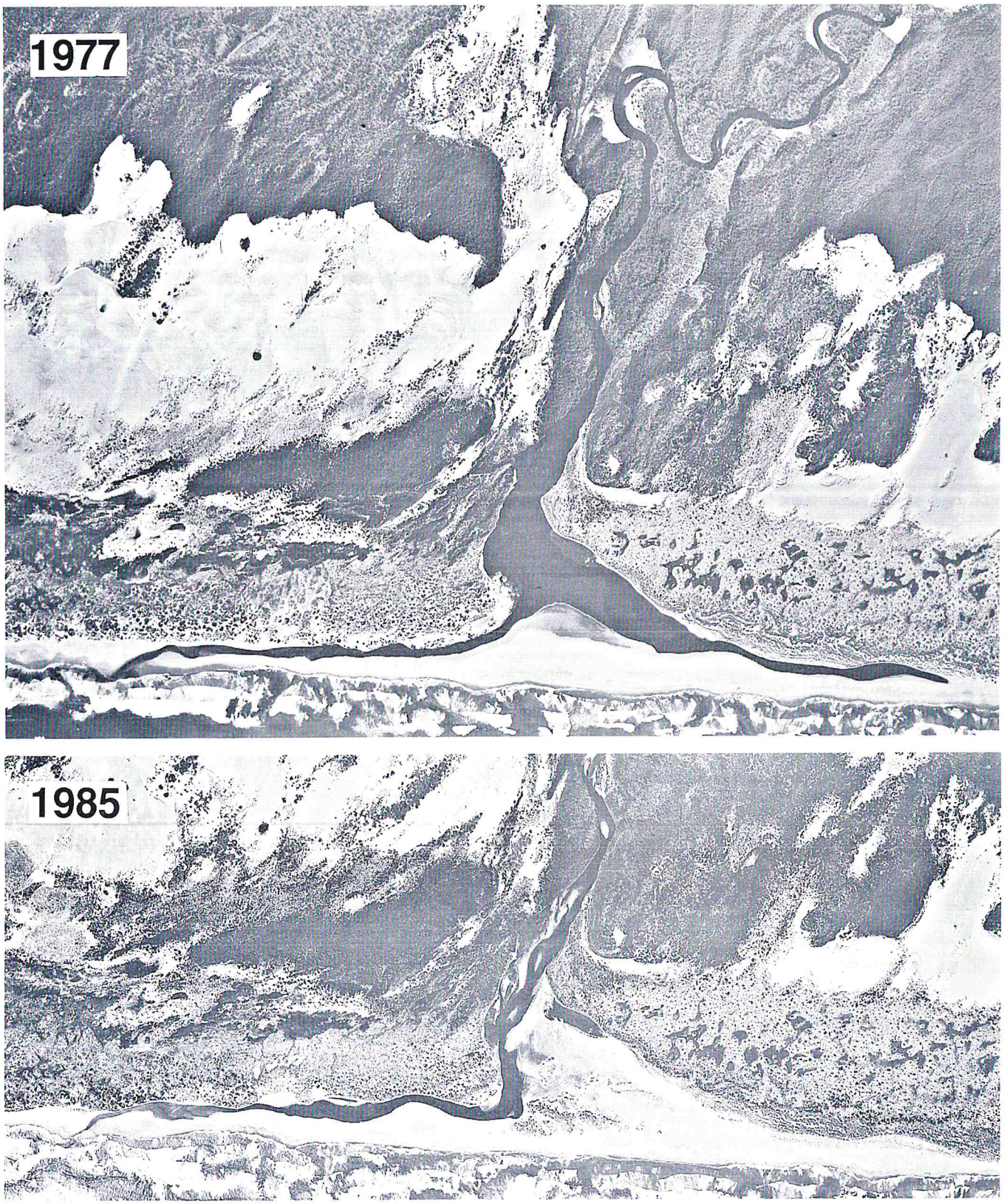


Figure 5.2 Vertical air photos of the Warren River mouth, 14 July 1977 and 26 November 1985. Photo: Land Administration, WA.

hummocky dunes between the beach and the steep slope of the Pleistocene dunes that rise to 150 m. The river widens to 100 m where it flows across the plain and beach. As flow slackens the beach builds up again and confines the flow to channels behind the beach and against the foredunes before discharging to the sea. The flow may be to the NW or to the SE and the channels up to 2 km long (Figure 5.2, the photos of the Warren mouth). The July 1977 air photos show channels in both directions with the NW channel still open 2 km from the river mouth. When seen in March 1984 the river had cut a channel across the beach just north of the river mouth. The SE channel was closed, with ridges of marram grass on it, and the NW channel persisted as an isolated pool against the foredune. The November 1985 air photos show the NW channel again open to 2 km from the mouth and the SE channel closed. In October 1988 a foredune with marram grass had built opposite the mouth and the river flowed against this and across the beach just to the north. A remnant of the former NW channel persisted against the eroded face of the foredunes and the SE channel was still closed.

The river is reported to flow to the sea most of the time and is only closed briefly by the beach, which is about 4 m above sea level. The beach is built of medium grain, predominantly siliceous sand, probably similar in composition to that of the Donnelly bar (Figure 3.21).

5.3 WATER DEPTHS

River water level is always well above sea level and when flow slackens sandy shallows are exposed at intervals across most of the width of the river to 4 km from the mouth, with deeper reaches between.

5.4 WATER CHARACTERISTICS

SALINITY Although waves may lap over the bar into the river the surface water behind the bar is fresh (less than 0.5 ppt) and it is unlikely that any significant amount of sea water enters it. The marginal vegetation consists of freshwater species except at the mouth where a small rush swamp has formed along the edge of the SE channel. River water is tannin stained, but clear.

NUTRIENTS AND POLLUTION The few samples (8) taken of estuary water have shown 0.03 mg/L or less total phosphorus, this is in spite of high levels of nutrients in the Tone River (Section 2.4), the water being diluted by the greater runoff from the forested, high rainfall catchment. There is no evidence of pollution.

6 GARDNER RIVER - PHYSICAL FEATURES

The Gardner River estuary is riverine, like the Donnelly and Warren estuaries, there is no lagoon and it only widens slightly where it is bordered by low dunes near the beach. The rock bar keeps the mouth open and the river is tidal for some kilometres although water movement is obstructed by rock bars and by logs in the upper reaches. The river flows to the sea most of the time, the surface water is fresh. However when river flow slackens, sea water flows back in under the outflowing fresh water with little mixing between them. The marginal vegetation and benthic fauna are of predominantly freshwater species to within a short distance of the mouth.

6.1 LANDFORMS

The river meanders through low lying land subject to inundation for much of its length and is probably tidal for about 5 km (Figures 6.11 and 6.12). However the channel is obstructed by shallow granite bars at the mouth, at 1.5 km and about 2.5 km upstream from the mouth. It flows between steep sandy banks through scrub covered flat land less than 5 m above sea level. Small dunes and patches of higher ground carry denser vegetation with peppermints and eucalypts. Just beyond the first bar the river is joined on the west by Blackwater Creek. The river is 150 m wide within 300 m of the mouth, it then narrows to 50 m and thereafter progressively to 10 m at 3 km from the mouth.

A small blowout on the west side near the bar is reported to have developed less than 50 years ago when a fence was built to keep cattle from straying, they went round it and beat a track that started the blow. The blowout has been partially stabilised by marram grass.

6.2 THE BAR

The river opens to the sea over a bar of rounded granite rocks that restrict the flow to narrow channels at about low water level. Sand from the beach builds up onto the granite which extends for some distance on either side and encloses a small bay (Figure 6.11). The bar is reported to be open most of the time and only closes briefly when blocked by masses of seaweed and soft sand.

6.3 WATER DEPTHS

The lower reaches of the river have depths of 3 m or more and it is navigable in a small boat for at least 3 km. However rock bars at 1.5 and 2.5 km from the mouth are exposed over most of their width at low tide and fallen logs obstruct the passage further upstream. Although tidal, the range in the river is attenuated by the sea bar.

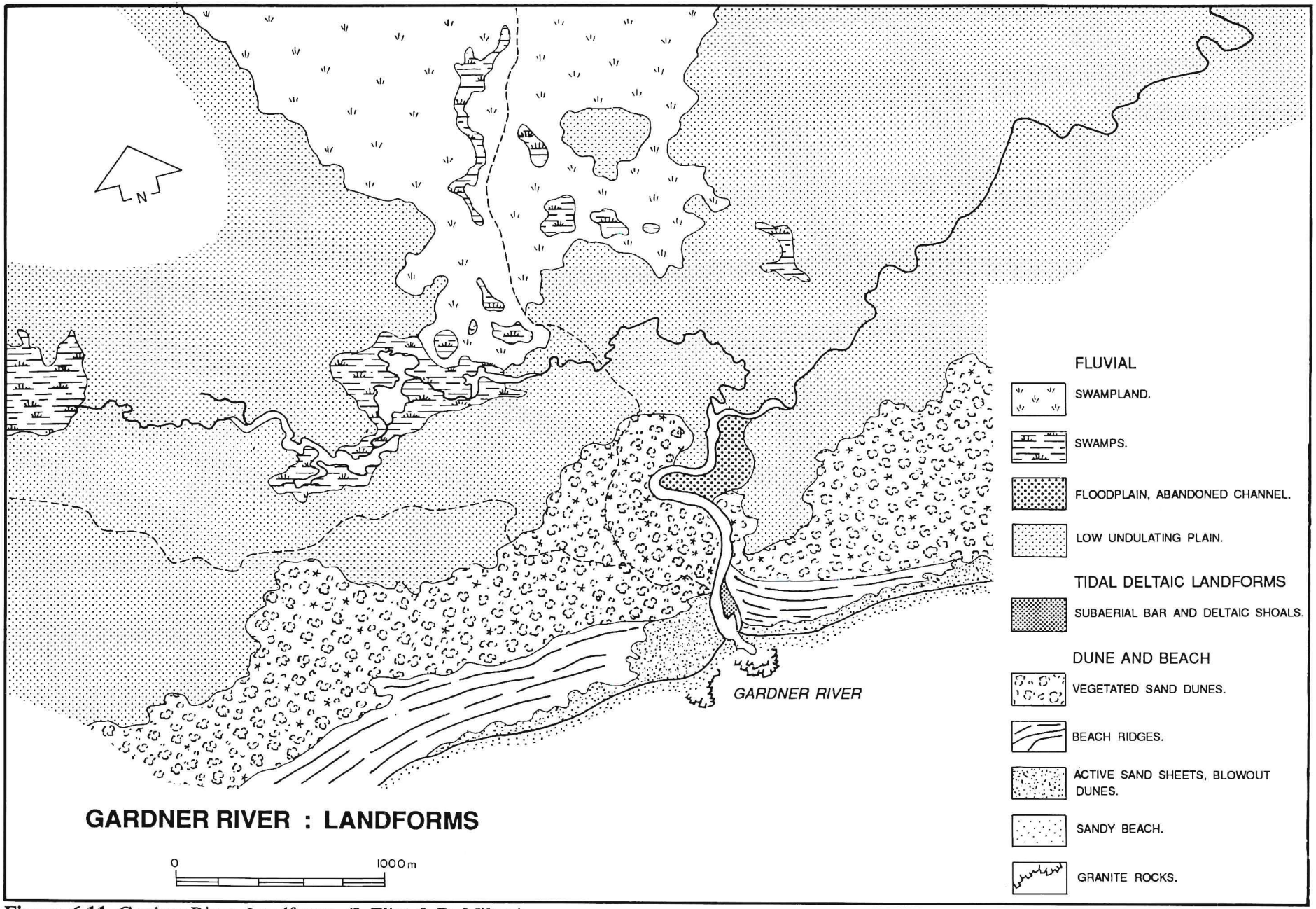


Figure 6.11 Gardner River. Landforms. (I. Eliot & D. Milton)

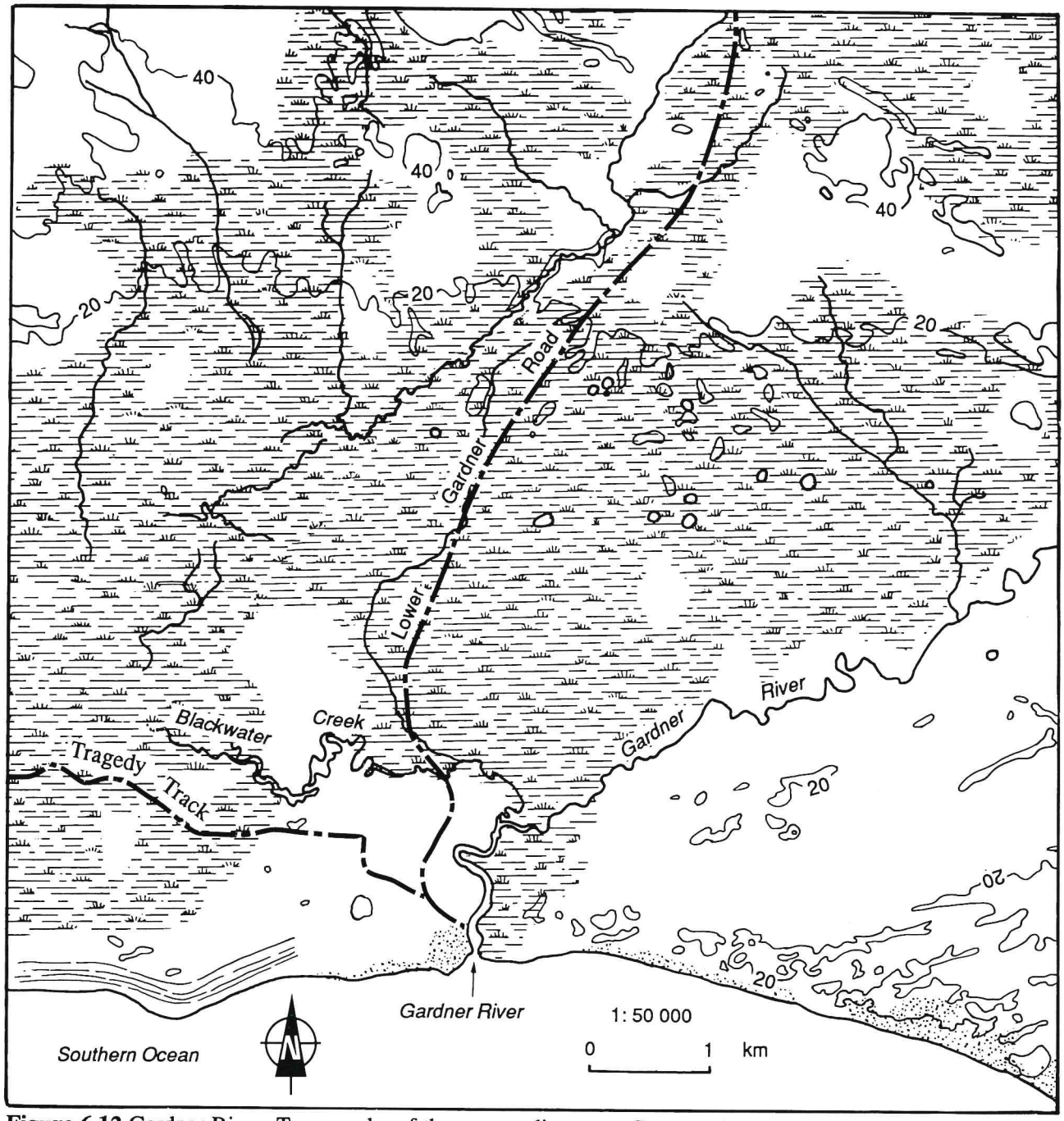


Figure 6.12 Gardner River. Topography of the surrounding area. Contours in metres.

6.4 WATER CHARACTERISTICS

The few surface water samples taken have all shown fresh surface water with a salinity of less than 1 ppt and when the river is flowing strongly the estuary is fresh throughout. However when river flow slackens the tides and waves carry sea water over the bar into the estuary. The water then becomes sharply stratified with a halocline (an abrupt change in salinity) at a depth of a metre or less, with sea water on the bottom (Figure 6.4). The river water is tannin stained from the swamps that it drains.

Water temperature probably ranges from 10°C or less in winter to 24°C in summer. In the January 1988 survey (Figure 6.4) surface water was 24°C and the deep water decreased gradually to 20.5°C at 3 m.

Water samples from the estuary and from the river at Chesapeake Road showed 0.01 to 0.08 mg/L of Total phosphorus . Part of the upper catchment of the river is cleared, mainly for cattle grazing, but the greater part remains uncleared and it is unlikely that there is significant pollution.

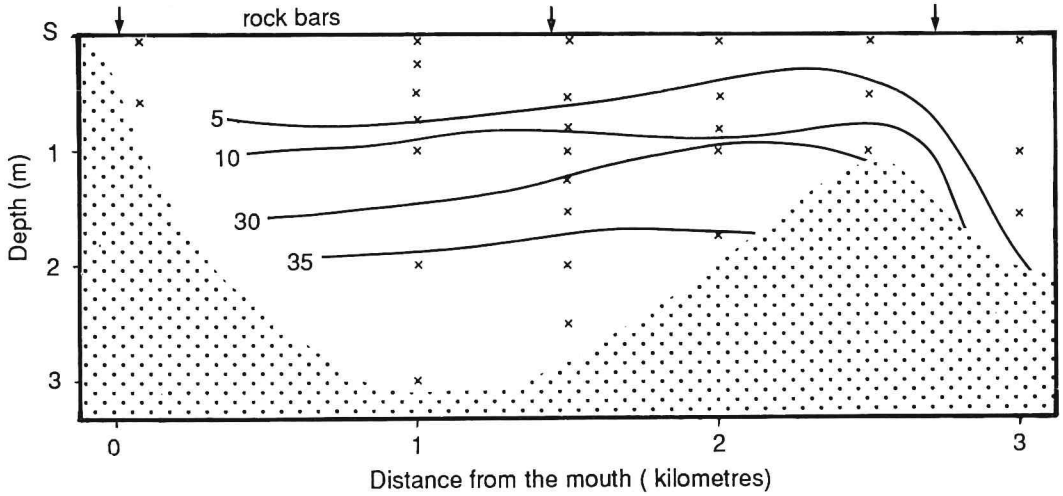


Figure 6.4 Gardner River. Salinity profile along the river, January 1988. (J.M. Chambers)

Granite outcrop in the mouth of the Gardner River. Photo: E.P. Hodgkin.

7 ESTUARINE VEGETATION

The vegetation of Broke Inlet and the Donnelly and Gardner rivers was surveyed by M. Cambridge in October 1976 and by J.M. Chambers in January 1987 and 1988 and the following account is compiled from their reports. Broke Inlet has a typical estuarine aquatic and fringing flora, but in the three river estuaries such plants only occur near the mouths, freshwater plants replacing them along the greater part of their length.

Detrital marine algae and seagrasses washed in from the sea accumulate in deeper water near the mouths and contribute to the productivity of the estuaries.

7.1 AQUATIC PLANTS

Broke Inlet. In both surveys aquatic vegetation consisted of the seagrass *Ruppia megacarpa*, the stonewort *Lamprothamnium papulosum* , the filamentous red alga *Polysiphonia* and the green alga *Cladophora*. They appear to have been more abundant in 1976 than in 1988, especially in the inlet channel, perhaps because of the different season. Both reports note the presence of epiphytic algal growths on the attached plants. In 1976 the *Ruppia* formed dense stands in the channel with a thick cover of epiphytic *Polysiphonia*.

Donnelly River. *Ruppia* and *Lamprothamnium* were found within 3 km of the mouth in the 1976 survey, but not in 1987. The alga *Cladophora* and mats of bluegreen algae were also present near the mouth in 1976. The freshwater leafy plants *Ranunculus rivularis* and *Triglochin procera* were present in shallow water and *Polygonum* sp. among the sedges at 3 km in the 1987 survey.

Gardner River. Both *Ruppia*, heavily coated with diatoms, and *Lamprothamnium* were found near the mouth, also various filamentous algae binding sediments in 1976. The dark, tannin stained water is probably unfavourable for the attached plants because of the lack of light at the bottom.

7.2 MARSH PLANTS

Salt marshes are of very limited extent in these estuaries. There is a small samphire swamp 250 m from the mouth of the Gardner River, another on the beach at the mouth of the Warren River and in a similar situation on the Donnelly River bar. Further upstream these are replaced by freshwater plants such as the sedge *Schoenoplectus validus* which forms a wide belt around the Donnelly River Broadwater. At Broke Inlet the swamps behind the narrow fringe of *Juncus kraussii* and *Melaleuca cuticularis* contain freshwater species with the rush *Juncus pallidus* and sedge *Baumea juncea*, *Melaleuca rhaphiophylla* and other species of paperbark trees, *Banksia littoralis* and the 'cedar' *Agonis juniperina*.

7.3 FRINGING VEGETATION

Salt tolerant plants have a restricted distribution in these estuaries reflecting the high rainfall and limited penetration of brackish water. Much of **Broke Inlet** is bordered by a narrow fringe of *Juncus kraussii* and *Melaleuca cuticularis*, though this is often dense along the southern shore. Behind this fringe the wet flats and swamps have a diverse flora with *Juncus kraussii*, the sedges *Gahnia trifida*, *Baumea articulata*, *Baumea juncea*, and the trees *Agonis juniperina*, *Melaleuca rhaphiophylla* and *Melaleuca preissiana* (Figure 7.31).

In the **Donnelly River** *Juncus kraussii* and the sedge *Isolepis nodosa* form a wide band along the first kilometre of the river bank, then more sparsely interspersed with the sedges *Baumea juncea* and *Schoenoplectus validus* to the Broadwater (Figure 7.32). *Melaleuca cuticularis* is also present. In the Broadwater and for a short distance upstream the river banks are dominated by *Schoenoplectus* backed by *Melaleuca rhaphiophylla* and *Agonis juniperina*, with the peppermint *Agonis flexuosa* in the forest behind. Some *Juncus kraussii* is still present in a small marsh at 5 km, with *Baumea articulata*, *Baumea juncea* and *Schoenoplectus*. Upstream of this marsh *Baumea juncea* and *Melaleuca rhaphiophylla* fringe the river with *Agonis juniperina*, *Agonis linearifolia* and *Oxylobium lanceolatum*. Higher up are the sedge *Leptospermum gladiatum* and the Kangaroo paw *Anigozanthos flavidus*. Near the boat landing Jarrah and Marri form an open forest on the high (2 m) banks.

At the **Gardner River** *Isolepis nodosa* fringes the bank near the mouth and *Juncus kraussii* and *Isolepis* occur sparsely along the steep banks with *Samolus repens* and *Schoenoplectus* for some distance further upstream. They are progressively replaced by *Baumea articulata*, *Lepidosperma gladiatum*, *Cyperus* sp. and numerous Restionaceous plant species. Where the river narrows about 2.5 km from the bar the banks are higher and are overhung by *Eucalyptus rudis* and other trees. The sedges and *Agonis juniperina* line the banks of Blackwater Creek.

Along the **Warren River** the bullrush *Typha* grows at the mouth and the fringing vegetation all appears to be freshwater species. A collection made about 1 km from the mouth included the rushes *Juncus pallidus* and *Juncus microcephalus*, the sedges *Cyperus* sp. and *Lepidosperma gladiatum*, the shrub *Oxylobium lanceolatum* and trees *Eucalyptus rudis*, *Agonis flexuosa*, *A. juniperina* and *Casuarina obesa*.

7.4 TERRESTRIAL VEGETATION

Species colonising the bars are *Ammophila arenaria*, *Arctotheca* sp. and *Cakile maritima*. Much of the sand dune country is covered by *Agonis flexuosa* shrub or woodland with some open heath with the species listed in Table 7.4. Inland from the dunes

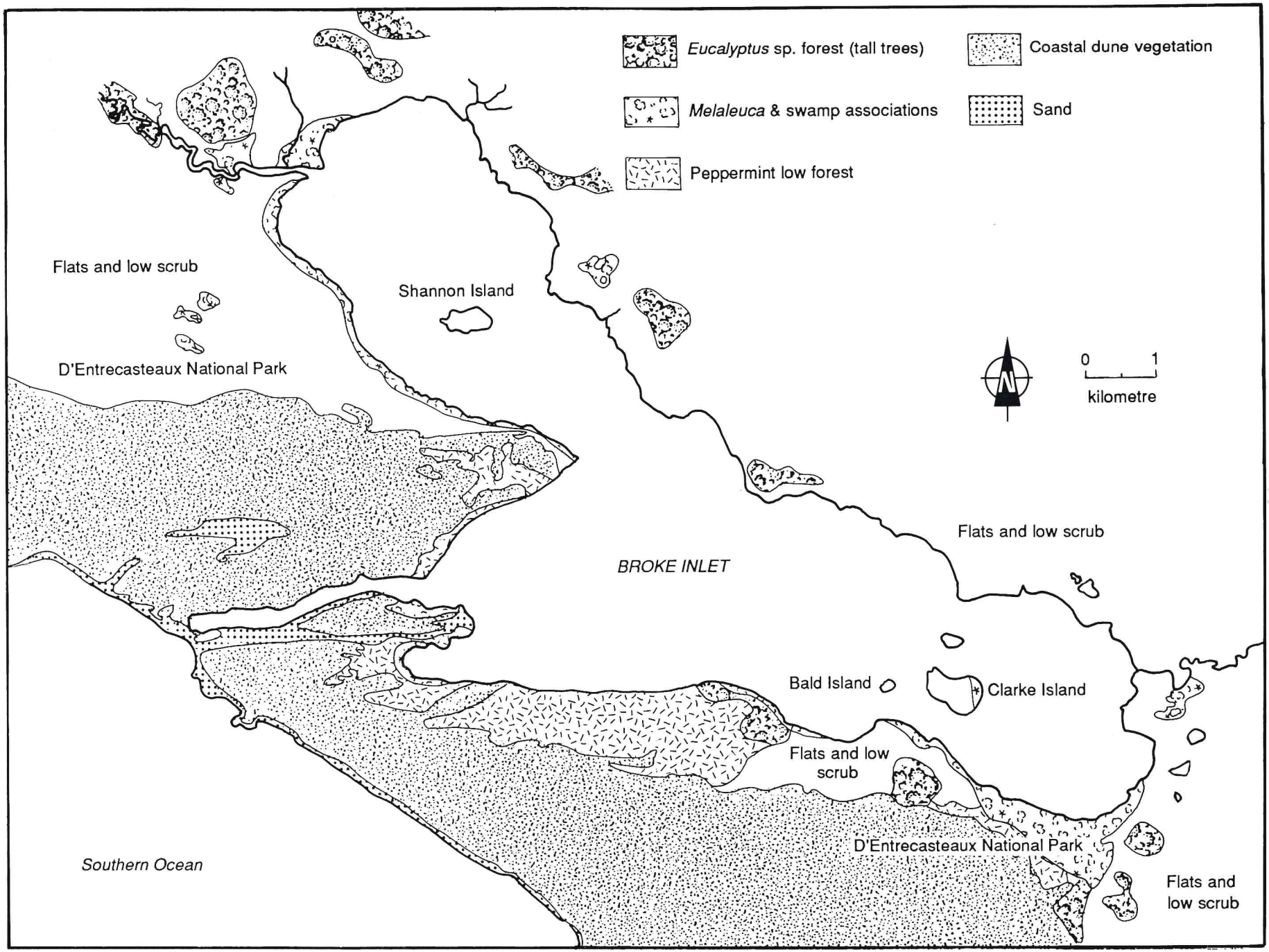


Figure 7.31 Broke Inlet. Vegetation. (J.M. Chambers)

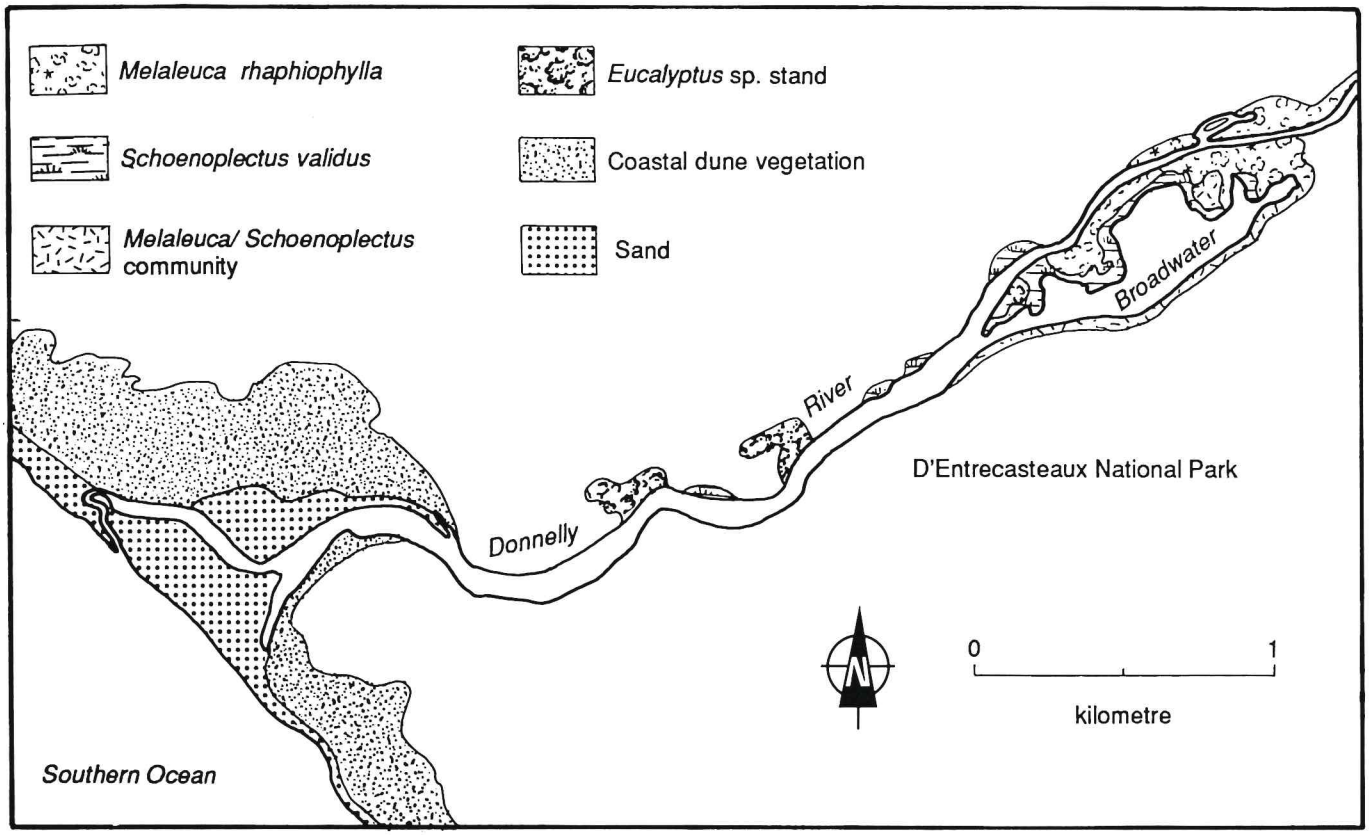


Figure 7.32 Donnelly River. Vegetation. (J.M. Chambers)

stands of Karri, Marri or Jarrah occur on hummocks of higher ground depending on the soils; lower sandy ridges carry *Banksia* woodland, while the lowland flats are occupied by tussocks of rush-like Restionaceous plants, Paperbark woodland and low forest of Yate (*Eucalyptus cornuta*).

Table 7.4 Coastal dune vegetation near the estuaries. (J.M. Chambers)

Isolepis nodosa	*Pimelea ferruginea*
Lepidosperma gladiatum	*Leucopogon parviflorus*
Rhagodia baccata	*Agonis flexuosa*
Carpobrotus sp.	*Scaevola crassifolia*
Acacia eglandosa	*Angianthus cunninghamii*
Acacia littorea	*Calocephalus brownii*
Spyridium globulosum	*Olearia axillaris*
Hibbertia cuneiformis	

8 ESTUARINE FAUNA

8.1 PLANKTON

The common estuarine copepod *Gladioferens imparipes* was abundant in samples taken in Broke Inlet in October 1976, both in the lagoon at the surface and 2.5 m (both 13 ppt) and in the channel at the surface (12.5 ppt) and at 3.5 m (29.8 ppt). Other more marine copepod species, *Acartia* sp., *Gladioferens inermis* and *Oithona* were present in February 1972 (20 ppt).

The Donnelly, Warren and Gardner rivers have not been sampled. The above four estuarine species are probably present in the Donnelly and Gardner and all three rivers probably have a small freshwater plankton fauna.

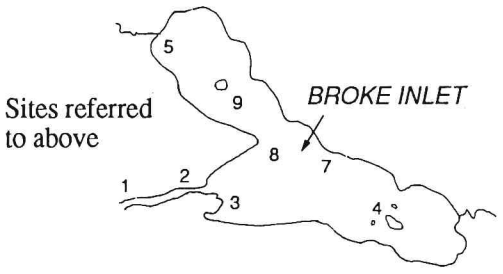
8.2 BOTTOM FAUNA

Table 8.21 lists the invertebrate animals found in two surveys made in Broke Inlet. They are predominantly common estuarine species which are widely distributed throughout the lagoon and inlet channel, though with different assemblages according to type of sediment and presence or absence of aquatic plants. The few differences between the surveys are probably related to the different seasons at which they were conducted (October 1976,

Table 8.21 Broke Inlet. Bottom fauna collected in surveys made in October 1976 (J. Wallace) and January 1989. (R. Clark & G.M. Cliff)

		1976	1989			
	Location	Whole	Channel	Coal Point	Basin	River delta
	Site number	estuary	1,2	3	4,7,8,9	5
OLIGOCHAETE:	Oligochaete sp.	-	-	+++	-	-
POLYCHAETA:						
Nereididae:	*Ceratonereis aequisetes*	++	-	-	-	+++
	Neanthes sp.	-	++	++	++	-
Orbiniidae:	*Scoloplos simplex*	++	+++	++	++	++
	Haploscoloplos sp.	-	-	-	++	-
Spionidae:	*Prionospio* sp.	+	+	-	-	-
Capitellidae:	*Capitella capitata*	+++	+++	++	+++	+
Serpulidae:	*Ficomatus enigmatica*	+	-	-	-	-
MOLLUSCA:	Gastropoda					
Hydrobiidae:	*Hydrobia buccinoides*	+++	-	-	-	-
	Tatea preissii	+	-	-	-	-
MOLLUSCA:	Bivalvia					
Mytilidae:	*Xenostrobus securis*	-	+	-	-	-
Leptonidae:	*Arthritica semen*	+++	-	-	-	++
Sanguinolariidae:	*Sanguinolaria biradiata*	+	+	++	+	-
Trapeziidae:	*Fluviolanatus subtorta*	++	++	-	+++	++
CRUSTACEA:						
Mysidacea:	Mysid sp.	+	++	-	+	-
Isopoda:	Sphaeromid sp.	++	++	++	++	+
Amphipoda:	*Melita* sp.	+++	-	-	++	-
	Corophium sp.	++	+++	++	+++	+
	Paracorophium sp.	+	-	+	++	-
Decapoda:	*Palaemonetes* sp.	+	+	+	+	-
INSECTA:						
Chironomidae:	*Pontomyia* sp.	++	++	+	+	-
Trichoptera larvae		++	-	-	-	-
	Depth (m)		1-3	1	0.3-1.5	0.5-1.2
	Bottom type		sand	mud	sand	sand/mud
	Ruppia cover (if any)		in channel	-	shallows	sand shallows

\- not found
\+ present
++ abundant
+++ very abundant



January 1989), the more abundant aquatic plants in 1976, and sampling methods (grab and shovel in 1976, corer in 1989). The salinity in the lagoon was 6 ppt in 1976 and 14 ppt in 1989. In and near the channel surface salinity was 13 ppt in 1976 and 14 ppt in 1989; the deep water was 34 ppt and 31 ppt respectively. The following additional mollusc species are represented in the WA Museum collections (Wells and Bryce, 1984): *Assiminea* sp., *Hydrococcus brazieri*, *Salinator fragilis* and *Spisula trigonella*.

King prawns have been abundant in Broke Inlet in some years and a flood from the Shannon River is said to have left 'acres of dead prawns in the Inlet' on one occasion. There is reported to have been an influx of small cockles (Katelysia) during the 1968 opening; by 1969 they had grown to 15 mm but many died when the bar did not open, probably killed by the low salinity water.

Table 8.22 lists invertebrate species found in surveys of the Donnelly and Gardner river estuaries. The Donnelly River samples were from the lower 3 km of the estuary and the Broadwater. At the Gardner River sampling was confined to within 2 km of the bar. The lists include both strictly estuarine species and freshwater insect larvae, such as mayfly (Ephemeroptera), caddisfly (Trichoptera) and dragonfly (Odonata). More such freshwater species might have been found had the surveys been extended further upstream. The Warren River has not been surveyed; the fauna is likely to be confined to freshwater species except perhaps close to the beach.

Table 8.23 lists species of Foraminifera found in Broke Inlet by Hassell (1962).

Table 8.22 Benthic fauna found in surveys of the Donnelly (D) and Gardner (G) river estuaries by J. Wallace in October 1976. Symbols as in **Table 8.21**

		D	G
OLIGOCHAETE:		++	-
POLYCHAETA:			
Orbiniidae	*Scoloplos simplex*	++	-
Spionidae	*Prionospio* sp.	+	-
Capitellidae	*Capitella capitata*	+++	-
MOLLUSCA	Gastropoda		
Hydrobiidae	*Hydrobia buccinoides*	+++	+++
	Tatea preissii	++	-
MOLLUSCA	Bivalvia		
Sanguinolariidae	*Sanguinolaria biradiata*	+	-
Trapeziidae	*Fluviolanatus subtorta*	+++	+
CRUSTACEA:			
Amphipoda	*Melita* sp.	++	+
	Paracorophium sp.	++	-
Decapoda	*Palaemonetes australis*	++	++
	Penaeus latisulcatus	+	-
INSECTA:			
	Ephemeroptera larvae	++	++
	Trichoptera larvae	++	-
	Odonata larvae	+	+
Chironomidae	*Chironomus* sp.	+++	+++

Table 8.23 Foraminifera of Broke Inlet. (Hassell, 1962)

Labrospira wiesneri	*Halplophragmoides canariensis*
Miliammina arenacea	*Quinqueloculina seminula*
Rotalia beccarii	*Ammobaculites agglutinans*
Elphidium poeyanum	*Sigmoilina schlumbergeri*

8.3 FISH

Table 8.3 lists the fish species recorded from Broke Inlet and the Donnelly and Gardner rivers. The larger number of species taken in Broke Inlet than in the two rivers partly reflects the greater sampling effort made in the Inlet, and more species would probably be found near the mouths of the two rivers late in summer.

Broke Inlet Table 8.3 records 17 commercial fish species at Broke Inlet. The Inlet attracts a number of recreational fishermen, but supports only a small commercial fishery in contrast to the much richer fishery in the similar sized Wilson Inlet. Broke Inlet appears to be poor in nutrients (oligotrophic) in contrast to Wilson Inlet which is now eutrophic and has a rich growth of *Ruppia*. Total catches have remained at about 5 to 10 tonnes a year since 1965 (with somewhat larger catches from 1968 to 1974) despite a slight increase in fishing effort. The catches now consist predominantly of Yelloweye mullet together with Sea mullet, King George whiting and Australian herring. All these species spawn in the sea and the young are recruited to estuarine populations.

These marine species are probably favoured by prolonged opening of the bar (Figure 3.22). Sea mullet and Yelloweye mullet, with their protracted winter spawning period, are well placed to enter the Inlet as small individuals and catch statistics (since 1964) show no connection between catch and length of bar opening. However both Yellow-finned whiting and Tarwhine (Silver bream) have restricted summer spawning seasons and the bar often closes before they are normally first recorded in the estuary (Figure 8.3). Sometimes the bar closes even before juveniles of King George whiting and Australian herring appear and catches of these species are reported to have decreased greatly since 1960.

The common estuarine species Black bream is not often caught, partly because populations are mainly confined to riverine habitats which are seldom fished or possibly because of the low salinities in the rivers.

The three river estuaries are seldom fished by commercial fishermen, but the Donnelly River especially is popular with recreational fishermen. Tarwhine (Silver bream), Black bream (now few), Cobbler (*Cnidoglanis macrocephalus*), Sea mullet, Yelloweye mullet, Australian herring, Flathead and Rainbow trout are reported to be taken in the estuary. Sea mullet, Yelloweye mullet and a few Australian herring are caught in the Warren River, also the freshwater species Rainbow trout and Cobbler (*Tandanus bostocki*). Few fish are caught in the Gardner River, mainly Sea mullet.

8.4 WATERBIRDS

Table 8.4 lists species observed by Mary Bremner in a thorough survey of Broke Inlet on 4 April 1988 together with other recordings.

Table 8.3 Commercial and non-commercial estuarine and marine species of fish caught in Broke Inlet (B), Donnelly River (D) and Gardner River (G). (R.C.J. Lenanton and G.M. Cliff - W.A. Fisheries Department, Lenanton, 1974 & Prince, *et al.*, 1982)
+ present, - not found.

Commercial		B	D	G
Engraulididae:	Australian anchovy *Engraulis australis*	+	-	-
Salmonidae:	Rainbow trout *Salmo gairdneri*	-	+	-
Plotosidae:	Cobbler *Cnidoglanis macrocephalus*	+	-	-
Hemiramphidae:	Southern sea garfish *Hyporhamphus melanochir*	+	-	-
Sillaginidae:	Yellow-finned whiting *Sillago schomburgkii*	+	-	-
	King George whiting *Sillaginodes punctata*	+	-	-
Carangidae:	Silver trevally *Pseudocaranx dentex*	+	-	-
	Trevally *Pseudocaranx* sp.	+	-	-
Arripidae:	Australian herring *Arripis georgianus*	+	-	-
	Western Australian salmon *Arripis truttaceus*	+	-	-
Sparidae:	Black bream* *Acanthopagrus butcheri*	+	+	+
	Tarwhine (Silver bream) *Rhabdosargus sarba*	+	-	-
Sciaenidae:	Mulloway *Argyrosomus hololepidotus*	+	-	-
Mugilidae:	Yelloweye mullet *Aldrichetta forsteri*	+	+	+
	Sea mullet *Mugil cephalus*	+	+	-
Labridae:	Western blue groper *Achoerodus gouldii*	+	-	-
Pleuronectidae:	Long snouted flounder *Ammotretis rostratus*	+	-	-

Non-commercial		B	D	G
Geotriidae:	Pouched lamprey *Geotria australis*	+	-	-
Ophichthidae:	Serpent eel *Ophisurus serpens*	-	-	+
Galaxiidae:	Black striped minnow *Brachygalaxia nigrostriatus*	+	-	-
	Mud minnow *Lepidogalaxias salamandroides*	+	-	-
Gonorynchidae:	Beaked salmon *Gonorhynchus greyi*	+	-	-
Poeciliidae:	Mosquito fish *Gambusia affinis*	-	-	-
Atherinidae:	Hardyhead Atherinid sp.	-	+	-
	Hardyhead* *Atherinosoma elongata*	+	-	-
	Silverfish *Leptatherina presbyteroides*	+	+	+
Scorpaenidae:	Devilfish *Gymnapistes marmoratus*	+	-	-
Percichthyidae:	Nightfish *Bostockia porosa*	+	-	-
Serranidae:	Western Pigmy perch *Edelia vittata*	+	-	-
Girellidae:	Zebra fish *Girella zebra*	+	-	-
Gobiidae:	Long finned goby *Favonigobius lateralis*	+	-	-
	South west goby *Favonigobius suppositus*	+	+	+
	Blue spot goby* *Pseudogobius olorum*	+	+	+
Tetraodontidae:	Banded toadfish *Torquigener pleurogramma*	+	-	-
Terapontidae:	Yellowtail grunter *Amphitherapon caudavittatus*	+	-	-

* estuarine species

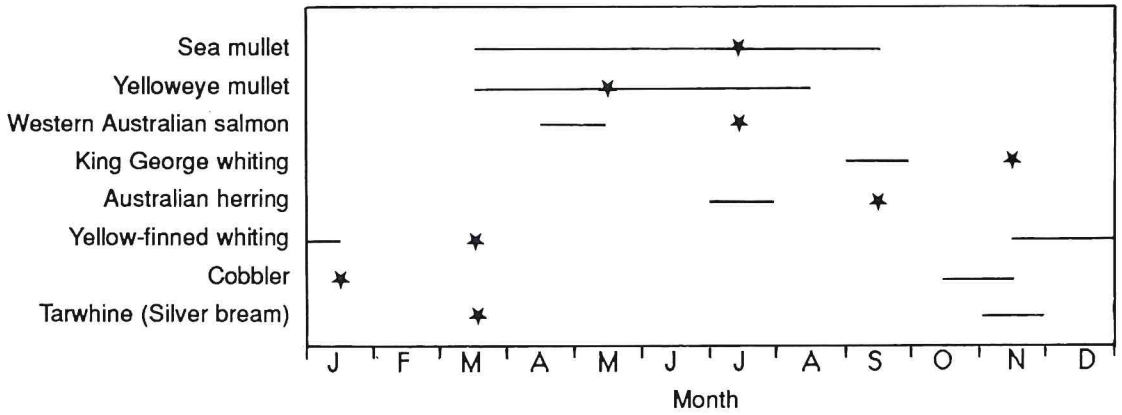


Figure 8.3 The duration of spawning and time at which juvenile fish (0+ individuals) of eight species were normally first recorded in estuaries of the south west of Western Australia. spawning period —— , first record of 0+ ✶ . Redrawn from Lenanton (1984).

Table 8.4 Waterbirds observed in Broke Inlet (B), Donnelly (D), Warren (W) and Gardner (G) rivers. (M. Bremner, R. Clark, RAOU) Numbers indicate highest recorded.

Common name	Scientific name	B	D	W	G
Great Crested Grebe	*Podiceps cristatus*	55	-	-	-
Hoary-headed Grebe	*Poliocephalus poliocephalus*	-	#	-	-
Australasian Grebe	*Trachybaptus novaehollandiae*	-	3	-	-
Unidentifiable grebe		500	-	-	-
Australian Pelican	*Pelecanus conspicillatus*	17	-	-	-
Great Cormorant	*Phalacrocorax carbo*	-	#	3	-
Pied Cormorant	*Phalacrocorax varius*	10	+	-	-
Little Black Cormorant	*Phalacrocorax sulcirostris*	24	34	-	#
Little Pied Cormorant	*Phalacrocorax melanoleucos*	330	7	-	-
White-faced Heron	*Ardea novaehollandiae*	33	-	-	-
Great Egret	*Egretta alba*	3	-	-	-
Yellow-billed Spoonbill	*Platalea flavipes*	3	-	-	-
Black Swan	*Cygnus atratus*	963	4	22	-
Australian Shelduck	*Tadorna tadornoides*	400	-	-	-
Pacific Black Duck	*Anas superciliosa*	150	42	#	-
Grey Teal	*Anas gibberifrons*	40	#	-	-
Maned Duck	*Chenonetta jubata*	6	4	-	-
Musk Duck	*Biziura lobata*	635	3	-	-
Australian Kestrel	*Falco cenchroides*	-	-	1	6
Purple Swamphen	*Porphyrio porphyrio*	-	2	-	-
Eurasian Coot	*Fulica atra*	134	125	-	-
Sooty Oystercatcher	*Haematopus fuliginosus*	-	-	-	5
Red-capped Plover	*Charadrius ruficapillus**	263	-	150	-
Red-necked Stint	*Calidris ruficollis**	330	-	-	-
Silver Gull	*Larus novaehollandiae*	-	-	10	-
Pacific Gull	*Larus pacificus*	25	#	-	-
Caspian Tern	*Hydroprogne caspia*	-	-	2-3	-
Crested Tern	*Sterna bergii*	-	-	100	1

* 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.

9 MANAGEMENT

All four estuaries are entirely within the D'Entrecasteaux National Park and river flow to them is predominantly from high rainfall forested catchments from which there is no excessive nutrient and sediment transport. The estuaries are not polluted and all are in a healthy condition. Increased sediment loads resulting from logging may have accelerated sedimentation in the rivers, especially the Donnelly and Warren.

There is little human impact on the estuaries apart from the occasional artificial opening of the Broke Inlet and Donnelly River bars. They are in as near natural a condition as any estuaries of the south west and management problems relate more to the park lands than to the estuaries themselves. Nevertheless increased use of the parks will undoubtedly affect their welfare and park management also concerns maintenance of the estuaries, of which they are physically a part (although not administratively in the case of Broke Inlet).

The estuaries are popular with fishermen. Broke Inlet attracts both recreational and professional fishermen, some of whom have huts at the Camfield townsite. The three rivers primarily give access to the ocean beaches, and to the Donnelly River cottages. All are off the tourist beat and they attract few visitors other than local residents, unlike the Nornalup-Walpole estuary (the only other in the Manjimup Shire).

The principal management problems relate to off-road vehicles that make new tracks through virgin bush and to the accumulation of rubbish left by visitors. Fresh vehicle tracks are followed by other users and dieback is spread to previously dieback-free areas, so destroying sensitive species in one of the world's richest plant environments. Also where tracks traverse the sandy soils of the coast they are susceptible to wind erosion and may initiate blowouts. The inconsiderate dumping of bottles, cans and other garbage spoils camping grounds for other users, it may create a fire hazard and wastes the time and energies of Park Rangers who have more important duties to perform than removing rubbish.

The mouth of the Donnelly River is only accessible by boat along the 12 km of the estuary. It is popular with local residents and owners of the holiday cottages along the river banks. There has inevitably been some damage to the marginal vegetation and wash from power boats can erode the river banks and mobilise sediment. There must be some leaching of nutrients to the river from domestic sources, however there is no evidence of pollution and the river evidently has the capacity to handle present loads. Nevertheless the condition of river water should be monitored under the different seasonal conditions. Access to the mouths of the Warren and Gardner rivers is difficult and their isolation protects them. The bush tracks are only suitable for use by people familiar with them and with 4 WD vehicles.

The management of sea bars is controversial and there are always differing vested interests. Fortunately this issue is not here complicated by the development of low lying land round the margins, as at Wilson Inlet. At present there are not the data on which to base rational decisions as to if and when the bars should be broken. There is no cause to break the Warren River and Gardner River bars, they rarely close. The Donnelly River bar is sometimes broken prematurely. Floods bring sediment down the river but also flush this, and bar sand, out to sea. Breaking the bar prematurely reduces the scouring action of floods and the long term effect could prove detrimental to the estuary by making it shallower, like the Warren River which has emergent sand banks along its course.

The Broke Inlet bar is sometimes broken by fishermen when the water reaches the top of the bar in order to release the river water and allow marine species of fish to enter. Recruitment to estuarine fish populations depends on there being larvae or young fish in coastal waters when the bars are open. Sea mullet and Yelloweye mullet have a protracted winter spawning period and there are juveniles in coastal waters over a long period. But juvenile King George whiting, Yellow-finned whiting, Australian herring and Tarwhine (Silver bream) have restricted spawning periods in spring and early summer and may be excluded if the bars close early (Lenanton, 1984).

Premature breaking of the Broke Inlet bar will reduce the scouring effect and may result in it remaining open for a shorter period than if allowed to break naturally, so possibly excluding recruits of the later breeders. It will also affect the brackish water status of the Inlet. If the bar only stays open for a short time, and this is followed by further strong river flow, the salinity will remain low. Alternatively a long open period after the river has ceased to flow allows the entry of more sea water and, followed by evaporation in summer, will raise the salinity higher than normal; water level will be low and the shallows exposed.

The present salinity regime is favourable to the small number of species that live in the Inlet, but any reduction in rainfall and river flow, as predicted with the Greenhouse Effect, will result in the bar breaking less frequently and higher salinities in summer. The limited data available probably do not allow the making of any useful conclusions as to the connection between the time and duration of bar opening, salinity of the water, and fish production. Broke Inlet and Wilson Inlet are similar hydrologically and in size. However, Wilson Inlet is much the more productive; it is eutrophic, with an abundant aquatic flora, in contrast to Broke Inlet which is poor in nutrients and has only a sparse flora.

Net fishing is prohibited in Broke Inlet and its tributary rivers from 1 November to 30 April inclusive. In the Donnelly River net fishing is prohibited upstream from the entrance to the Broadwater at all times, but excluding the Broadwater lagoon itself (Fisheries Department, 1988). There are no restrictions on fishing in the Warren and Gardner rivers.

10 FURTHER INVESTIGATION

The information reported in this study is based on limited observations made by the authors, by Fisheries Department officers and other scientists on sporadic visits to the estuaries, and on the recollections of local residents and fishermen. There have been no continuing, coordinated studies such as are essential to a proper understanding of the ecology and the problems for management. It is obvious that there are still important gaps in our knowledge which it is desirable to fill.

Because of their sheltered position within park land, their largely forested catchments and the high rainfall, there is probably no great urgency for further investigation of environmental issues. Nevertheless the estuaries will come under increasing pressure and they should be monitored from time to time, especially with respect to nutrient enrichment and sediment deposition. Moreover data on these relatively pristine environments is valuable when assessing the status of other estuaries that are already under pressure from human activities or from the stresses of more arid environments further east.

The condition of the estuaries depends greatly on the behaviour of the bars, but there are not the data on which to base an accurate assessment of the effect of bar opening, natural or artificial, on them. The wisdom of breaking the Donnelly River and Broke Inlet bars prematurely was questioned above (Section 9) and the effect that this action has on the estuaries and the fisheries warrants further investigation. Natural bar opening depends greatly on the volume and periodicity of river flow and it is important to

maintain continuing records of river flow, the dates of opening and closing of the bars, and of water levels in the estuaries. It will be valuable also to have a record of salinity, temperature and nutrient concentration in estuary water.

This information will also be valuable in assessing the effects of possible changes resulting from the Greenhouse Effect. Rainfall has already decreased in the area in the last half century, though this is not yet reflected in a significant reduction in river flow in the two rivers for which there is a long enough record (the Donnelly and Warren). If river flow decreases or the pattern of rainfall changes (with decreased winter and increased summer rain), then the frequency, timing and duration of bar opening will change and so too the hydrology and biology of the estuaries and their fish production, especially in Broke Inlet.

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12 REFERENCES

Beard, J.S. (1981). Vegetation survey of Western Australia. Swan 1:1 000 000 Vegetation Series.

Collins, P.D.K. and Barrett, D.E. (1980). Shannon, Warren and Donnelly river basins water resources survey. Engineering Divn., Public Works Dept., W.A. Water Resources Branch.

Collins, P.D.K. and Fowlie, W.G. (1981). Denmark and Kent river basins water resources study. Engineering Div., Public Works Dept., W.A. Water Resources Branch.

Fisheries Department, WA. (1988). Recreational fishing. A guide to the rules, Perth, WA.

Hassell, G.W. (1962). *Estuarine sedimentation on the south coast of Western Australia with particular reference to Nornalup Inlet*, PhD Thesis, University of Western Australia.

Hodgkin, E.P. and Clark, R. (1988a). Nornalup and Walpole Inlets. Environmental Protection Authority W.A., *Estuarine Studies Series*, No. **2** p. 10-11.

Hodgkin, E.P. and Clark, R. (1988b). Wilson, Irwin and Parry Inlets. Environmental Protection Authority, W.A., *Estuarine Studies Series*, No. **3.**

Lenanton, R.C.J. (1974). Fish and Crustacea of the Western Australian south coast rivers and estuaries. *Fisheries Research Bulletin* No. **13.** Department of Fisheries and Fauna, W.A.

Lenanton, R.C.J. (1984).Life history strategies of fish in some temperate Australian estuaries. In *Estuarine and coastal environments of the Southern Hemisphere*, (ed. E.P. Hodgkin) pp. 119-137. Dept. Conservation and Environment, W.A., Bull. **161**.

McArthur, W.M. and Clifton, A.L. (1975). Forestry and agriculture in relation to soils in the Pemberton area of Western Australia. *CSIRO Soils and Land Use Series* No. **54**.

McWhae, J.R.H., Playford, P.E., Linder, A.W., Glenister, B.F. and Balme, B.E., (1958). The stratigraphy of Western Australia: *Geol. Soc. Australia Jour.*, v. **4**, pt 2, 161 p.

Muir, B.G. (1981). D'Entrecasteaux National Park resource study. National Parks Authority of Western Australia, Perth.

Prince, J.D., Potter, I.C., Lenanton, R.C.J. and Loneragan, N.R. (1982). Segregation and feeding of Atherinid species (Teleostei) in south-western Australian estuaries. *Aust. J. mar. Freshw. Res.* **33**, 865-880.

RAC, (1989). Touring and accommodation guide book.

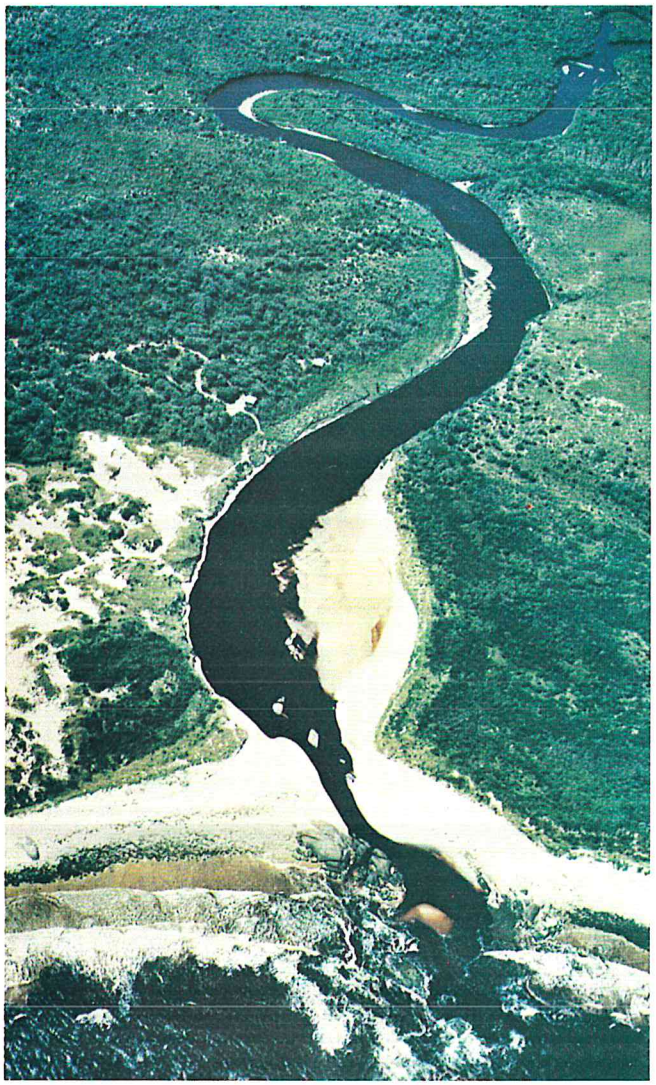
Smith, F.G. (1972). Vegetation map Pemberton, Irwin Inlet. Department of Agriculture.

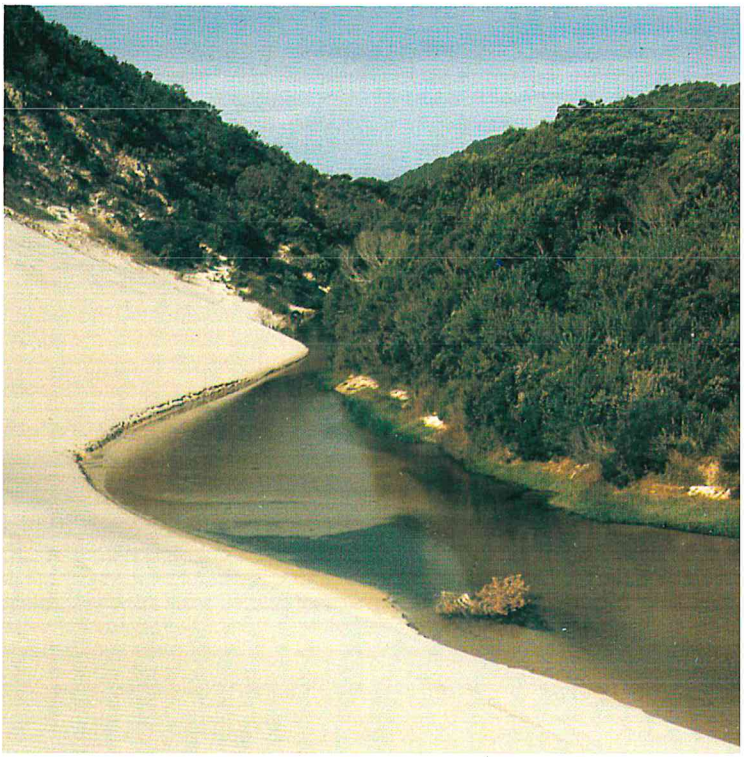
Walker, A. (1987). Shannon Park and D'Entrecasteaux National Park Management Plan. Department of Conservation and Land Management. W.A.

Wells, F.E. and Bryce, C.W. (1984). A guide to the common Molluscs of South-western Australian estuaries. W.A. Museum. pp 112.

Wilde, S.A. and Walker, I.W. (1984). Pemberton - Irwin Inlet Western Australia. West. Australia Geol. Survey 1:250 000 Geol. Series Explan. Notes.

WA, Water Resources Branch, PWD, (1984). Streamflow records of Western Australia to 1982. Vol. 1, Basins 601-612.





Left: Gardner River, November 1988. Photo: Land Administration, WA.

Above: Meerup River, March 1984. Photo: E.P. Hodgkin.

Below: Donnelly River. Photo: CALM Manjimup.