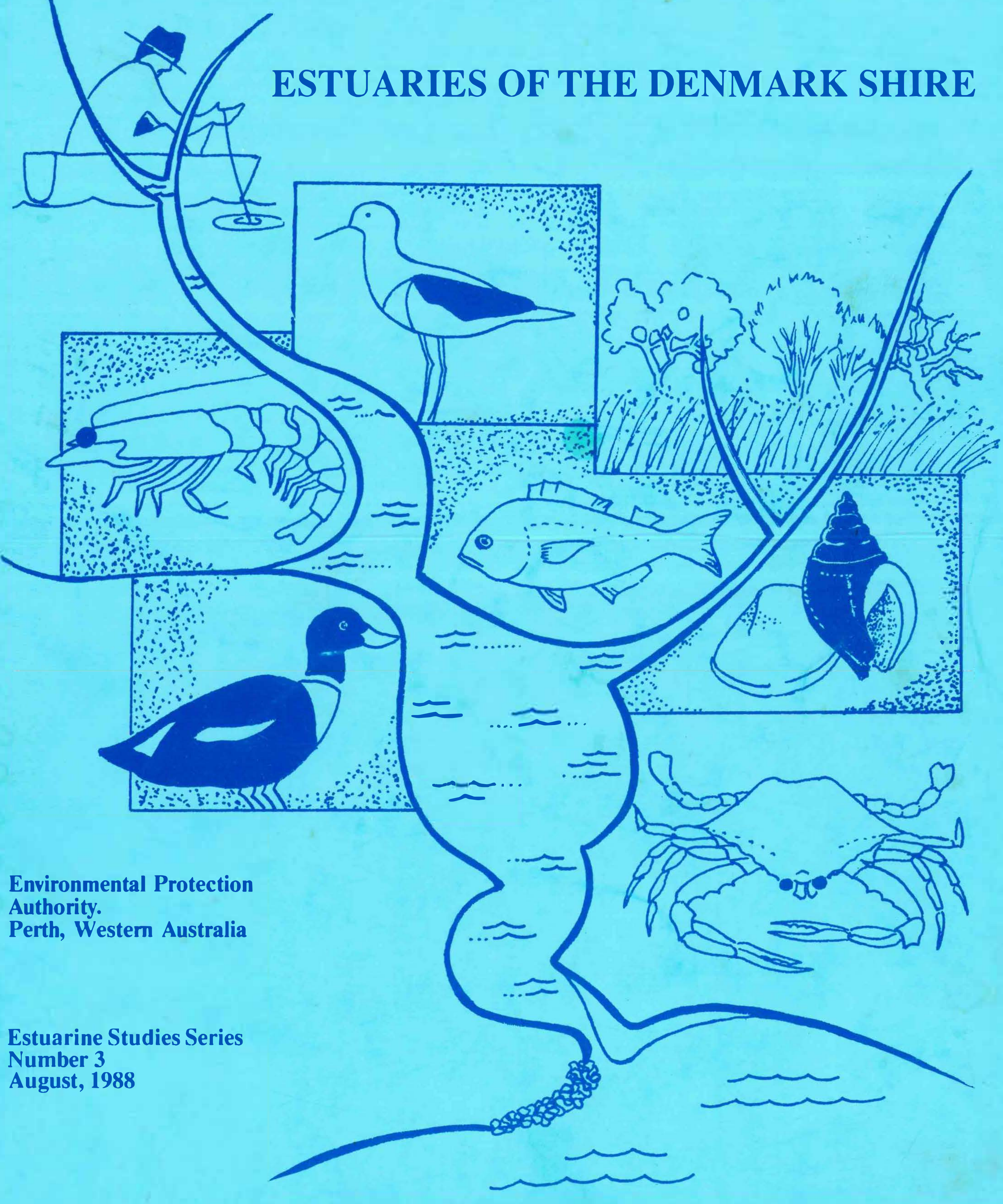
ESTUARIES AND COASTAL LAGOONS OF SOUTH WESTERN AUSTRALIA

WILSON INLET

IRWIN INLET PARRY INLET

ESTUARIES OF THE DENMARK SHIRE



Environmental Protection
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Perth, Western Australia

Estuarine Studies Series
Number 3
August, 1988

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

WILSON, IRWIN AND PARRY INLETS

the estuaries of the Denmark Shire

By Ernest P. Hodgkin and Ruth Clark

Wilson Inlet March 1988 Photo: Land Administration, WA

Environmental Protection Authority
Perth, Western Australia

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COMMON ESTUARINE PLANTS AND ANIMALS

Approximate sizes in mm.

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

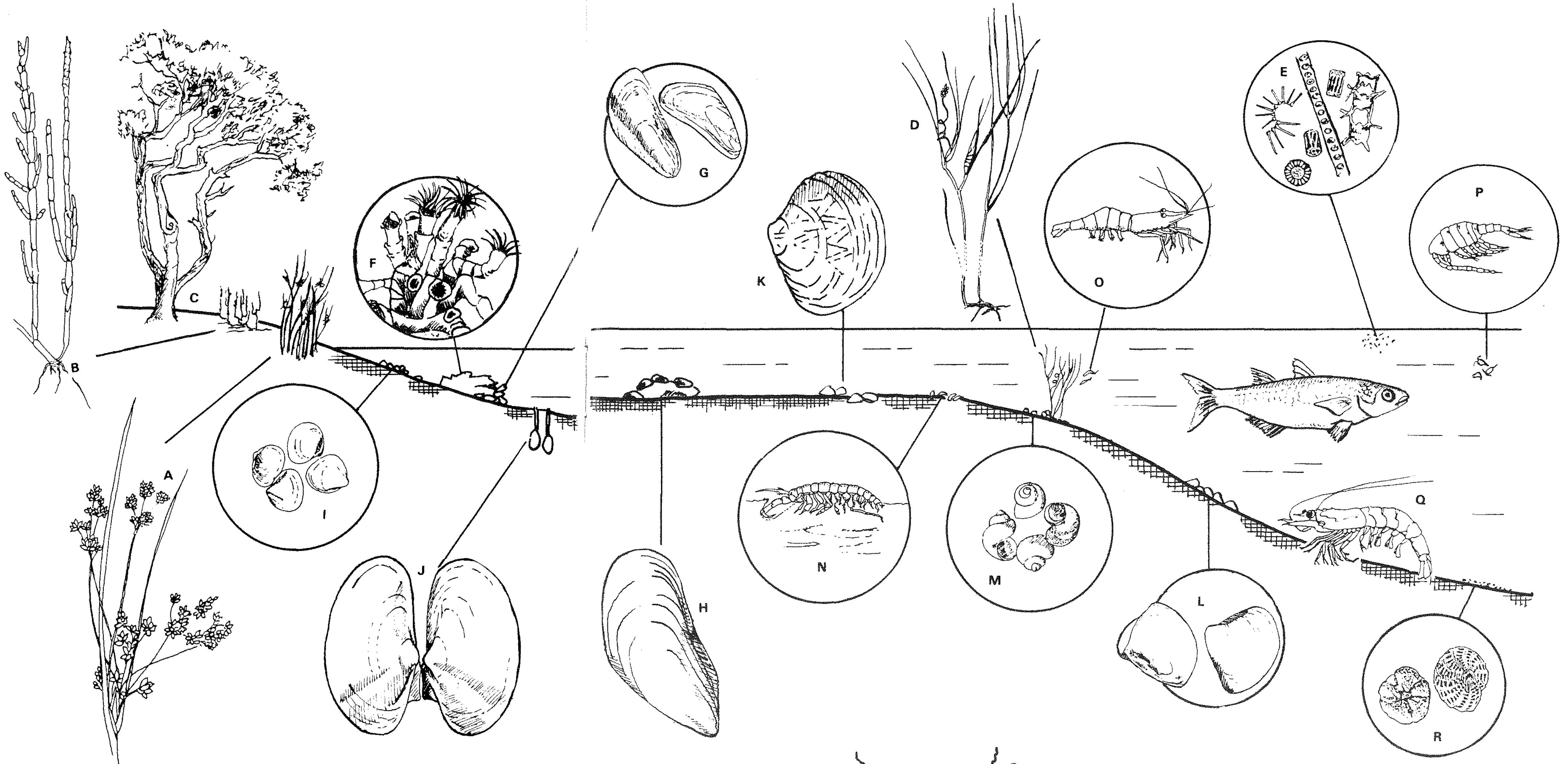
F Tubeworms - *Ficopomatos enigmaticus* 20

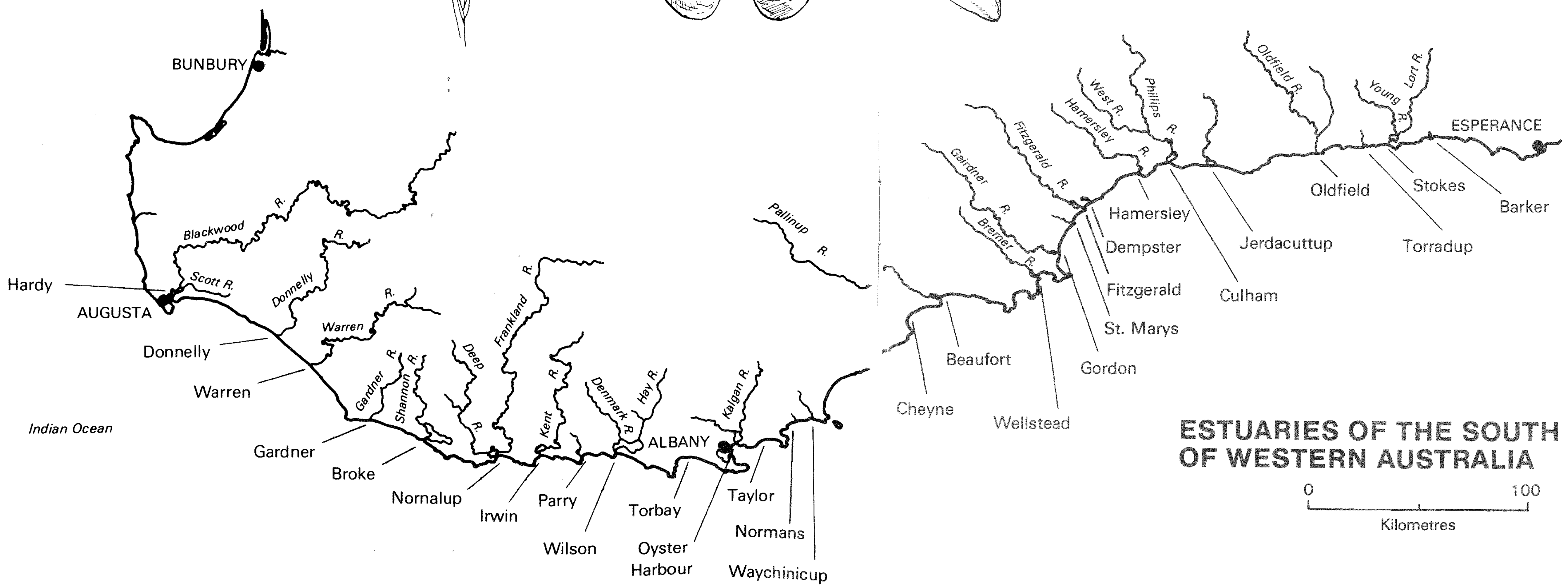
Bivalve molluscs
- G Estuarine mussel - *Xenostrobus securis* 30
- H Edible mussel - *Mytilus edulis* 100
- I *Arthritica semen* 3
- J *Sanginolaria biradiata* 50
- K Cockle - *Katelysia* 3 spp. 40
- L *Spisula trigonella* 20

Gastropod molluscs
- M Snail - *Hydrococcus brazieri* 4

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

R Foraminifera 0.02





ESTUARIES OF THE SOUTH COAST OF WESTERN AUSTRALIA

Hon Barry Hodge, MLA

Minister for the Environment

FOREWORD

This inventory of the three estuaries of the Denmark Shire is the third in the Environmental Studies Series produced by the Environmental Protection Authority as part of the State Conservation Strategy. The two previous studies were on Wellstead Estuary and on the Nornalup - Walpole estuarine system.

The studies summarise and interpret data on the estuaries and provide valuable sources of information for organisations such as local authorities, planners and conservation groups concerned with management, as well as for individuals interested in further study of our estuaries and coastal lagoons.

The aesthetic attraction of estuaries for residential development and their recreational potential have placed them under increasing pressure, and the varied interests of those who use them often present authorities with difficult conflicts to resolve. This is particularly true of Wilson Inlet where both the resident population and tourist interests are expanding and where a large estuarine fishery has flourished since the turn of the century.

Clearing and cultivation in the catchments of tributary rivers has caused river water to become saline and more plant nutrients to enter the estuaries. Measures are being taken to prevent further damage to the catchments, especially that of the Denmark River from which Denmark town draws its water supply. It is anticipated that these and other measures will also decrease the loss of nutrients to drainage water and so reduce the risk that the estuaries will experience the algal problems which have plagued the Peel-Harvey estuary.

Clearly an overall approach is needed to land use in whole catchments, of which rivers and estuaries are part. Good catchment and waterway management will be most likely to occur when local residents become aware and concerned about any degradation and they understand existing and potential problems.

I therefore welcome the interest shown in the welfare of the estuaries by the Shire of Denmark and by local people, and am glad to learn that Management Committees have been established for both Irwin Inlet and Wilson Inlet.

I hope that this inventory of Wilson, Irwin and Parry Inlets will assist local as well as State groups in better planning and management.

CONTENTS

1 INTRODUCTION

The three estuaries of the Denmark Shire, Wilson Inlet, Irwin Inlet and Parry Inlet, have many common features and present similar problems for management. All are lagoonal systems, with relatively small estuarine reaches of their tributary rivers. All have bars that close the estuary off from the sea for several months in most years. They are situated on a narrow coastal plain between the hills on the southern edge of the Western Shield plateau and the dunes and rocky headlands of the south coast. Their mouths open near the western ends of bays where they are protected by headlands from the winds and storms of the Southern Ocean (Figure 1). However they also have important individual features and problems associated with their different dimensions and consequent economic importance. Wilson Inlet is 48 km^2 in area and relatively deep, Irwin Inlet is 10 km^2, and Parry Inlet is 1.4 km^2 and very shallow.

Management problems hinge largely on control of the ocean sand bars. The length of time the bars are open, the consequent volume of water exchanged with the ocean, the condition of the water when they are closed, and the recruitment of fish populations are all matters of concern. The location, time and water level at which the bars are breached are matters of much controversy and conflicts of interest. Clearing for cultivation in the catchments of the major tributary rivers has caused them to become increasingly saline. Although this is unlikely to have any noticeable effect on the estuaries it is serious for Denmark town which draws its water supply from the Denmark River. However the increased load of plant nutrients from fertilizer application to these, and the smaller coastal catchments, has produced potentially eutrophic conditions in the receiving estuary water. The rich growth of aquatic plants poses problems for management in Wilson Inlet.

Rainfall is high near the coast, 1100 mm at Denmark decreasing to 600 to 700 mm in the cleared agricultural land in the upper catchments of the Kent and Hay rivers. The southern, high rainfall parts of the catchments are still largely forested. Rainfall is mainly in winter and effective river flow is generally confined to five months (June to October). After the sea bars close in summer, evaporation may reduce water level in the estuaries by a metre or more and expose large areas of the shallows. This has disastrous results for the aquatic fauna and flora of the smaller estuaries; indeed Parry Inlet may dry out almost completely.

Under these conditions estuary water experiences a wide range of salinity. The range is least in the large, relatively deep Wilson Inlet (about 30% to 90% of sea water salinity) which provides particularly favourable conditions for the few species of fish that dominate the flourishing amateur and professional fisheries. Irwin and Parry experience greater salinity extremes when the bars are closed, from almost fresh to more salt than the sea. The more extreme salinities and the big variation in water depth in these smaller estuaries have been associated with great fluctuations in fish numbers.

The first settlement in the area was by the Randall family who farmed near Ocean Beach in the mid 1880s, and by the Young family near Youngs. Denmark, on the northern shore of Wilson Inlet, is the only town in the Shire. Millar's Karri and Jarrah Forest Ltd. established mills there in 1895 and at the end of the 19th century it was a small timber milling town, with a population probably exceeding 1000. The Company built a railway line to Albany to export the timber, together with fish from the Inlet. The timber was cut out by 1905, the railway closed and Denmark virtually became a ghost town (Sheriff, 1951). The Randall family had established a farm near Ocean Beach in 1895 and the Young family one near Youngs. With the reopening of the railway in 1907, market gardening, potato growing and dairy farming developed near the town. The Group Settlement schemes of the 1920s and the depression years of the 1930s saw considerable clearing along the coastal strip, though with little success for the many immigrants who had no experience of the land and of its then unknown mineral deficiencies. Early in the 20th century development progressed westwards, with clearing and cultivation of the coastal strip and adjacent valleys to the north. The population declined after the second world war, but from the 1970s it has grown considerably with many retirement and holiday homes being built. The Shire now has a population of 2540 (1985) and Denmark is an important tourist centre.

1.1 PREVIOUS STUDIES. Wilson Inlet and its catchment have been studied more than any other estuary of the south coast except Hardy Inlet. Spencer (1952) records 6 years of water sampling; Lenanton (1974a) discusses physical features of the estuary as they relate to the fishery; Collins and Fowlie (1981) report on a study of water resources in the catchments of the three estuaries; Humphries *et al* (1982) present a resource inventory for Wilson Inlet; Lukatelich *et al* (1984, 1986) report their studies of the nutrient status of the Inlet. Further work is in progress; on fish in Wilson Inlet by the Murdoch University Estuarine Research Group and on nutrient and pesticide loadings in drainage water by EPA. The present study has drawn on the resources of these publications and presents other published and unpublished material relevant to understanding the ecology of Wilson Inlet and its two smaller neighbours, about which much less is known. Reference should be made to the above publications for more detail on specific aspects.

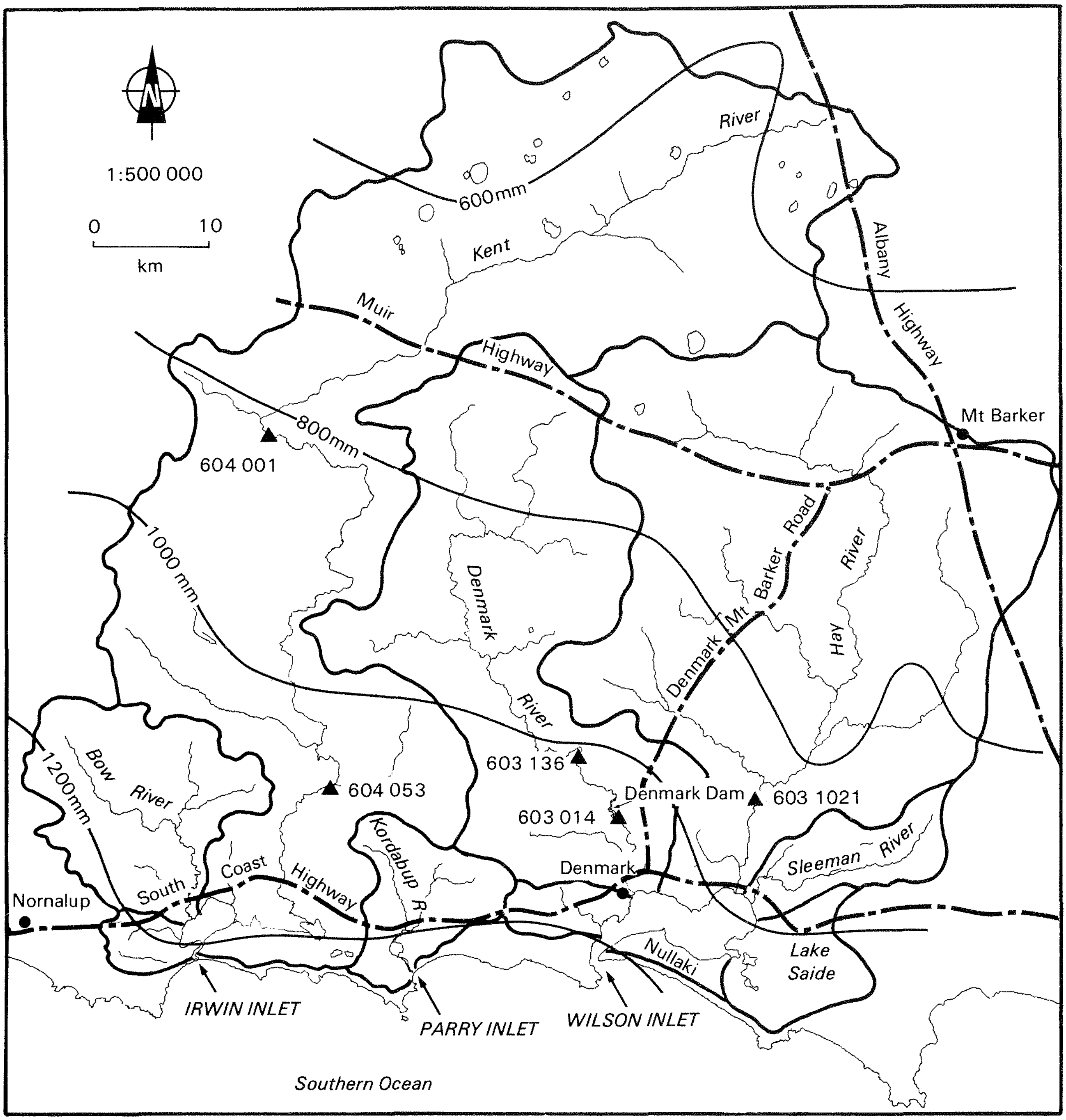


Figure 1 Catchments of the Irwin, Parry and Wilson Inlets.

1.2 LOCATION AND ACCESS

Access to the three estuaries is from South Coast Highway. Wilson Inlet at Denmark is 49 km, Parry Inlet is 68 km and Irwin Inlet at Bow Bridge is 90 km, west of Albany. Grid references are to maps 2328 Denmark and 2327 Parry Inlet on the 1:100 000 topographic map series published by Natmap.

Wilson Inlet lies between 117°20' and 117°29' East and 34°38' and 35°02' South. The mouth is at grid reference 300240. Several roads give access to the north and west shores with boat ramps at Rudgyard Beach, the Denmark Caravan Park and Poddy Point. Ocean Beach Road extends to the mouth of the estuary. Access to eastern and southern shores is by boat, or on bush tracks mainly through private property.

Irwin Inlet lies between 116°56' and 116°59' East and 34°58' and 35°01' South. The mouth is at grid reference 960227. The only road access to the Inlet is along the western shore from Peaceful Bay Road where boats can be launched in very shallow Inlet water or into the Bow River through private property. The mouth is only accessible by vehicle along the beach from the west.

Parry Inlet is located at 117°09' East and 35°01' South. The mouth is at grid reference 146233. Parry Road runs along the west side of the Inlet to Parry Beach. The mouth is accessible by vehicle along the beach from Parry Beach or by a gravel track to the top of the sand cliff at the mouth.

1.3 GEOLOGICAL HISTORY OF THE ESTUARIES

The estuaries are of very recent origin geologically. Early in the Pleistocene (the last 2 million years) there would have been an open seaway from Irwin Inlet to the hills west of Wilson Inlet and from there probably to Princess Royal Harbour. The granite headlands of today would then have been islands. The high dunes of the Nullaki peninsula formed during the Pleistocene and hardened to rock, partially closing off Wilson Inlet; also the dunes south of Owingup Swamp and perhaps to Irwin Inlet. During the last major glaciation, only 20,000 years ago, sea level was more than 100 m lower than it is now and there was dry land for some kilometres beyond the present coastline. Today's estuaries were valleys and the rivers flowed through them, many metres below their present shallow bottoms.

With the Holocene rise of sea level the valleys were flooded by the sea 8000 to 6000 years ago, and for some time sea level may have been about 2 m higher than it is now. At first probably all three Inlets were wide open to the sea and extensive areas of the swamps adjacent to them would have been part of the Inlets. They would have been tidal and less subject to the salinity extremes they now experience. The Aboriginal fish traps in Wilson Inlet may date from that time.

The ocean beaches formed during and following the rise in sea level from sand eroded from the seabed. The finer sand was blown up into dunes and was stabilised by vegetation. Wave action moved sand onshore - offshore and alongshore, gradually narrowing the entrances and building the bars. Tidal currents carried sand into the estuaries to form flood tide deltas and obstruct the channels. Wind and waves built up the ocean bars and formed major barriers to water flow. For a time the channels would have continued to be open to the sea, but neither the seasonal river floods nor the small tides of the south coast could prevent the bars closing seasonally.

Where rivers do not flow continuously there must be shelter from wave action (as at Nornalup Inlet) and a shortage of sand (as at Oyster Harbour) if the channels are to remain permanently open. Where sand is abundant and wave action is heavy, the bars close seasonally and it is only the river floods that can regularly break them, and so prevent permanent closure of the mouth, as has happened at Culham Inlet. It was probably about 3000 years ago that the bars first closed seasonally and the estuaries became brackish water environments with the present seasonal hydrological extremes.

A considerable depth of river sediment has accumulated in the Inlets and swamps during the last 6000 years. This, and a large amount of organic material, has been redistributed to make their relatively flat bottoms. The marginal shoals and adjacent beach ridge flats have been formed by erosion of the shore lines and redistribution of the sandy sediments. Sand has spilled into the southern shores of the Inlets from the dunes encroaching on them, in some places with steep slopes to the water.

These processes of erosion and sedimentation continue at the present time; the estuarine environments are not static, they are constantly changing. The estuaries are filling from both ends, a natural process that has accelerated in the last hundred years. Though the rate of change is 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 the sedimentary processes and the quantities involved, or on the effect that human activities have had on them. In particular, it has been claimed that the growth of the Wilson Inlet delta has been accelerated by the premature opening of the bar and consequent reduced scouring of the channel. While this seems probable there is no direct evidence to support this contention. Irwin Inlet is further down the road to extinction as a lagoonal estuary than Wilson Inlet; much of what was probably an estuary 6000 years ago is now swamp. Parry Inlet has shrunk to the point where the excess of evaporation over rainfall may empty it in summer.

2 CATCHMENT CHARACTERISTICS

The tributary rivers and their catchments are shown in Figure 1. The boundaries of the upper Kent River catchment are ill-defined and there are areas of internal drainage and salt lakes. River water flowing from the northern, cleared areas of the Kent, Denmark and Hay river catchments is increasingly saline. A wide belt of forest separates the cleared agricultural land in the north from patchily cleared land along the coastal strip. Most of the southern catchments are in the Denmark Shire. In the north the Kent, Denmark and Hay rivers enter the Plantagenet Shire and the Kent River extends into the Cranbrook Shire. The Nullaki peninsula and the small catchments to the east of Wilson Inlet and the Hay River are in the Albany Shire.

2.1 LANDFORMS, GEOLOGY AND SOILS

The three estuaries lie on a narrow coastal plain, between the coastal dunes and granite hills to the north, interrupted by the hills west of Wilson Inlet and along its northern shore. The open swamps and low-lying land adjacent to the estuaries have silty sand of recent estuarine origin. South of Wilson Inlet the dunes have hardened to limestone along the Nullaki peninsula. The greater part of the catchments lie in the Albany-Frazer geological province with its Precambrian granitic rocks overlain by Quaternary sands and laterite. The headwaters of the Hay and Kent rivers are mainly in agricultural land, with many salt lakes, swamps and saline seepages the bare soil of which is more susceptible to erosion when cleared.

Most of the Denmark River catchment and the middle reaches of the Hay and Kent rivers are in dissected granite country with some extensive swampy patches in the upper reaches of the Denmark River and along the Kent River. Much of this is still forested and there is little risk of erosion of the yellow mottled soils and dissected laterites. On the lower slopes, nearer the estuaries, there are areas of Tertiary sandstone and spongolite (Pallinup Siltstone) with low gradients, and these rocks also underlie coastal plain sediments. The smaller rivers, Bow, Kordabup, Sleeman and the lower tributaries of the larger rivers have much of their catchments on these rocks. The soils are mainly sandy and swampy and the tannin stained, acid drainage water would carry mainly organic matter. The geology of the area is described and mapped by Muhling and Brakel (1985) and Wilde and Walker (1984).

2.2 COASTAL FEATURES

All three estuaries open to the sea towards the western ends of bays, where the mouths are sheltered by rocky headlands from the prevailing winter south westerly winds and swells. The dune patterns reflect these winds, except at the western ends of Peaceful and William bays where coastal eddies and the summer south easterlies have shaped them. **Wilson Inlet** opens hard against the Wilson Head peninsula. For 2 km to the east of the mouth the wide beach is backed by unconsolidated dunes bound only by the dense vegetation, and with a large blowout in them. Further east the high limestone cliffs of the Nullaki peninsula back the narrow shore of Ratcliffe Bay (Figure 2.21). **Irwin Inlet** opens via a narrow, 1.5 km long channel through low, poorly consolidated dunes onto the open Quarram Beach (Figure 2.22). The mouth is sheltered from the south west by Point Irwin, but it is 3 km from the nearest rock at Peaceful Bay. In the absence of rock the position of the mouth is not fixed and may have been much further west within the last few hundred years. There is no rock exposed along the wide beach of Foul Bay to the east of the mouth. **Parry Inlet** opens via a narrow, 2 km long channel through low, unconsolidated dunes. The mouth is sheltered from the south westerlies by Point Hillier, but is 1 km from the nearest rock at Parry Beach (Figure 2.22). To the east of the mouth there are only low dunes along the wide beach of William Bay.

2.3 RAINFALL

Rainfall is high near the coast, with an annual average of 1120 mm at Denmark and 1257 at Nornalup, but it decreases rapidly inland with only 600 mm at Cranbrook near the source of the Hay River and 751 at Mount Barker in the upper Kent River catchment (Figure 1). This is mainly winter rainfall (Figure 2.31) but there are occasional summer storms (181 mm January 1939, 196 mm March 1943, 139 mm February 1955 at Denmark). Annual rainfall extremes are listed in Table 2.3. Average monthly rainfall exceeds average pan evaporation for the five months May to September, but evaporation exceeds rainfall during the remaining seven months (Figure 2.32), when there is little flow to the estuaries.

Near the coast, rainfall has decreased progressively, as shown by the annual means at Denmark and Nornalup rainfall stations:

Denmark Post Office		Nornalup	
Decade	mm	Decade	mm
1898 - 1911	1202	1956 - 1965	1465
1955 - 1964	1067	1966 - 1975	1319
1977 - 1986	965	1976 - 1985	1265

There has been no comparable decrease at the inland rainfall stations, Mount Barker and Cranbrook.

Table 2.3 Highest and lowest, monthly and annual rainfalls (mm) for Mount Barker Post Office, Nornalup, Denmark Post Office and at Parry Inlet rainfall stations. (Commonwealth Bureau of Meteorology)

	MOUNT BARKER 1886-1984	NORNALUP 1913-1980	DENMARK 1897-1984	PARRY INLET 1969-1986
Average annual	751 mm	1257 mm	1120 mm	980 mm
Highest annual	1102 (1917)	1839 (1917)	1708 (1917)	1183 (1973)
Lowest annual	466 (1891)	890 (1969)	763 (1940)	806 (1972)
Highest monthly	261 Jly (1912)	348 Apr (1961)	353 Jn (1923)	253 Jn (1970/78)
Highest two monthly	352 My/Jn (1917)	569 My/Jn (1945)	628 My/Jn (1910)	448 Jn/Jy (1978)

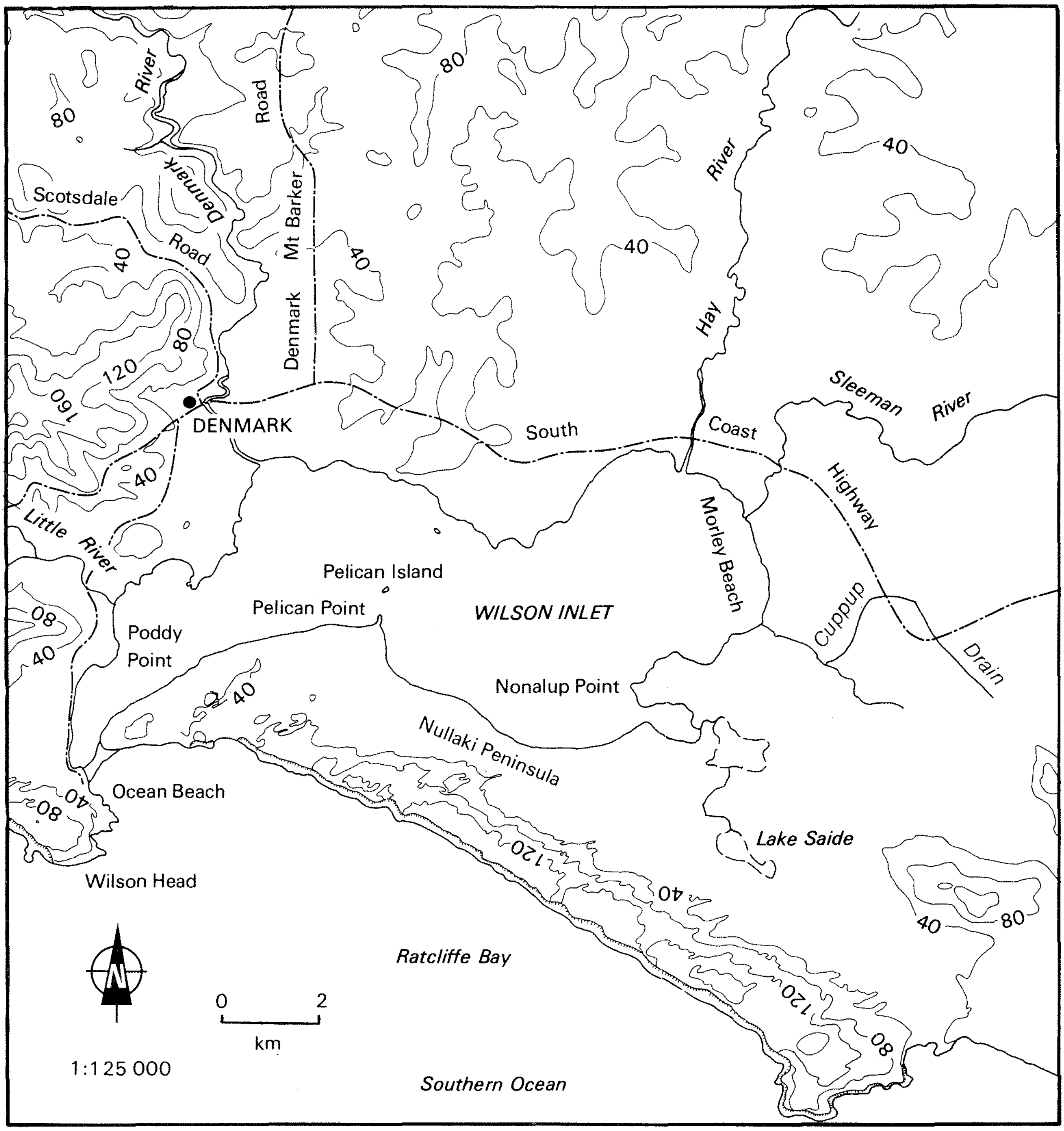


Figure 2.21 Wilson Inlet. Map of coastal area. Contours in metres.

2.4 RIVERS

Wilson Inlet has two major rivers which drain from the hills to the north: the Hay River, 80 km in length, at the eastern end and the Denmark River, 60 km long on the north shore. The Denmark River flows through a deeply cut valley almost to the Inlet. The Hay enters through low hills and a sandy, alluvial plain. The two rivers drain 89% of the catchment. The Sleeman River (22 km) drains low hills and swamps to the east of the Inlet. The Lake Saide Drain and the small Cuppup River drain coastal swamps to the east and Little River mainly hilly country to the west.

Two major rivers discharge to **Irwin Inlet** from the hills: the Kent River, over 100 km long, enters from the east after passing through the large Owingup Swamp; the Bow River, 20 km long, enters from the north west. The small Karri Creek drains low land to the north east and Kwokalup Creek drains swampy and hilly country to the west.

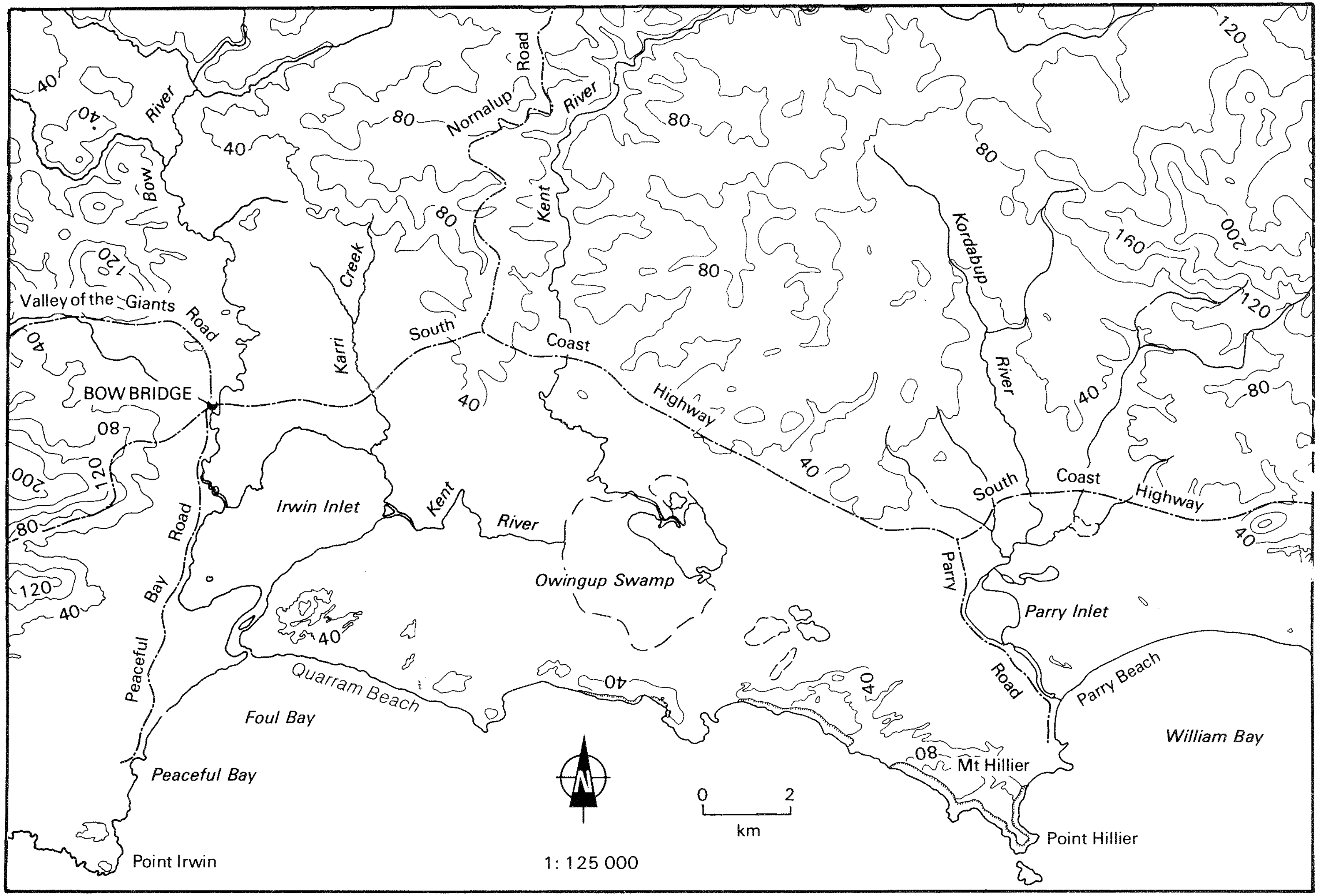
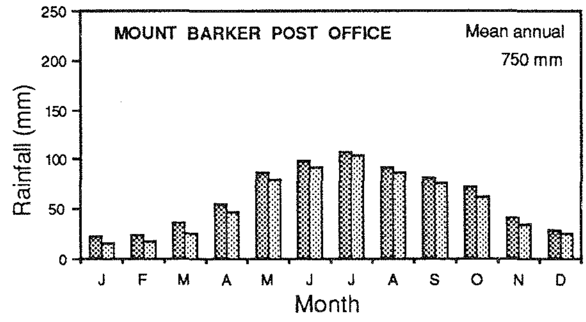
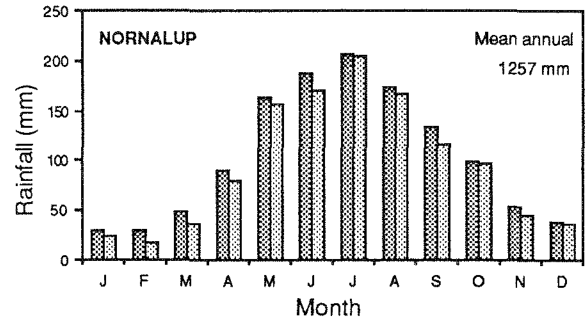
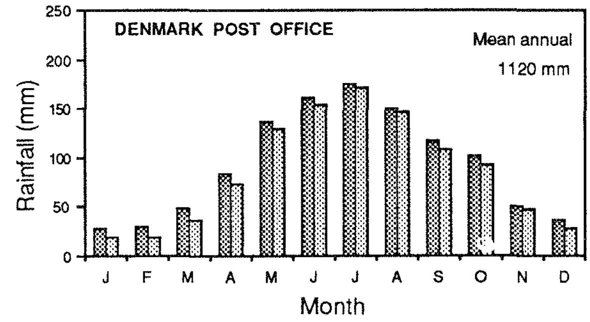


Figure 2.22 Irwin and Parry Inlets. Map of coastal area. Contours in metres.







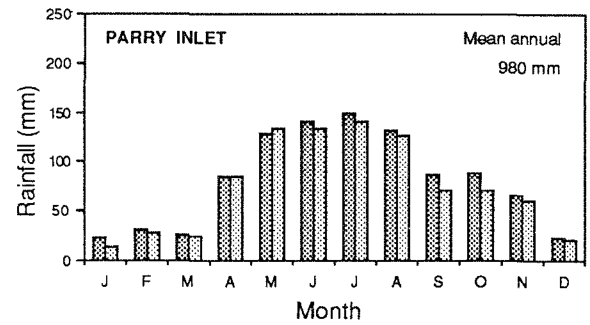


Figure 2.31 Monthly rainfall at Mount Barker station (009 581) 1886-1984, Nornalup station (009 589) 1913-1980, Denmark station (009 531) 1897-1984 and Parry Inlet station (009 784) 1969-1986. means ▩ , medians ▤ . (Commonwealth Bureau of Meteorology)

The only river flowing to **Parry Inlet** is the small Kordabup River about 12 km long which, with its tributaries, enters the Inlet through a swamp on the north east. The river drains coastal plain land and low hills. There is also swampy land on the west of the Inlet.

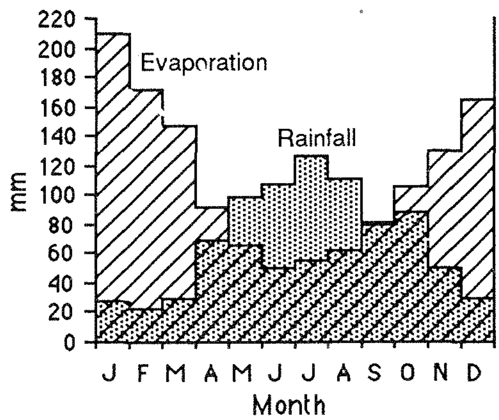


Figure 2.32 Mean monthly rainfall and evaporation at Albany.

DAMS The Denmark River was dammed in 1961 to provide water for Denmark town. The dam is about 10 km upstream from the Inlet at the old 603 014 gauging station (Figure 1). It is now proposed to dam the Quickup River, which discharges to the Denmark River downstream of the dam.

RUNOFF AND FLOW Runoff from the various catchments (the portion of rainfall which ultimately reaches the streams) varies greatly with their location in relation to rainfall, and the areas cleared, as discussed by Collins and Fowlie (1981) (Figure 2.41). The average runoff from the Kent River catchment is estimated to be 49 mm (above station 604053); it is only 20 mm from the upper part of the catchment (above station 604 001), but is 93 mm from below that point. Runoff is 70 mm from the Denmark River catchment (603136) (78 mm near the Inlet). From the Hay River catchment (6031021) it is 60 mm.

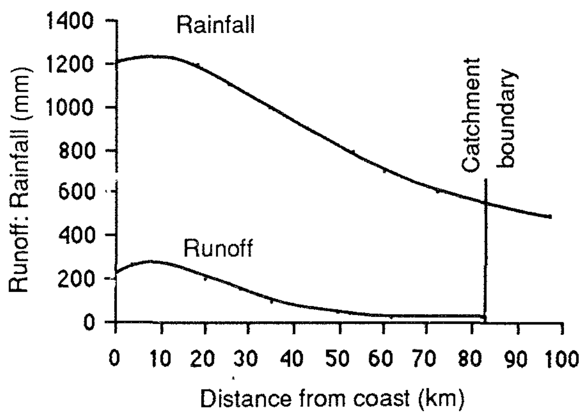


Figure 2.41 Profile of rainfall and runoff distribution in the Denmark and Kent River catchments. (Collins and Fowlie, 1981)

The total average annual river discharge to **Wilson Inlet** is estimated to be 207 x 10^6 m^3. However that figure has limited meaning because of the great variability in the volume of river flow and runoff. For example, recorded flow in the Denmark River (station 603 136) is from a low of 9.1 x 10^6 m^3 in 1982 to a high of 79.9 x 10^6 m^3 in 1978 (Figure 2.42). Mean monthly flow rates are shown in Figure 2.43. When compared with rainfall data in Figure 2.31 it will be seen that there is a long delay between rainfall and river flow because of the time taken to saturate the soils before there is effective runoff. Again, the great variability in flow should be noted; the July 1978 flow of 35 x 10^6 m^3 was nearly half the flow for that year, and greater than the mean annual flow (32.4 x 10^6 m^3, at 603 136).

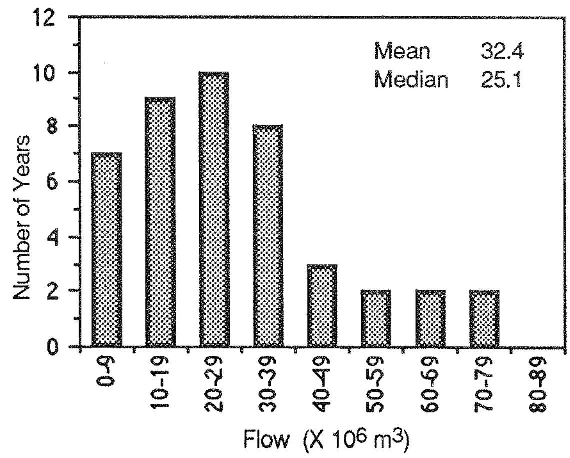


Figure 2.42 The variability of flows in the Denmark River gauging stations (603 136 and 603 014) between 1940 and 1982. (Water Resources Branch, 1984)

The average annual flow to **Irwin Inlet** is approximately 172 x 10^6 m^3. The estimated long term annual average flow in the Kent River at gauging station 604 053 is 90 x 10^6 m^3, varying from 29 (1972) to 190 (1978). Mean monthly flow rates are shown in Figure 2.43. Flow in the Bow River is estimated to be 16 x 10^6 m^3. There is further substantial flow from small streams discharging directly to the Inlet.

To **Parry Inlet**, the average annual flow from the Kordabup River is about 13 x 10^6 m^3.

WATER CHEMISTRY Water in the Denmark River has become increasingly saline. Total soluble salts were 42 mg/l for the decade 1940-1949 (station 603 014) increasing to 537 mg/l for 1973-1982 (station 603 136). There has been a further increase since 1982. The Hay River is saline, more than 1000

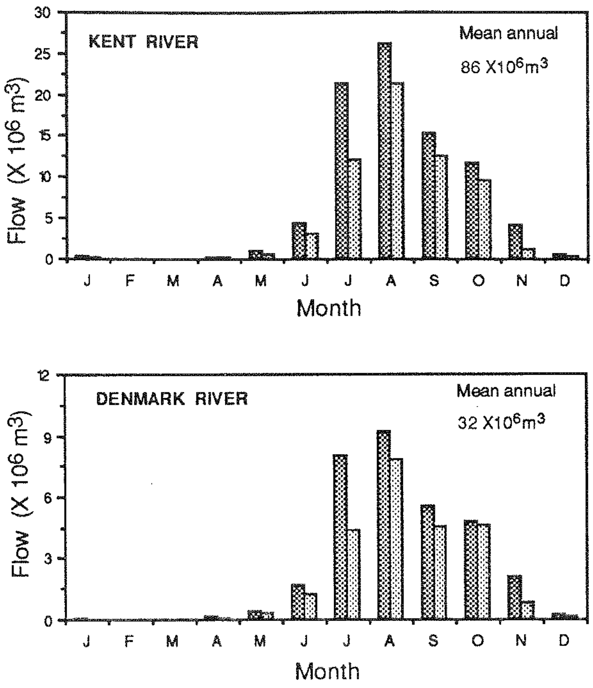


Figure 2.43 Monthly flows at the Kent River, 604 053, (1956-1982) and Denmark River, 603 136 (1960-1982) gauging stations. means ▮ , medians ▯ . (Water Resources Branch, 1984)

mg/l (1 ppt) and clearing in the catchment has now been restricted to prevent further increase in salinity. The Sleeman River and other smaller tributaries to Wilson Inlet are fresh (< 500 mg/l).

The Kent River is saline (about 1000 mg/l). The Bow River is fresh, with dark tannin stained water. The Kordabup River is also fresh.

2.5 LAND OWNERSHIP AND USE

There was little clearing in the catchment before the 20th century. By 1930 about 1800 km^2 had been alienated and perhaps half of this had been cleared, and by the 1970s about 75% of the area (Collins and Fowlie, 1981). Table 2.5 shows the areas of cleared land in the catchments of the rivers. The upper parts of the catchments of the three major rivers, and to the east of the Hay River, receive less than about 800 mm of annual rainfall. Almost all is privately owned land and most of it is cleared for agriculture, mainly for sheep and some cereal growing. Between this and the coastal strip there is a wide belt of mainly forested land in the catchments of these rivers and the Bow River, most of which is in State Forest and other reserves.

The coastal belt and the valleys and southern slopes of the hills are alienated land. Much of it has been cleared, mainly for grazing by beef cattle or for potato, fruit and vegetable growing. However there are considerable, scattered areas of uncleared land, especially low-lying, swampy land on the coastal plain. In particular, Owingup Swamp has not been

Table 2.5 The catchment areas and approximate cleared areas of rivers flowing to Wilson, Irwin and Parry Inlets. (R.Clark, R.Shaw - DOLA)

River	Catchment area(km^2)	Cleared area(km^2)	% cleared
WILSON INLET			
Hay	1298	909	70
Denmark	800	220	28
Lake Saide	119	92	77
Sleeman	94	72	77
Little	40	20	50
Nullaki	28	0	0
Total	2379	1293	54
IRWIN INLET			
Kent	1985	1026	52
Bow	254	57	22
Other	31	20	64
Total	2270	1103	49
PARRY INLET			
Kordabup	119	95	98
Final Total	4768	2420	51

cleared and there is still a considerable area of uncleared alienated land in the sandy south eastern catchments of Wilson Inlet. Only 4% of the immediate Lake Saide-Nemanup drain area has been cleared.

Along the coast itself there is a narrow strip of reserved land from Wilson Head to Irwin Inlet and beyond, mainly in the Walpole-Nornalup National Park. At Peaceful Bay, 5 km south of Irwin Inlet, a small area is leased to the Denmark Shire for holiday homes. East of Wilson Head the coastal strip with the high dunes of the Nullaki peninsula is alienated land, as yet uncleared.

Clearing bans are now in force on uncleared land in the catchment of the Denmark River dam to prevent the town water supply becoming more saline. The ban does not apply to the catchment of the Scotsdale Creek tributary, the water of which is still fresh in summer. In 1978 legislation was enacted to control clearing in the Kent River catchment in order to prevent further increase in salinity in that river.

Denmark is the only town in the vicinity of the three estuaries. It has a hotel, 2 motels, 6 guest houses, 5 caravan parks and a youth hostel. The maximum available accommodation for visitors is 1500, including facilities such as tents, vans and chalets and a caravan park near the beach (RAC, 1986). There is a small settlement at Bow Bridge and a group of holiday homes on the coast at Peaceful Bay. The caravan park at Peaceful Bay can accommodate up to 300 people.

2.6 VEGETATION

The natural vegetation of the area has been described and mapped by Beard (1979). Before the northern, low rainfall region was cleared it carried a low Jarrah-Marri forest and open woodland with Wandoo and a variety of understory species in swampy, sandy places. The forest belt is predominantly an open Jarrah forest with some Karri forest nearer the coast where the summer rainfall averages about 300 mm. The coastal belt has a more varied flora with low Jarrah forest on the hills and a diverse swamp vegetation and dense woodland with several species of paperbark (*Melaleuca*)and Peppermint (*Agonis flexuosa)*. Of particular interest is the small *Eucalyptus ficifolia* forest west of Irwin Inlet. The dunes are covered with a typical low coastal heath on their seaward face, changing to a dense low woodland dominated by Peppermint and *Banksia* on the sheltered side.

3 WILSON INLET — PHYSICAL FEATURES

The Wilson Inlet estuarine system includes not only the Inlet but also short stretches of the Denmark and Hay rivers. When the bar is open there is tidal exchange with the sea, water level in the estuary is about sea level, and estuary water is a mix of sea water and water from the land. When the bar is closed water level and the character of estuary water change with rainfall, river flow and evaporation.

3.1 LANDFORMS

RIVERS The Denmark River is estuarine for about 2.5 km and is up to 4 m deep. It discharges to the Inlet across the northern shallows through which there is a dredged boat channel. The Hay River is estuarine for about 5 km and is 3-4 m deep in places. It discharges over the wide eastern shallows of Morley Beach which bars the Hay and Sleeman rivers off from the Inlet when water level is low in summer. The estuarine reaches of the rivers are incised through sandy alluvial and estuarine deposits. Their channels are well defined, with steep banks 3 m or more high in the upper reaches.

Gates were installed at Eden Road to prevent Inlet water entering Nenamup Inlet and the Lake Saide potato fields. Subsequently pumps were installed upstream from Nenamup Inlet to pump water from Lake Saide and the Eden Road gates are now generally open.

INLET Wilson Inlet is a 14 km long lagoon lying parallel to the coast in an east west direction; it is 4 km at the widest part and has an area of 48 km^2 (Figure 3.11). The volume at mean sea level (MSL) is approximately 85 x 10^6 m^3, assuming an average depth of 1.78 m.

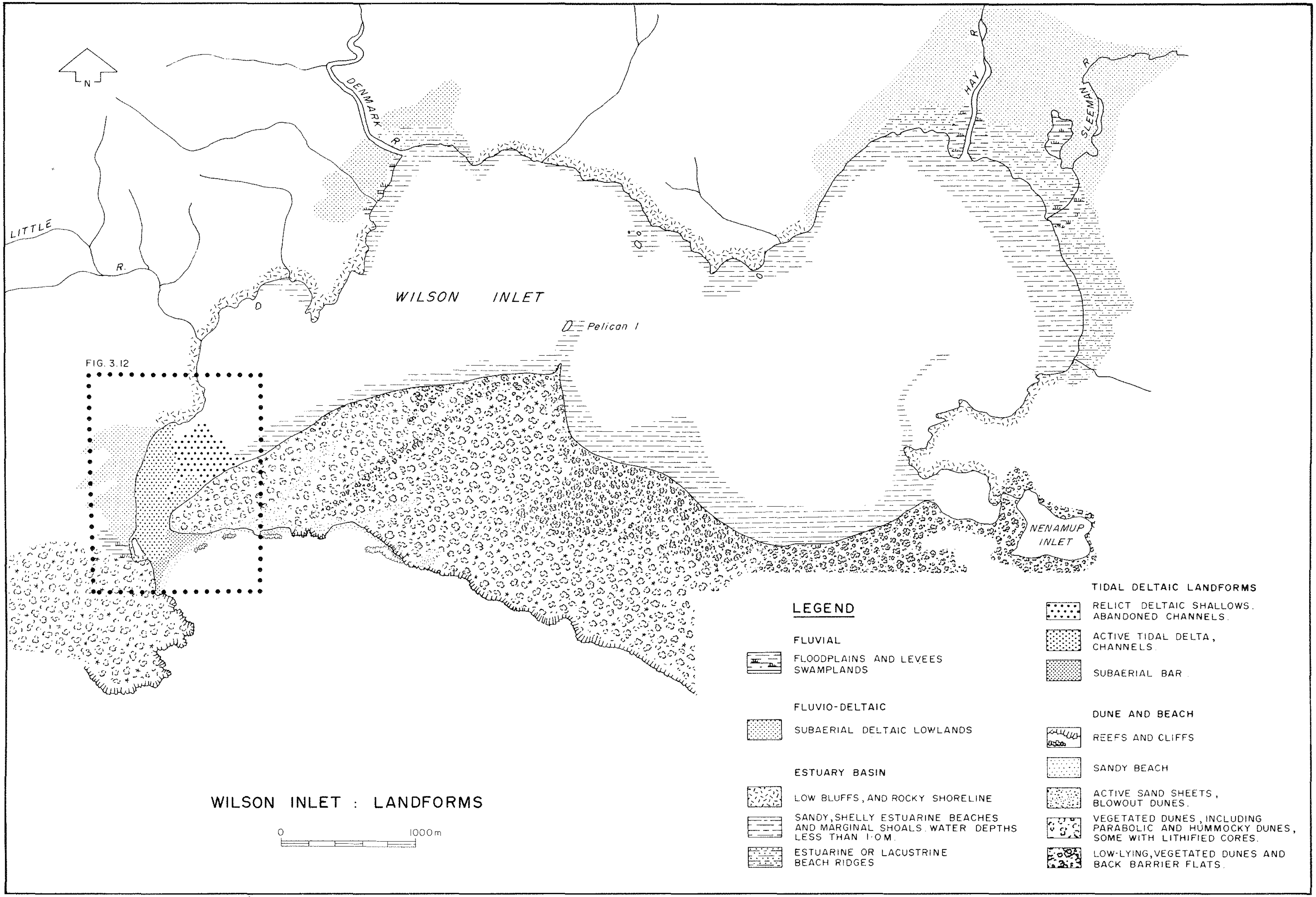


Figure 3.11 Wilson Inlet: Landforms. (I. Eliot)

The Inlet is partially divided into eastern and western basins by Pelican Island and the shallow sill between it and Pelican Point on the southern shore. The central area is over 3 m deep, but there are extensive shallows around the margins, particularly at the eastern and western ends.

The western and northern shores of the Inlet are mainly rocky (granite) with small swamps and sandy bays (with quartz river sand). Several small rocky islands lie close to shore and there are small granite outcrops in the Inlet. Morley Beach at the eastern end is bordered by low beach ridges, behind which there is swamp, and there is a small beach ridge plain east of the Denmark River mouth. The wide, shallow sand flat here becomes exposed in late summer. On the southern shore there is granite around Nornalup Point, but the rest of the shoreline is sandy along the northern shore of the Nullaki peninsula.

INLET CHANNEL and MOUTH These are at the extreme western end of the Inlet. The channel is 1 km wide at Poddy Point and narrows to 500 m at the mouth. It swings from south west to south and then south east in the shelter of Wilson Head (Figure 3.12). It is almost completely blocked by the large flood tide delta, through which flow channels have taken different routes. They are unstable and are filled in or scoured out according to the pattern of flow when the bar is open. In the past one channel was along the western shore, but little is left of it and this part of the delta is now well vegetated dry land and the old channel remains as a swamp and pool. The main flow channel is now generally near the eastern shore and has been at least since the 1940s as shown by air photographs.

The tidal delta was formed during the Holocene closure of the bar and there is no evidence to show whether it is now being added to. There is a net inward transport of sand while tidal flow is the only flow through the channel and estuary water level follows the ocean level. This sand forms a subtidal bar, the 'flood tide shoals' in Figure 3.12, through which subsequent channels are scoured. Sand blown up from the beach also adds to the beach sand bar and the tip of Nullaki Point appears to be growing westwards as the sand is stabilised by vegetation.

3.2 THE BAR

The bar projects from the western end of the Nullaki peninsula to the cliff behind Wilson Head, following the shore line of Ratcliffe Bay. It is about 150 m wide and slopes gradually from the crest across the flood tide delta. The height of the bar depends on the strength and duration of the south easterly winds; it builds up to about 1.5 m above MSL. It is composed of moderately well sorted, medium to coarse sand; quartz 65%, skeletal fragments 35%.

The bar closes the mouth for about six months each year, usually from January or February to July or August (Figure 3.21). It is opened when the water level in the Inlet reaches 1.01 m above MSL (5.4 feet above a datum on the old railway bridge). This artificial situation was initiated to prevent flooding of the Elleker - Nornalup railway line when it was realigned along the northern shore of the Inlet between 1926 and 1929. Previously the water level rose to the top of the bar and then either broke naturally or was breached when Inlet water reached the top and was lapping over it, usually in July, so that little was needed to start water flowing. Aboriginals are reported to have done this and the early settlers followed suit. Since the closure of the railway line the bar has continued to be opened when Inlet water reaches the 1 m level. This is to prevent flooding roads and developments along the shores and to drain water from farm land in the Sleeman and Cuppup river catchments. The Lake Saide potato paddocks are of particular concern.

In July 1975 the bar was breached when the Inlet level had reached 1.11 m above AHD and ocean level was 0.10 m below MSL, a head difference across the bar of 1.21 m. The maximum rate of discharge was 464 m^3/sec, made up of 420 m^3/sec from the lowering of the water level and an estimated 44 m^3/sec input from river flow. The water level fell at an average rate of 0.03 m/hour. As will be seen from the water level record (Figure 3.22) it took some eight hours before the level began to fall at the maximum rate. During this period the energy of flow was being used to cut the channel through the bar. Over the next 3 to 4 days the rate decreased regularly, the level followed a parabolic path, in accordance with the known behaviour of flow through a constant outlet. It takes three to four days for the Inlet water to drain to the sea and the level to fall to that of the sea.

Closure of the bar results from a combination of factors which reduce flow in the bar channel; these include reduced river discharge, growth of the subtidal estuary sill, and build up of the wave-caused ocean bar. The bar generally starts to close around November and other factors contributing to its closure are evaporation, the generally lower sea levels of summer and the dominant long period waves which bring sand back onto the beaches after the scouring effect of the short period waves of winter storms.

It has been claimed that the bar now closes sooner than when the water built up high enough to break naturally and there was sufficient scour to produce a deep and wide channel allowing the accumulated sand to return to the sea, but there is no record of opening and closing dates before 1955. However it is clear that the damming of the Denmark River in 1959/60 reduced the flow of water into the Inlet and presumably contributed further towards reducing the scouring effect of water flow through the channel. The bar opening is discussed below in Section 8.1.

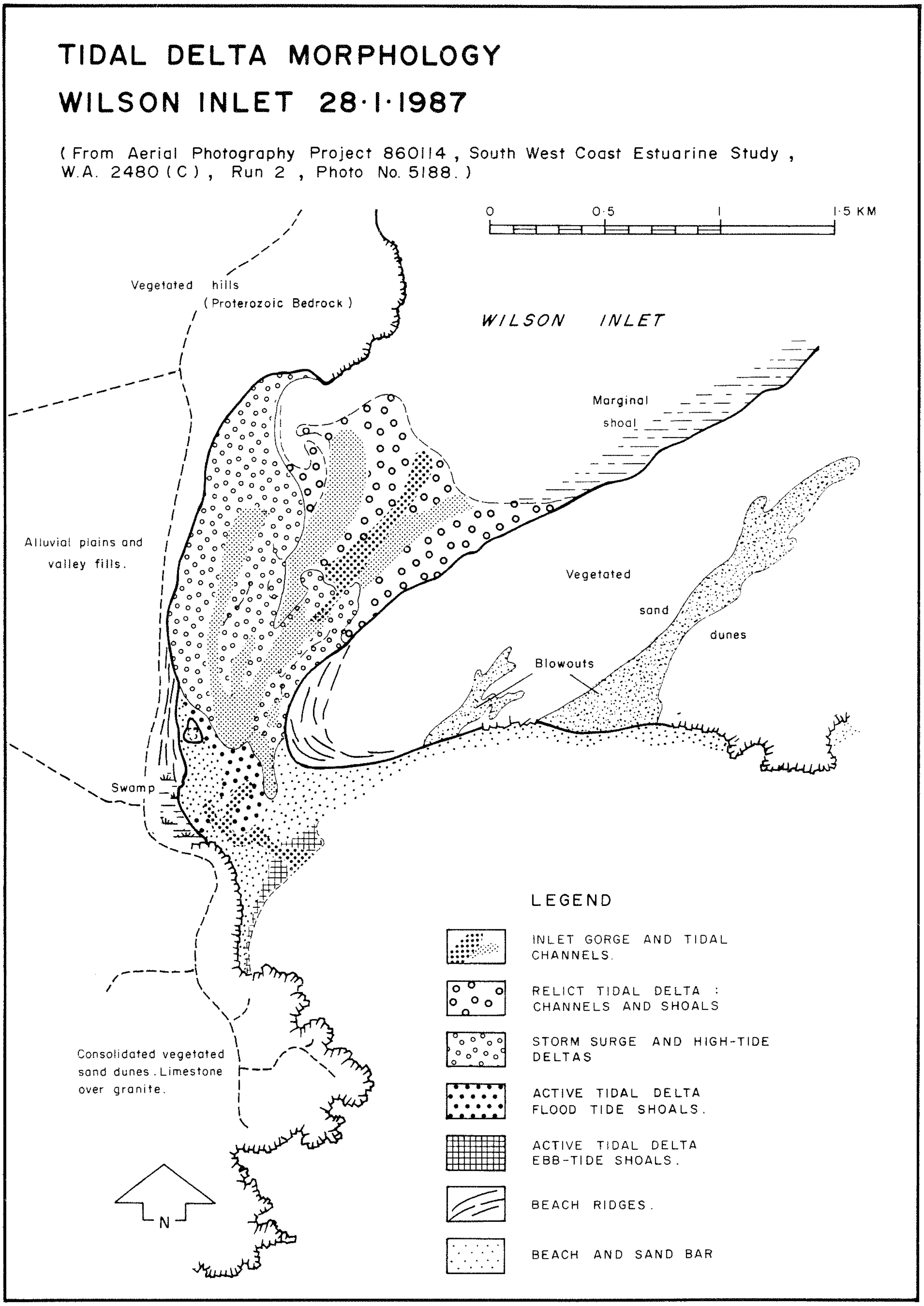


Figure 3.12 Wilson Inlet. Tidal delta morphology - 28.1.1987. (I. Eliot)

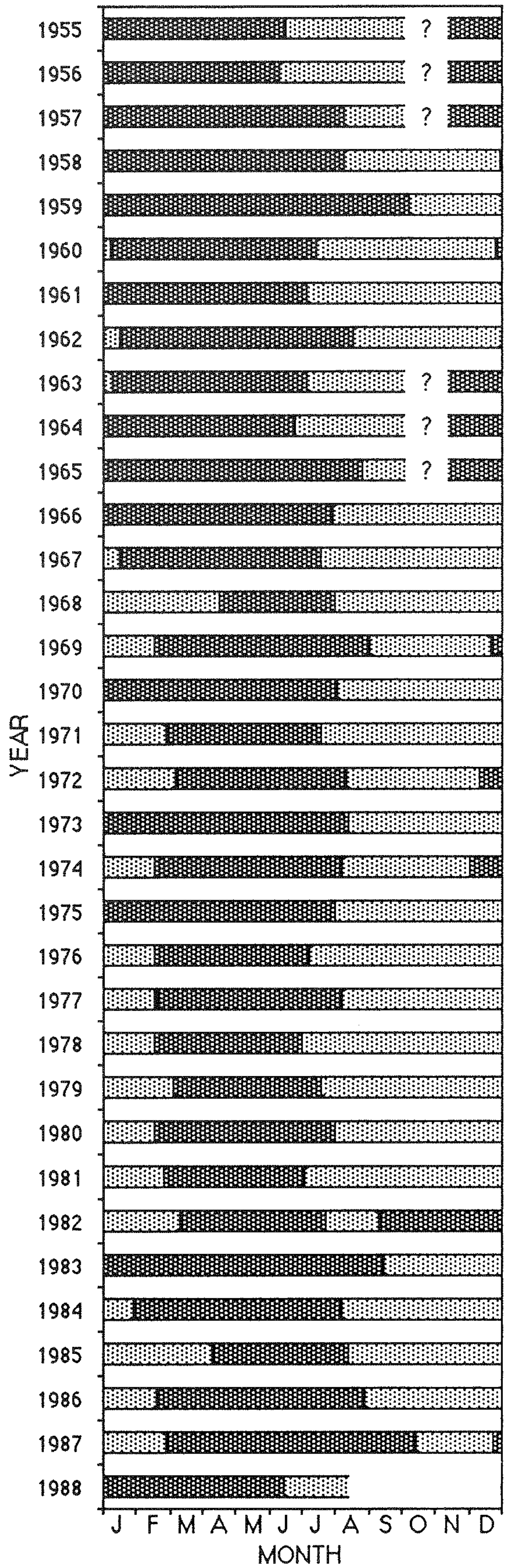


Figure 3.21 Wilson Inlet. Reported opening and closing of the bar. Question mark indicates unknown closing dates. closed ▩ , open ▤ . (WA Water Authority)

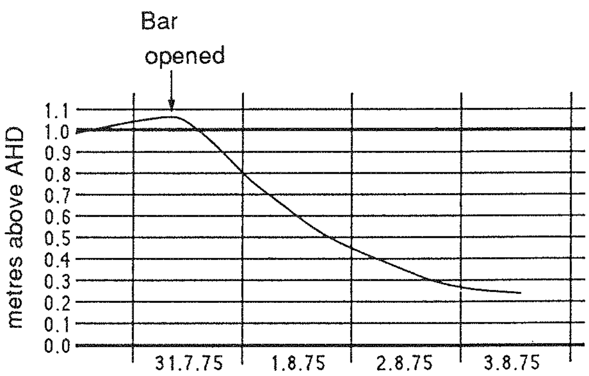


Figure 3.22 Water levels in Wilson Inlet after bar opening on 31.7.75. (Public Works Department)

3.3 WATER DEPTHS

A hydrographic survey was made of the Inlet in 1983 (Figure 3.31). The average depth of the Inlet is about 1.8 m below mean sea level (MSL). There is a large central basin more than 2 m deep and the maximum depth is 5 m. Much of the tidal delta area is out of the water when the bar is open and the extensive shallows of Morley Beach at the eastern end are often uncovered when the bar is closed in summer.

Water level in the Inlet now varies about 1.5 m. When the bar is open water level is normally close to MSL. When it is closed evaporation can cause the level to fall 0.5 m below MSL by the end of summer, as at the end of April 1988. Evaporation averages about 0.8 m from December to May, when there is generally negligible flow to the estuary. With reduced evaporation and direct rainfall onto the Inlet in April-May the level rises again even before the first effective river flow in June (E in Figure 3.32). Major river flow causes the level to rise rapidly to 1 m above MSL (F and G in Figure 3.32). The heavy rains of May 1988 raised the level from -0.5 m to 1.01 m in six weeks and the bar was broken on 14 June.

When the bar is broken, the water level falls about 1 m and about one third of the water in the estuary is lost to the sea. When the bar was breached in 1982 at 1.1 m an estimated 48 x 10^6 m^3 of water was lost from the estuary, this was about one third of the volume before the break. However, following the low winter rainfall of 1987 the bar was opened on 13 October 1987 when Inlet water level was only 0.77 m above MSL and barometric pressure was low. Water level only fell to 0.5 m in 4 days and there was a much smaller loss of estuary water.

When the bar is open the estuary is tidal, however tidal exchange is so restricted by the small channel to the sea that the daily, astronomic tides are less than 10 cm in the Inlet, only 10% of the ocean tide. The greatest changes in water level, and consequent exchange of water with the ocean are caused by

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Figure 3.31 Wilson Inlet. Bathymetry, July - September 1983. Depths in metres. (PWD - 55452-1)

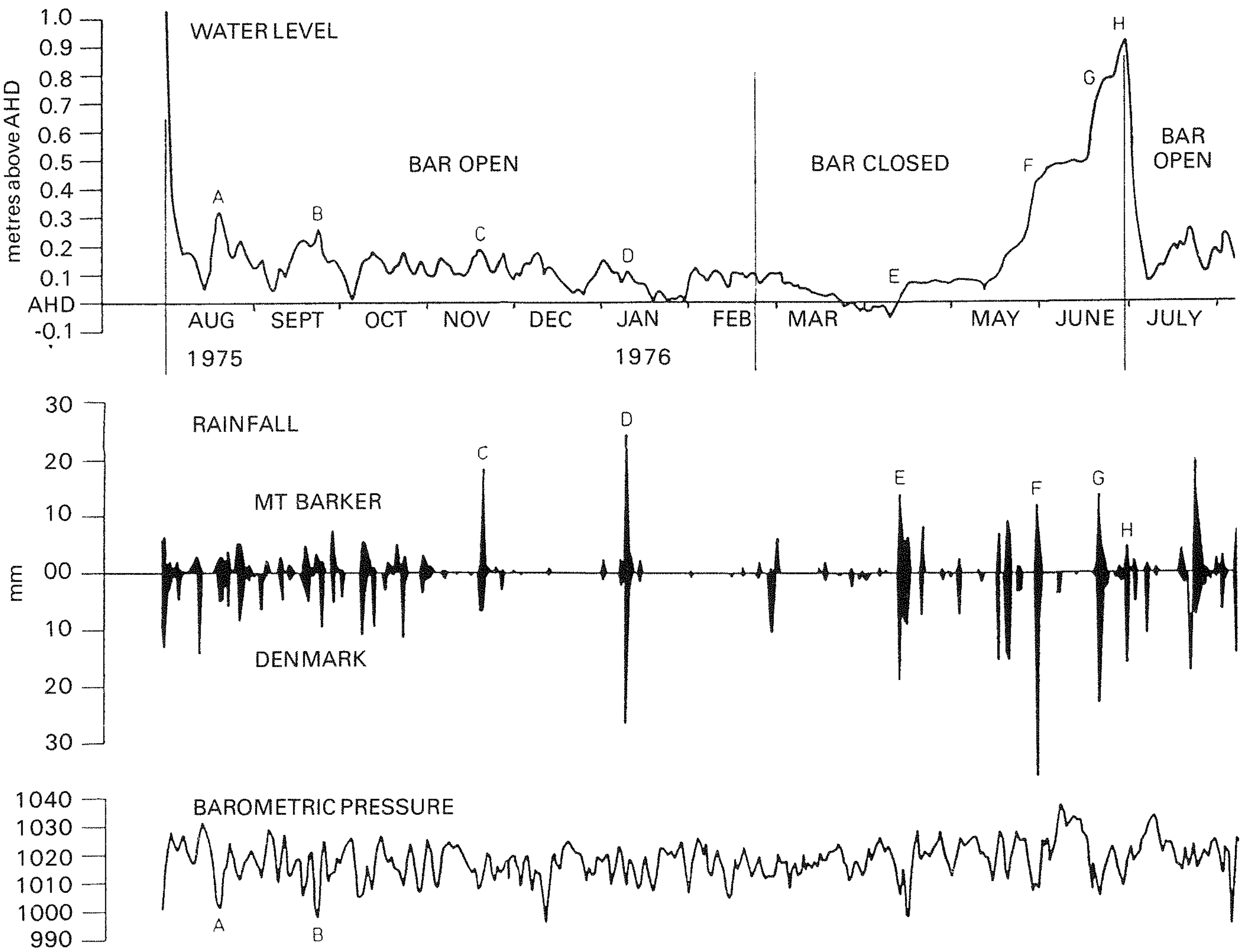

Figure 3.32 Daily non-tidal water levels in Wilson Inlet, rainfall at Mount Barker and Denmark, barometric pressure at 9am, August 1975 to July 1976. (Public Works Department)

changes in barometric pressure: meteorological tides (A and B in Figure 3.32). With the passage of a low pressure system, and the associated rise in sea level, the level in the Inlet may rise 0.3 m or more over a period of days and fall again when pressure rises again. Heavy rain over a short period also causes a corresponding rise in water level. Strong winds along the long fetch of the Inlet cause water level to rise and fall up to 0.2 m at opposite ends of the Inlet, a set up or seiching effect with periods of about 55, 90 and 250 minutes (PWD). Winds can also cause waves up to 1.2 m in height.

3.4 BOTTOM SEDIMENTS

A core sample from the deep basin produced dark grey, sandy, silty, sparsely fossiliferous mud in the first 50 cm, and from 50 cm to 83 cm below the surface a mottled pale to dark grey muddy sand with a small proportion of fragments (Treloar, 1977). The basal sediment type is a transgressive phase deposit, overlain by mud in the deeper parts of the basin. The surface sediment of the deeper areas has a high water and organic content. The sediments of the marginal shallows are sandy , varying in coarseness and the silt and shell content with the location. There are coarse shell deposits south of Pelican Island, dominated by cockles (*Katelysia*). Analyses of three sediment samples for their physical properties and nutrient content are listed by Lukatelich *et al* (1984). The nutrient content of the sediments was well correlated with the type of sediment, with fine silty sediments having the highest nutrient concentrations.

A core taken by Treloar (1977) near the inner edge of the flood tide delta, near Poddy Point showed the following:

> 0-138 cm. Skeletal-quartzose sand: skeletal fragments decrease upwards, becoming scarce in upper 35 cm. Beneath upper zone there is a moderate % of marine skeletal

fragments (bryozoans, sponges, etc). The sediment coarsens upwards reflecting shoaling, and skeletal fragments are mainly derived from estuarine fauna; the absence of marine fragments reflects a lower % introduced, and reworking into deeper water.

This core was interpreted as evidence of an initial high influx of marine sediment during the formation of the delta, which decreased as the mouth became constricted and barred, followed by reworking of the finer sediment and growth of the delta into the Inlet.

There are no data on the current rate of sedimentation in the Inlet. Observations at Beaufort and Stokes Inlets indicate that the rate of sediment transport by rivers has increased dramatically following clearing in the catchments. This may not yet have had any great effect on Wilson Inlet, though the more saline soils and steeper gradients of the upper Hay catchment are more subject to erosion than those of the Denmark River catchment. This is a question that will need to be reviewed when current studies on catchment erosion and sediment transport have progressed.

3.5 WATER CHARACTERISTICS

Hydrological data are recorded by Spencer (1952), Rochford (1953), Lenanton (1974a), Lenanton and Edmonds pers. comm., Lukatelich *et al* (1984,1986 and 1987).

SALINITY Wilson Inlet water is always brackish and salinity ranges from about 12 to 20 ppt (parts per thousand, sea water is 35 ppt) in spring and early summer, then rises rapidly to 20 to 30 ppt before the first rains (Figure 3.51). Strong winds usually keep the water well mixed and the salinity uniform within one ppt throughout the Inlet, both from end to end and from top to bottom, except close to the bar when it is open and near the mouths of the rivers when they are flowing. Some stratification occurs when the bar is open and a thin layer of high salinity water lies in deeper parts.

The estuarine reaches of both the Denmark and Hay rivers can flow fresh in winter. When there is low river flow the water is sharply stratified, with 1 m or less of almost fresh water lying over water of 10 to 30 ppt.

TEMPERATURE The temperature of Inlet water ranges from 10°C in winter to 24°C in summer (Figure 3.52). River water temperatures are somewhat higher. There is little stratification and only minor differences from place to place, except that more extreme temperatures are experienced in the shallows and in the river water. Surface and deep river water temperatures may differ by several degrees when the water is stratified.

LIGHT Inlet water is generally clear and light penetration good, though it may sometimes be reduced in summer. In 1982-1983 the Secchi depth always exceeded the depth of the water indicating good light penetration to the floor of the estuary.

OXYGEN Inlet water is well oxygenated, close to or above 100% saturation at the surface nearly all year. Supersaturation is attributed to photosynthetic oxygen production by seagrass, because

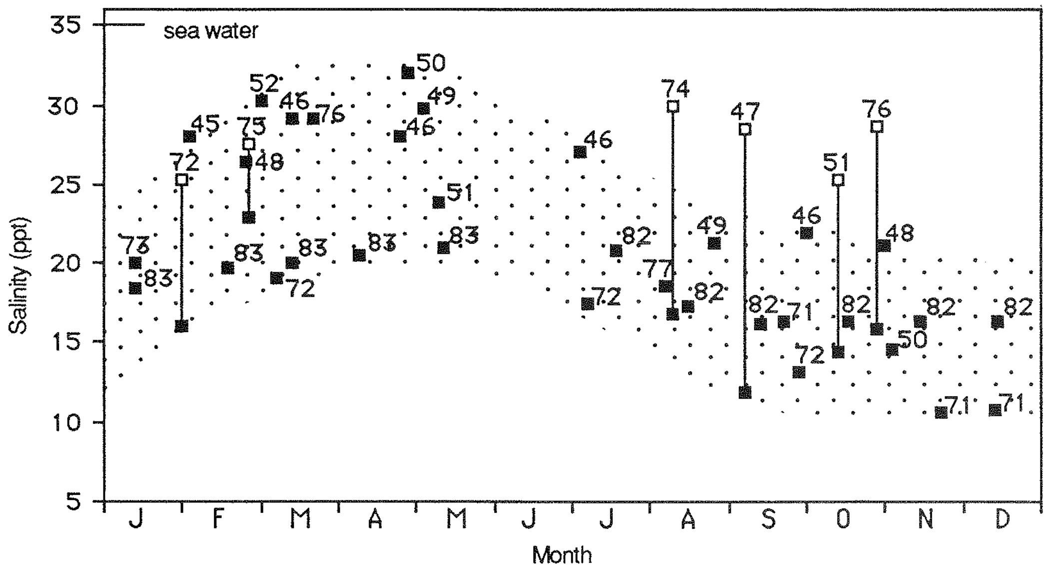

Figure 3.51 Salinities in Wilson Inlet near Pelican Island between 1945 and 1977. Surface salinity ■ , bottom salinity □ when different from surface. Figures - dates of observations. Stippled area - envelope of observed surface salinity. (Spencer, 1952; Rochford, 1953; Lenanton, 1974a; Lenanton and Edmonds; Lukatelich).

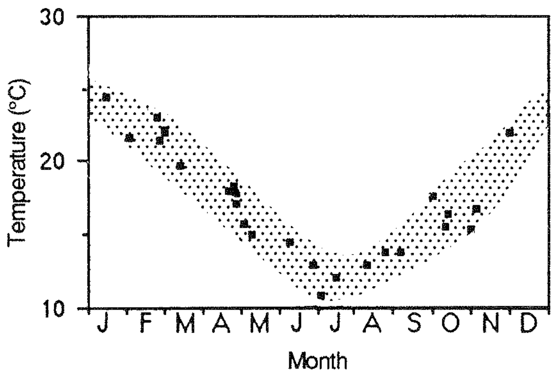

Figure 3.52 Wilson Inlet. Surface water temperature taken in the centre of Wilson Inlet between 1946 and 1985. (Spencer, 1952, Lenanton and Edmonds, 1975 and Lukatelich, 1986)

phytoplankton is sparse. There may be minor deoxygenation of bottom water when there is stratification. The deep water of the rivers is probably deoxygenated when it is stratified.

POLLUTION The only evidence of pollution is the accumulation of small quantities of rotting weed on some beaches in summer. This is not new. It is caused by the excess of plant nutrients, fertilizers in the wrong place - in estuary water.

Considerable quantities of pesticides are applied to potato crops, and concentrations are high in the soils, but as yet there are no data on amounts entering the estuary.

3.6 NUTRIENTS

The nutrient status of Wilson Inlet is the key to its present potentially eutrophic condition. In 1982-1985 this was studied for the Department of Conservation and Environment by Lukatelich *et al* (1984, 1986). The following account briefly summarises the main findings of the study, but the two Bulletins should be consulted for a detailed assessment of the nutrient status of the estuary and of the degree of eutrophication.

The study showed that nutrient levels were low in the water and that there was no evidence of an increase in concentration as compared with data for 1945-1952 (Spencer, 1952; Rochford, 1953). Phosphorus appears to be the principal nutrient limiting plant growth in the estuary. Phosphate is the form most readily available to plants, and concentrations of this were very low, the maximum recorded being 6 µg/l. There is generally an excess of nitrogen. Nitrate and ammonia, the forms of nitrogen most readily available to plants, were also low: nitrate nitrogen less than 10 µg/l most of the time and ammonia nitrogen about 30 µg/l. Total phosphorus concentrations (a mean of 52 µg/l) and total nitrogen (1028 µg/l) were similar to those in the Swan River estuary and much lower than in Harvey Estuary. Plant plankton was sparse and the chlorophyll levels were low, a further indication of the small amount of available nutrients present in the water.

The seagrass *Ruppia* was abundant and acts as a major bank of plant nutrients (Figure 3.61). It gains its nutrients mainly through its roots from the sediment. There was no significant nutrient enrichment of the bottom sediment. Nutrient concentrations in the water column were correlated

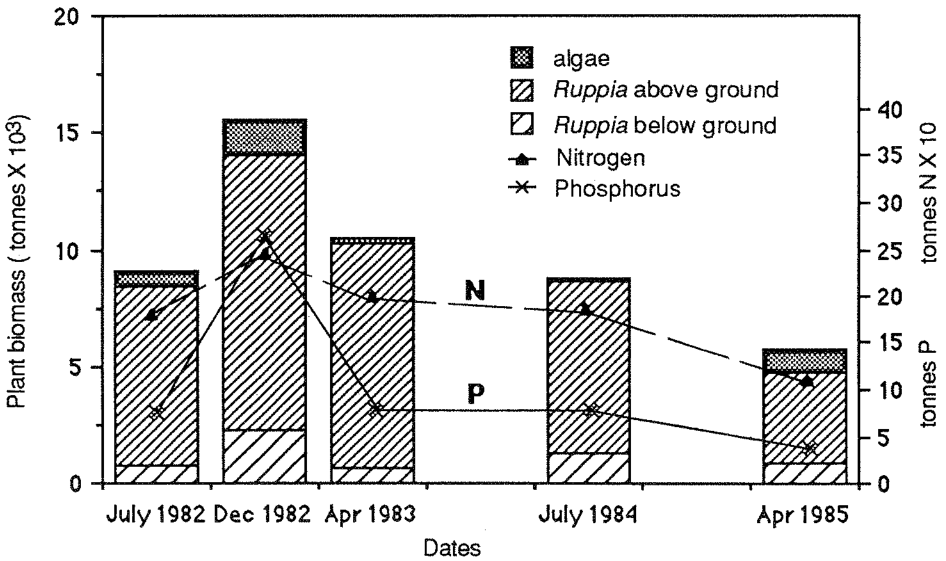

Figure 3.61 Wilson Inlet. Tonnes (dry weight) of Nitrogen and Phosphorus in *Ruppia* and algae in Wilson Inlet between July 1982 and April 1985. (Lukatelich, 1986)

Wilson Inlet. The western shore. Granite boulders on Honeymoon Island.

Irwin Inlet. The inlet channel, bar and Quarram Beach. January 1988.

Irwin Inlet. Western shore of the inlet channel with salt marsh and eroding bank.

Wilson Inlet. Excavating the cut through the bar, 14 June 1988.

Irwin Inlet. Digging the cut through the bar, 31 May 1988 (Photo B. Gallash).

Kent River fringing vegetation, *Juncus, Melaleuca incana, Agonis juniperina.*

Wilson Inlet. Two days after breaching the bar, 16 June 1988.

Hay River. High tree-clad banks and a cleared eroding bank in the distance.

Parry Inlet. The inlet channel from the mouth, mats of floating green algae.

with the concentrations of extractable phosphate and nitrate in the sediment, suggesting that the concentrations in the water column are to some extent determined by exchange between water and sediment.

NUTRIENT SOURCES The rivers and streams flowing to the Inlet were monitored for nutrients over the periods of main river flow in 1982 and again in 1984. Nutrient concentrations were much lower in flows from the Denmark and Hay rivers than from catchments in the southern higher rainfall areas, much of which are cleared for agriculture, have high drainage densities, large proportions of leaching sandy soils, and are more heavily fertilized. These sandy soils have a low absorbtive capacity for phosphorus and are probably already saturated so that the phosphate content of any fertilizer will be readily released to drainage.

Total phosphorus concentrations were low relative to those of eutrophic situations elsewhere. They were much higher in flow from the southern catchments than from the northern agricultural areas. Phosphate levels were only high in water from the small Denmark Agricultural Research Station catchment. The very low phosphate levels found in Denmark and Hay river water is important because these two catchments comprises 89% of the Wilson Inlet catchment.

Phosphorus concentrations in river water did not differ greatly between the two seasons studied, but with the higher rainfall and river flows in 1984 the load (tonnes) of nutrients discharged to the Inlet were much greater than in 1982, as shown in Figure 3.62. The 1984 rainfall was about average and the riverflow and nutrient loads may also be regarded as the average annual input to the estuary. The load of 19 tonnes of phosphorus is not considered unduly high for a body of water such as Wilson Inlet.

The difference between the two years is particularly striking with respect to nutrient input from the two large rivers. The Denmark and Hay River catchments contributed 1.4 tonnes of phosphorus in 1982 and 8.5 tonnes in 1984 as shown in Table 3.6. In 1984 flow in the Denmark River was 4.9 times that of 1982, but the phosphorus load was 6.5 and the nitrogen load 9.1 times higher. In the Hay River in 1984 flow was 3.7, the phosphorus load 5.9 times and the nitrogen load 12.7 times that of 1982. These increases were probably largely the result of greater flows from the lower rainfall, agricultural areas of the two catchments, the flows being contributed by much larger areas of cleared land. (Runoff to the Denmark River was 16 mm in 1982 and 84 mm in 1984.) From the smaller, higher rainfall catchments, the 1984 flows and nutrient inputs were only about double those of 1982.

NUTRIENT LOSS The main nutrient loss to the ocean occurs following the bar opening. The amount lost depends on the volume of water discharged and

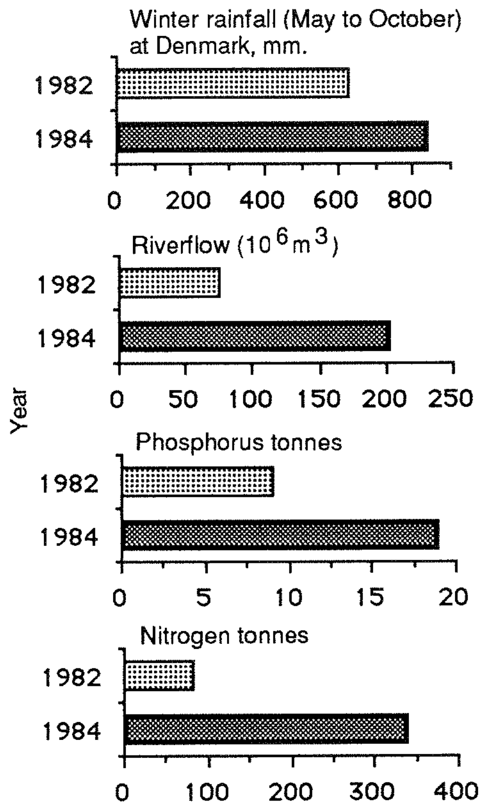

Figure 3.62 Comparison between 1982 and 1984; rainfall, riverflow, phosphorus and nitrogen levels discharged to Wilson Inlet. (Lukatelich, 1984, 1986)

the nutrient concentration in the estuary water at the time. Further loss with tidal exchange between ocean and estuary water depends on how long the bar remains open, the differences in nutrient concentration between ocean and estuary water, and the extent to which they mix. The differences are usually small and little nutrient is lost in this way. While the bar is open there can be further loss from any river flow.

Table 3.6 Nutrient loads (tonnes) of some rivers flowing to Wilson Inlet in 1982 and 1984.(Lukatelich, 1984, 1986)

River	1982 Tot P	1982 Tot N	1984 Tot P	1984 Tot N	Discharge ($10^6 m^3$) 1982	Discharge ($10^6 m^3$) 1984
Denmark R	0.4	6.1	2.6	55.3	11.0	53.5
Scotsdale Bk	0.8	7.6	1.8	13.9	10.0	17.0
Hay R	1.0	14.4	5.9	182.8	23.3	87.1
Sleeman R	3.3	2.5	3.6	2.5	11.3	12.8
Cuppup R	1.0	6.6	2.2	29.5	4.4	13.4
Other	2.4	21.5	2.7	33.1	14.3	18.7
Total	8.9	81.6	18.7	339.3	74.3	202.7

There is significant net retention of nutrients in the Inlet: 9 tonnes of phosphorus (half the river input) and 216 tonnes of nitrogen were estimated to have been retained in 1984. To what extent this represents an increase in nutrients available for plant growth is not clear. Nitrogen is lost to the atmosphere by microbial denitrification and phosphorus becomes fixed in the sediments. Under the present well oxygenated conditions the sediment has an enormous capacity to take up excess phosphorus. The sediment phosphorus is available to the rooted seagrass, but it only becomes available to algae in large quantities if oxygen is deficient, when the sediment phosphorus is released to the water.

EUTROPHICATION The large amount of *Ruppia* is the one major symptom of eutrophication of the estuary. There has probably been some increase in the amount of *Ruppia* in recent years, however it is clear from the accounts of old-time residents, especially fishermen, that aquatic plants (*Ruppia* and possibly the charophyte *Lamprothamnium*) have fluctuated greatly in abundance over the last 50 years or more and that they were plentiful even before the increased use of superphosphate from the 1950s. Environmental conditions have fluctuated markedly, particularly the extent of freshwater flushing, and there have been great variations in the populations of fish (see Figure 7.3), waterbirds and the invertebrate fauna (eg mud oysters and mussels). Such periodic fluctuations are to be expected in an ecosystem subject to the salinity extremes experienced in Wilson Inlet, especially following wet winters or occasional summer floods such as that of 1939 which killed the mud oysters. Moreover the natural ecosystem has been disrupted by the premature opening of the bar and consequent reduced flushing, and possibly shortening of the time the bar remains open.

However, the estuary is currently in a biologically healthy condition. It is mildly eutrophic (mesotrophic) as judged by the dissolved nutrient concentrations, which have not increased since the 1950s, when compared with the data of Spencer (1952) and Rochford (1953). The *Ruppia* uses the excess nutrients and stores them.

Clearly this is a potentially unstable condition the balance of which could be disturbed by a significant increase in nutrients retained in the estuary, either because of reduced loss to the sea or from increased input, especially of phosphate. Greater nutrient enrichment will favour the algal epiphytes which grow on *Ruppia* in summer and reduce the light available to the plants for photosynthesis. An excess of epiphytes could kill the *Ruppia* and release its load of nutrients to the water. The decomposing plants would create a biological oxygen demand (BOD) which would exhaust the oxygen in the bottom water. Under such anoxic conditions phosphorus would be released to the water from the sediment store and could fuel a bloom of phytoplankton and large algae similar to that in the Peel-Harvey estuary. These would be a far greater nuisance than the *Ruppia* they replaced. The implications for management are discussed below in Section 8.1.

4 IRWIN INLET — PHYSICAL FEATURES

The estuary includes the Inlet, short stretches of the Bow and Kent rivers and the long channel to the sea (Figure 4.11). The Inlet is shallow and when the bar is closed water level varies over a metre. The extensive shallows and river bars may be exposed when the level falls with evaporation. There is also a considerably greater range of salinity than in Wilson Inlet, from fresh water to sea water, or slightly hypersaline when the bar is closed in summer. The shores are sandy except for two small granite outcrops on the northern shore east of the Bow River and one on the south western shore. The south eastern shore rises steeply to well vegetated dunes. Much of the eastern and northern shores and part of the western shore are marshy. Boats are launched from a ramp on the shallow western shore.

4.1 LANDFORMS

RIVERS The Kent River is estuarine and navigable for about 5 km through densely vegetated sandy lowlands, with some coffee rock, to where it disappears into Owingup Swamp. Kent River is about 2 m deep. The Bow River is estuarine for about 2 km through similar sandy lowlands and swamps and is up to 5 m deep. Both rivers have dark tannin-stained water. Both are barred at their mouths by deltas that are part of the wide marginal shallows of the Inlet, and in a dry summer they may be cut off from the Inlet.

INLET The Inlet is elongate, 5.5 km north east to south west and 2.5 km wide, and is 10.2 km^2 in area (Figure 4.11). The central basin is about 2 m deep throughout. It is surrounded by shallow, marginal sandflats, up to 500 m wide. The northern shallows are more muddy. A private boat channel has been dredged through them. There is a small granite island in the shallows of the south-western corner of the Inlet. There has not been a depth survey of the Inlet.

INLET CHANNEL and MOUTH The Inlet is separated from the sea by low coastal dunes that are 1.5 km wide at their narrowest point. The channel through these is nearly 2 km long, 200-300 m wide and 1.5 to 2 m deep, with a maximum depth of 3.5 m at the northern end (Figure 4.12). It shallows towards the seaward end where the bottom is beach sand, though the channel may be scoured to 2 m when the bar is open. Half way down the main channel there is a low, 400 m long, island with swamp vegetation. Flow channels run on either side of the island and the main channel is generally close to the western bank, but its position varies greatly; it is 2 to 5 m deep. The banks are largely

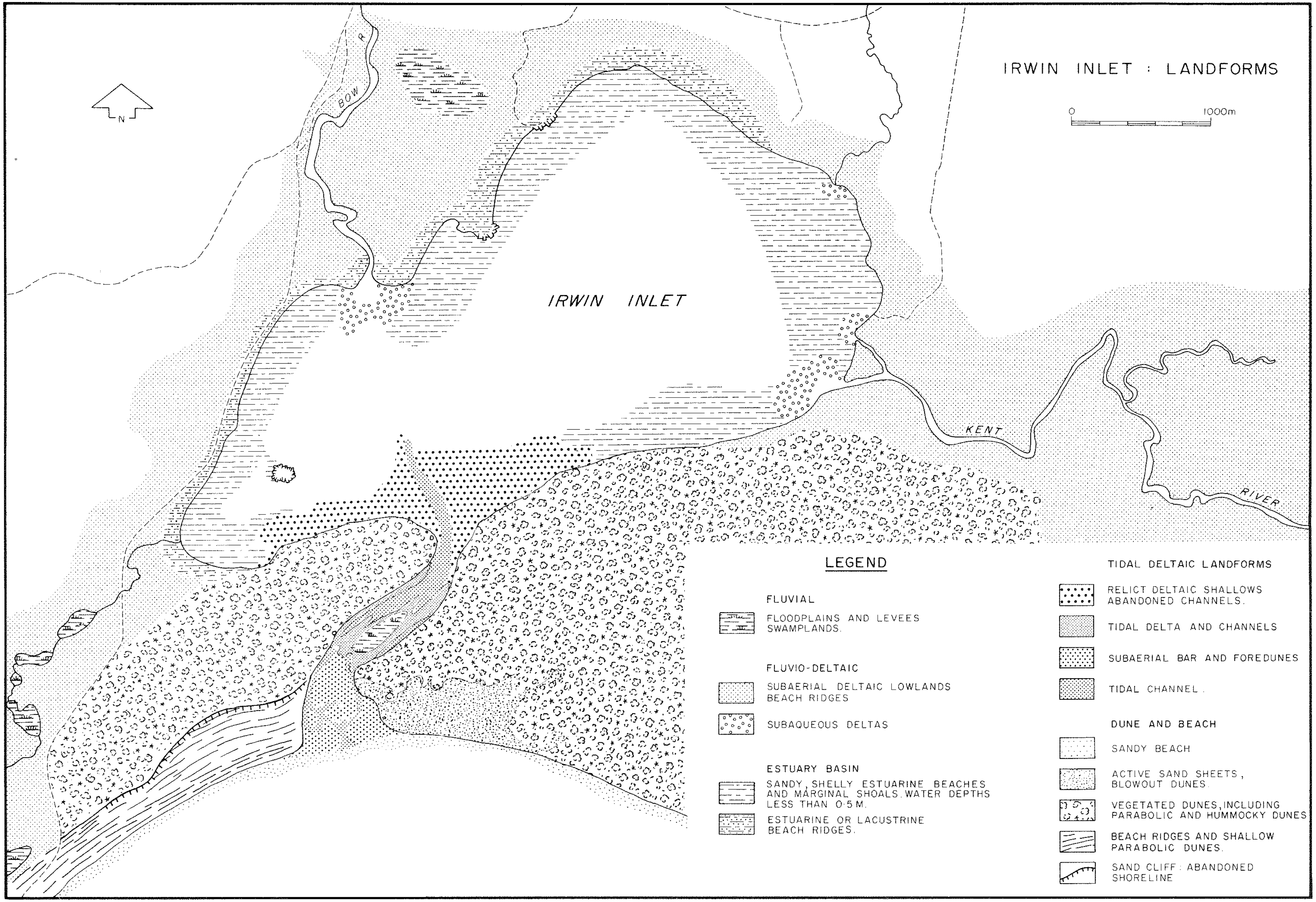

Figure 4.11 Irwin Inlet: Landforms. (I. Eliot)

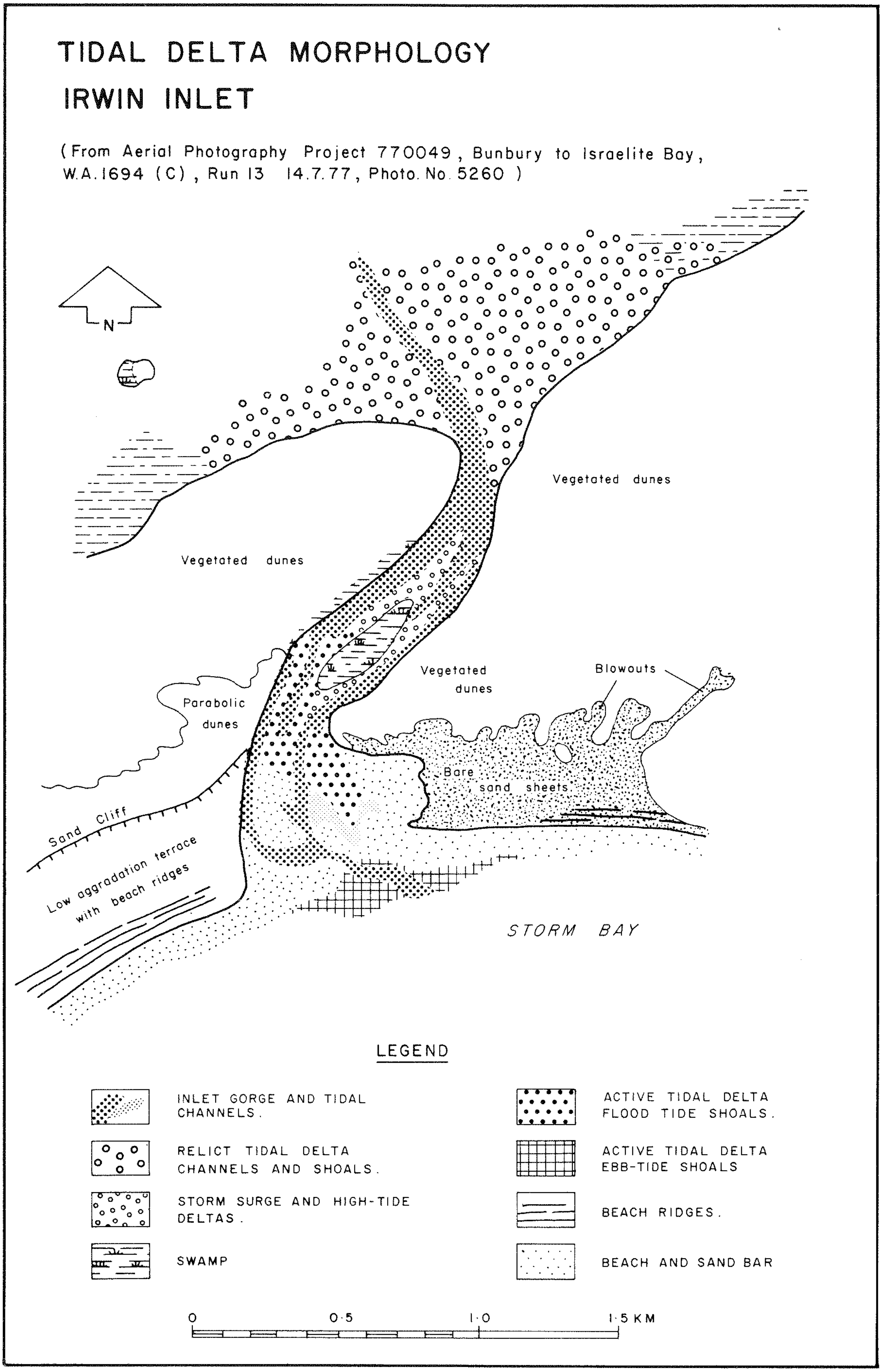

Figure 4.12 Irwin Inlet. Tidal delta morphology - 14.7.77. (I.Eliot)

unconsolidated sand with some soft rock in places on the west bank, and there is evidence of erosion of the bank and the low rush beds that border the channel in places.

The channel discharges to the sandy shore of Quarram Beach. The beach is devoid of rock and in consequence the position of the mouth is unstable. It is evident that in recent times the channel and mouth have been migrating westwards. On the western side, the dunes are about 10 m high and though well vegetated they have collapsed steeply to the shore where flow in the channel has cut into them and where waves attack them when the bar is opened. To the east of the mouth, fronting low vegetated dunes, there is a wide area of bare sand through which the channel sometimes flows as it winds its way to the sea. A low scarp on the western dunes 500 m from the beach and a series of low beach ridges suggest that the mouth may have been considerably west of its present position quite recently.

SEDIMENTS The eastern marginal shallows are sand with little fine sediment and near the western shore there is a larger silt-clay component with shells. The sediment of the basin is sandy silt with a high water content, there are quantities of oyster shells on the bottom.

4.2 THE BAR

The bar is 150 m wide; it is part of the open shoreline of Quarram Beach and only about 1 m above sea level when closed. A flood tide delta extends a further 500 m into the channel. The bar contains pale yellow moderately well sorted medium to fine sand containing approximately 90% quartz and 10% skeletal remains. The sand behind the bar can be dangerously thixotropic, a semi liquid-mass into which any heavy object can disappear.

The bar opens naturally with enough rain, in June to August, or when the water tops the bar it is breached by fishermen or by surrounding landowners to prevent flooding. The record in Figure 4.2 gives a reasonably accurate picture of the history of bar opening; some of the dates have been interpolated on the basis of recollections and rainfall records. The bar sometimes remains open through summer, as between 1983 and 1986 after it had been opened by local fishermen. The Shire opened it again in 1987. In 1988 it was dug about 40 m from the western shore, but it rapidly swung to the west cutting a channel 110 m wide. The estuary drained to sea level and became tidal within 20 hours of the cut being made. Once the bar is open the flow takes various routes across the bar, often swinging from west to east behind the beach and parallel to it.

When the bar is open the estuary is tidal and the daily tidal range in the Inlet is 30 cm or more when the bar is wide open.

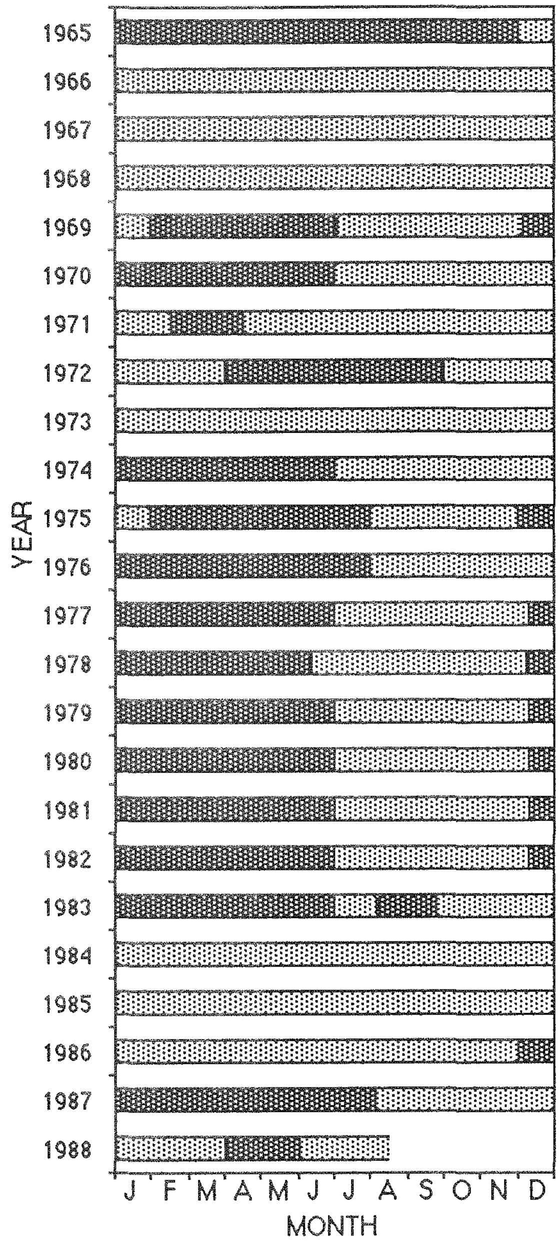

Figure 4.2 Irwin Inlet. Reported opening and closing of the bar. closed ▩ , open ▒ .

4.3 WATER CHARACTERISTICS

There are only limited data on the hydrology of the estuary and more data are needed before it can be adequately characterised.

SALINITY The salinity varies from fresh in winter to around sea water when the bar is open and there is no river flow. It may be more salt than the sea when exchange with the sea is restricted in summer, over 40 ppt. The water in the Inlet is normally well mixed, but when the rivers first flow it may be stratified in deeper parts, river water lying over the more saline Inlet water with little mixing (Figure 4.3), or when the bar breaks sea water flows in under the Inlet water. Water in the estuarine part of the Kent river appears to exchange fairly freely with Inlet water so that the salinities are similar when river flow has ceased. Exchange between the Bow and the Inlet appears to be more restricted, the water less well mixed and stratified at times.

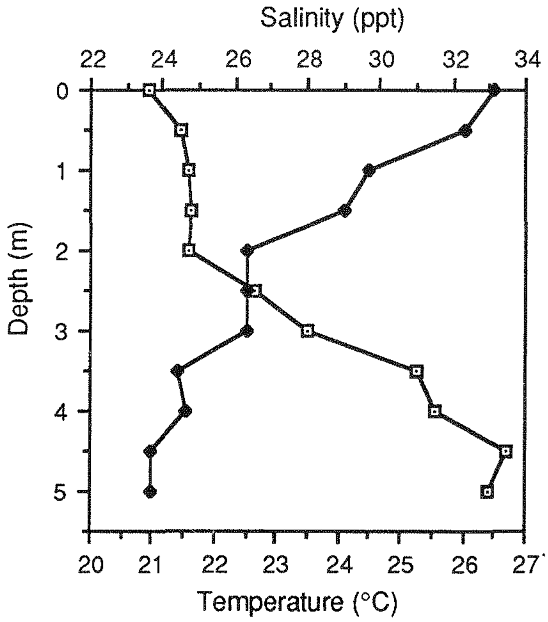

Figure 4.3 Irwin Inlet. □ Salinity and ◆ temperature profile in Irwin Inlet one kilometre from the sea bar. 11 March 1987. (J. Bowyer)

TEMPERATURE Water temperatures are probably similar to those in Wilson Inlet with slightly greater extremes because of the shallower water.

LIGHT Inlet water is often tannin-stained and the river water even more so, especially the Bow River. The water is nevertheless generally fairly clear except when wind stirred.

OXYGEN The water is probably generally well oxygenated. When there is stratification the more saline bottom water may become partially deoxygenated.

NUTRIENTS The few records show total phosphorus figures ranging from 10 to 50 µg/l in the Inlet and the Kent River and up to 70 µg/l in the Bow River, somewhat lower than in Wilson Inlet.

5 PARRY INLET — PHYSICAL FEATURES

This, the smallest of the three estuaries, might almost be called an evanescent estuary because there are times when there is little or no water in it. In consequence it is often an unfavourable environment for the aquatic fauna and flora, which may be inundated with fresh water, doused in hypersaline water or exposed to the air. It has an area of only 1.4 km^2, a short estuarine stretch of the Kordabup River, and a long, narrow channel to the sea (Figure 5). The swamp on the eastern shore covers almost as large an area as the Inlet itself.

5.1 LANDFORMS

RIVER The Kordabup River is the only river flowing to the estuary. It is estuarine for about 2 km where it borders the north side of the swamp and from which there are drainage channels to it. Several drains discharge to the western shore.

INLET The Inlet is a shallow basin with a slightly deeper channel along the eastern shore. The average depth is about 0.5 m. It dries out in some summers, except for the channel, and vehicles are driven across it. The Inlet is surrounded by low, sandy, rush covered shores and has a low rush covered island. There is a small granite outcrop at the entrance to the inlet channel. The bottom sediment is mud over clay.

INLET CHANNEL The inlet channel is nearly 2 km long, in a north west to south east direction. It is only about 20 m wide where it leaves the Inlet, but widens to over 100 m half way to the sea and then narrows again approaching the bar. The maximum depth is about 2.5 m below sea level. The northern half has low sandy shores with small rush covered islands and swamps. Towards the seaward end of the channel the eastern shore has a series of low beach ridges for some distance between the channel and the dunes, while the western shore is cut into dunes about 10 m high with steep, sparsely vegetated slopes to the channel. It is evident that the channel has eroded the western dunes and that the mouth has progressed south west in recent times. The location of the flow channel varies and may approach either bank; it is up to 2 m deep, with shallow banks alongside it.

5.2 THE BAR

The bar is low, only about 1 m above AHD and part of the beach. There is no rock near the bar. When the channel opens it flows close to the south western shore but soon migrates north east behind the beach and may flow to the sea anywhere within 300 m from the south western shore. The bar opens naturally or is opened by the Shire in winter (July to September) to prevent flooding of the road along the western shore of the Inlet and of pastures and potato paddocks. It may close and open again several times during the winter. The bar now normally closes each summer but is reported to have remained open for five years in the early 1940s. It is usually opened midway across its width so as to prevent erosion of the south western shore. It cuts a channel about 100 m wide and 2 m deep.

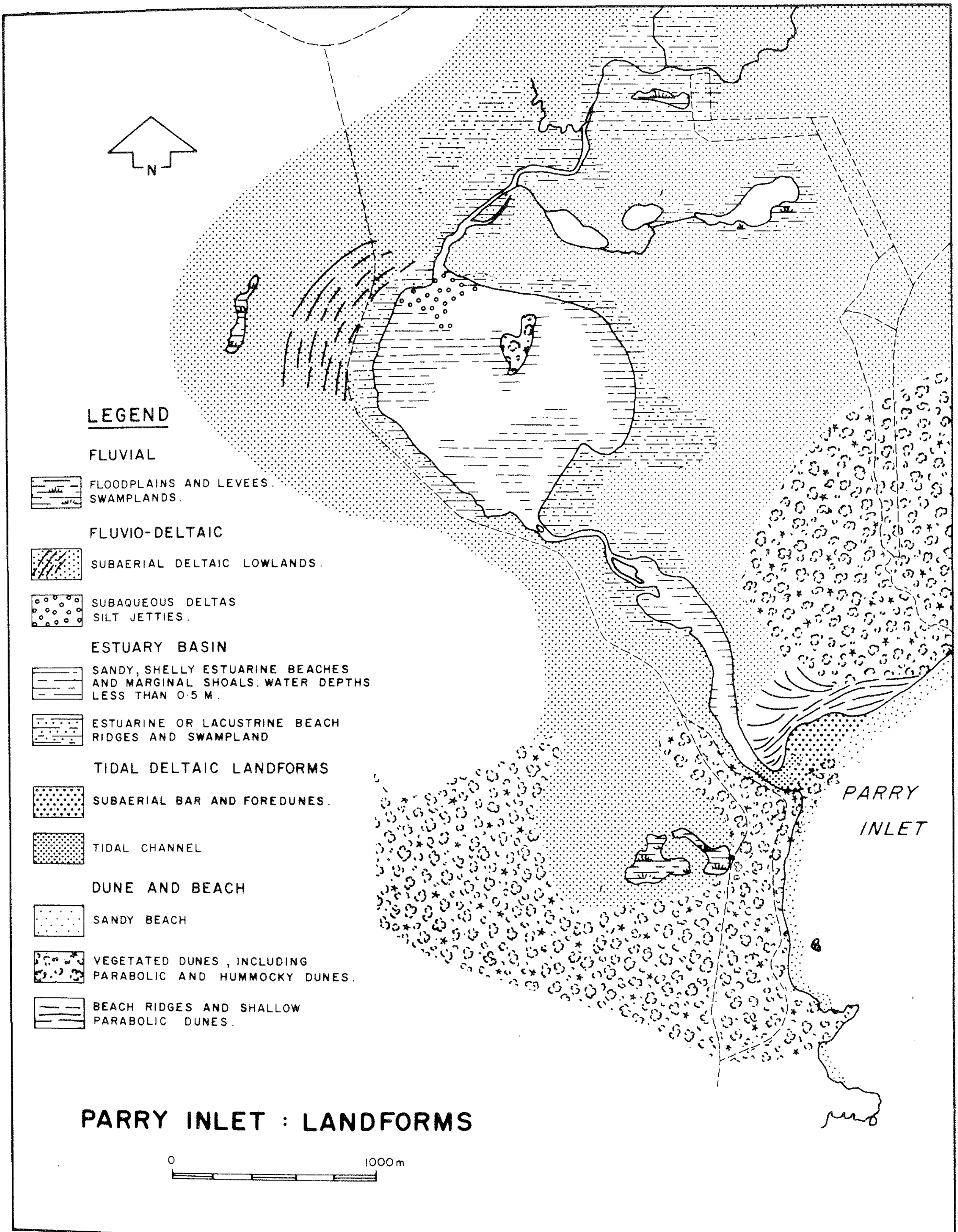

Figure 5 Parry Inlet: Landforms. (I. Eliot)

5.3 WATER CHARACTERISTICS

SALINITY The few samples that have been taken show that the water varies from almost fresh to hypersaline, probably much more saline than the highest recorded (40 ppt) in summer.

TEMPERATURE There are no data on water temperatures, but these are likely to be similar to those in Irwin Inlet in winter. As the Inlet dries up in summer they probably become higher than in Irwin Inlet.

There are no data on light and oxygen. The water is brown, tannin-stained. Such a shallow body of water is probably well oxygenated.

There are no data on nutrients.

6 ESTUARINE VEGETATION

Lukatelich *et al* (1984 and 1986) reported on the phytoplankton and other aquatic plants found in Wilson Inlet in 1982-83 and 1984-85. The aquatic vegetation of the three estuaries was surveyed by M. Cambridge in October 1976. J. Chambers made a more detailed survey of the estuaries and the surrounding vegetation in January 1987 and 1988 and the following is substantially her report. Figures 6.11, 6.12 and 6.13 show the vegetation of the areas around Wilson Inlet, Irwin Inlet and Parry Inlet respectively.

6.1 AQUATIC PLANTS

Wilson Inlet. Table 6.11 lists the genera of phytoplankton taken in 1982-83. 'On all occasions diatoms were the dominant microalgae. From July to January, *Chaetoceros* and *Cerataulina* were dominant'. 'From January to June the dominant genera were *Synedra* and *Amphora*, benthic and epiphytic diatoms that happened to be suspended in the water column'. (Lukatelich *et al*, 1984). Phytoplankton levels were relatively low when compared with those found in other estuarine systems studied (Peel-Harvey and the Swan).

Table 6.11 Genera of microalgae observed in Wilson Inlet. (Lukatelich *et al*, 1984)

Blue-Greens:	Diatoms:	Diatoms:
Lyngbya	*Bacillaria*	*Mastogloia*
Oscillatoria	*Cerataulina*	*Melosira*
Dinoflagellates:	*Chaetoceros*	*Navicula*
Ceratium	*Cocconeis*	*Nitzschia*
Gonyaulax	*Cymbella*	*Pleurosigma*
Diatoms:	*Diploneis*	*Striatella*
Achnanthes	*Gramatophora*	*Synedra*
Amphora	*Gyrosigma*	

The seagrass *Ruppia megacarpa* is the dominant plant in the estuary. It extends over most of the Inlet; Figure 6.14 shows its distribution and abundance in December 1982. Table 6.12 lists the macroalgae found in the estuary in 1982-83 and 1988. The following algae were found colonising rocky littoral areas around the Inlet in 1988: brown algae - *Cystoseira trinodis* and *Ectocarpus* sp.; the red alga - *Gracilaria verrucosa*; green algae *Chaetomorpha* sp. *Cladophora* sp. and *Enteromorpha* sp.

Table 6.12 Macroalgae observed in Wilson Inlet (Lukatelich *et al*, 1984) and (J.M. Chambers)

Chlorophyta:	*Acetabularia (Polyphysa) peniculus*
	Chaetomorpha linum
	Chaetomorpha aurea
	Cladophora sp.
	Enteromorpha intestinalis (and other species)
	Rhizoclonium sp.
	Ulva sp.
Charophyta:	*Lamprothamnium papulosum*
Rhodophyta:	*Ceramium* sp.
	Polysiphonia sp.
	Chondria sp.
	Audouinella sp.
	Gracilaria verrucosa
Phaeophyta:	*Cystoseira trinodis*
	Dictyotales (one species)
	Ectocarpus sp.

A stonewort, Charophyta (probably *Lamprothamnium*) was found growing at the eastern end of the Inlet in 1976, near the mouth of the Hay River and near and in the shallow bay adjacent to Nenamup Inlet. This, and the *Ruppia*, were covered with a heavy load of *Polysiphonia* sp. and other epiphytic algae. Some of the *Chaetomorpha* was covered with *Audouinella* and other epiphytes.

Irwin Inlet. *Ruppia* grows in a continuous band on the sandy shallows of the Inlet. The foliage dies when exposed, as in the autumn of 1987, but regenerates again from the rhizomes when flooded in winter. Cambridge noted that the *Ruppia* was dense and flowering freely in the spring of 1976, when the salinity was 4-5 ppt. The green algae *Enteromorpha paradoxa* and *Chaetomorpha* sp. were present in the shallows in 1987. The charophyte *Polyphysa peniculus* was present attached to shells on the northern shore.

Parry Inlet. *Ruppia* grows in the shallows of the Inlet and channel, but is now reported to be less abundant than previously. *Enteromorpha intestinalis* and another *Enteromorpha* sp. were present near the mouth in the 1988 survey, together with *Chaetomorpha* and the blue-green alga *Lyngbya*. *Enteromorpha* and *Chaetomorpha* were also present in the Inlet basin.

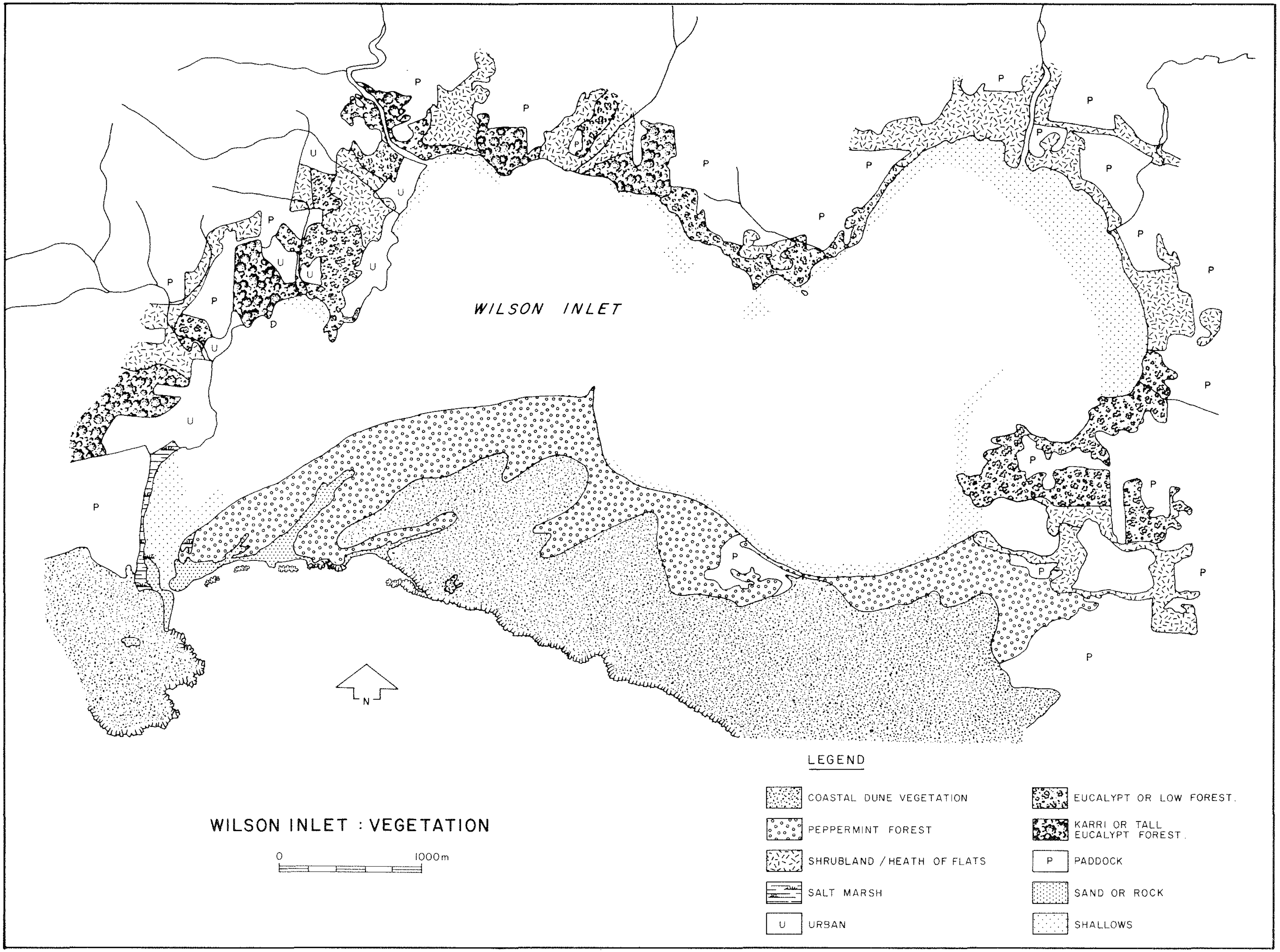

Figure 6.11 Wilson Inlet: Vegetation. (J. M. Chambers)

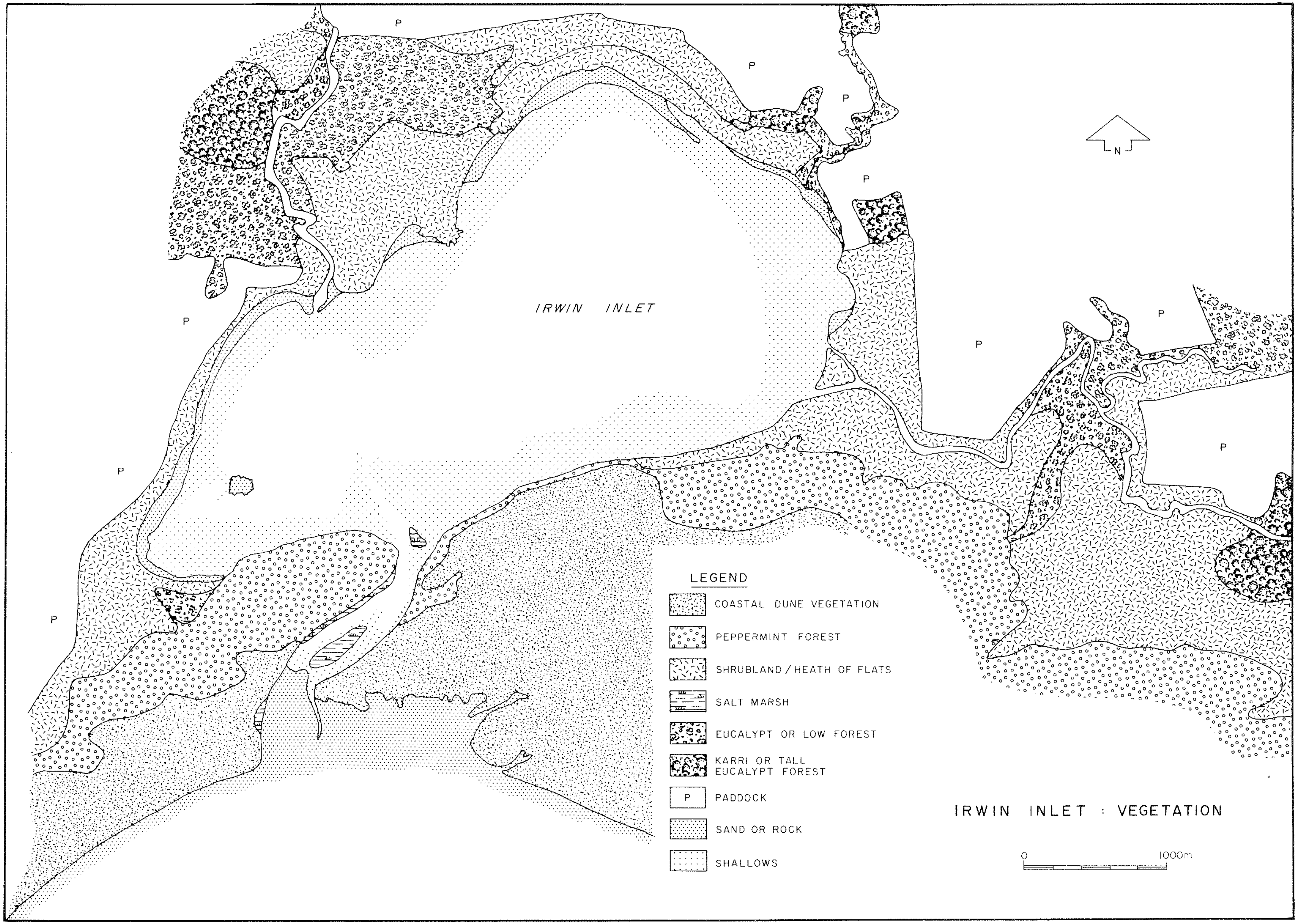

Figure 6.12 Irwin Inlet: Vegetation. (J. M. Chambers)

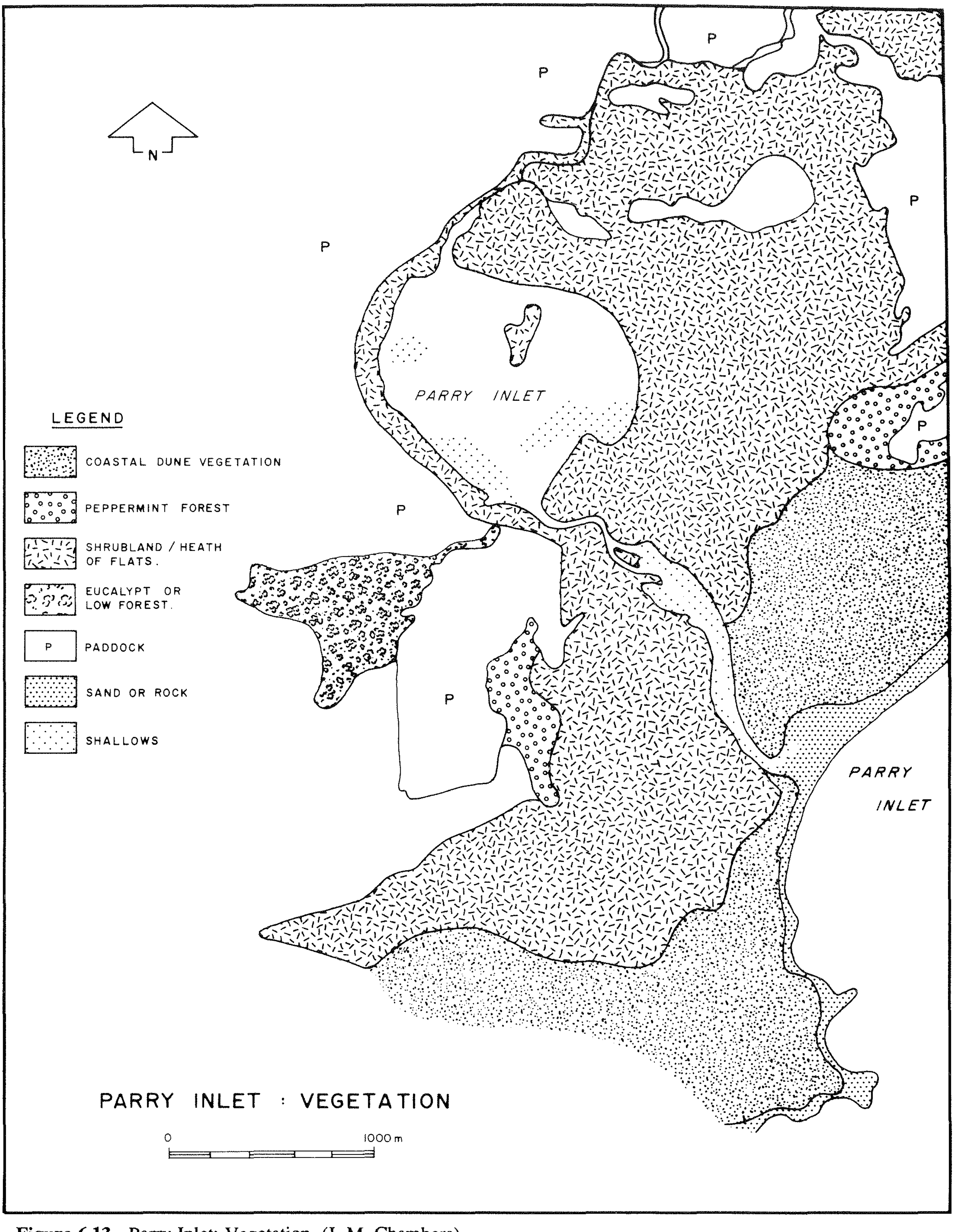

Figure 6.13 Parry Inlet: Vegetation. (J. M. Chambers)

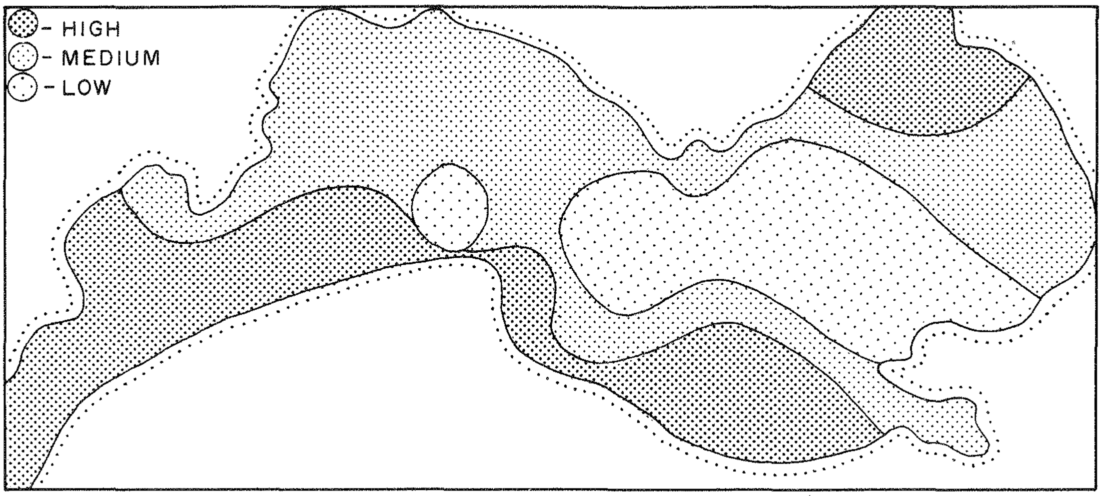

Figure 6.14 Density of *Ruppia* in Wilson Inlet, December 1982 - Adapted from Lukatelich *et al*, (1984).

6.2 SALT MARSH PLANTS

All three estuaries are fringed with the rush *Juncus kraussii* and the salt-tolerant paperbark tree *Melaleuca cuticularis*, around the Inlets, along the channels and for a short distance up the rivers. *Juncus* forms single species stands near the mouths of Wilson and Irwin Inlets or mixed with samphire (*Sarcocornia quinqueflora*), *Samolus repens* and occasional *Melaleuca cuticularis* in salt marshes. In disturbed areas of the salt marshes there are introduced grasses: salt water couch (*Sporobolus virginicus*), *Polypogon monspeliensis* and at Wilson Inlet buffalo grass (*Stenotaphrum secundatum*).

At Wilson Inlet a second community can be found in flatter areas behind the *Juncus / Melaleuca* community; this is dominated by the sedges *Isolepis nodosa* and *Baumea juncea* and the herb *Samolus repens*. At Parry Inlet the sedge (*Gahnia trifida*) grows behind the *Juncus / Melaleuca* community.

6.3 FRINGING VEGETATION

Along the river banks, shrubs and trees become dominant where soil salinity is lower. At Wilson Inlet the Hay River dissects a shrubland/heath with the species listed in Table 6.3, and Karri forest extends down to the banks of the Denmark River. At Irwin Inlet there are stands of the trees *Casuarina obesa*, *Melaleuca incana*, *Agonis juniperina* and the shrubs *Oxylobium lanceolatum*, *Astartea fascicularis* and *Polygonum serratulum*. At Parry Inlet *Agonis juniperina*, *A. parviceps* and *Astartea fascicularis* fringe the banks with the sedge *Baumea juncea*.

Table 6.3 Heath/Shrubland on low-lying flats of Wilson, Irwin and Parry Inlets. (J.M. Chambers)

Dry summer flats:	Dry summer flats:	Dry summer flats:
Banksia coccinea	*Beaufortia sparsa*	*Acacia pulchella* var *goadbyii*
Banksia quercifolia	*Melaleuca striata*	*Mesomelaena tetragona*
Jacksonia horrida	*Melaleuca incana*	*Poa* sp.
Kunzea ericifolia	*Astartea fasicularis*	Swampy flats:
Agonis parviceps	*Leucopogon parviflorus*	*Melaleuca rhaphiophylla*
Agonis juniperina	*Kingia australis*	*Agonis juniperina*
Agonis linearifolia	*Xanthorrhea preissii*	*Agonis parviceps*
Gahnia trifida	*Scaevola phlebopetala*	*Astartea fascicularis*
Acacia hastulata	*Anigozanthos flavidus*	*Adenanthos obovatus*
Oxylobium lanceolatum	*Sollya heterophylla*	*Pimelea ferruginea*
Dryandra nivea	*Evandra aristata*	*Cassytha* sp.
Callistemon speciosus	*Hypolaena ramosissima*	*Gahnia trifida*
Pultenaea reticulata	*Anarthia prolifera*	*Baumea juncea*
Hakea varia	*Loxocarya flexuosa*	*Lepidosperma striata*
Hakea sp.	*Lepidosperma striata*	*Leptocarpus aristatus*

6.4 TERRESTRIAL VEGETATION

The coastal dunes carry a plant community of similar composition at all three estuaries (Table 6.41). At Wilson Inlet it forms a dense shrubland up to 2 m in height, of high species diversity. At Irwin Inlet the community forms a low heath (< 1 m), except in sheltered areas where the peppermint *Agonis flexuosa* and the shrubs *Spyridium globulosum* and *Olearia axillaris* dominate a taller shrub community. At Parry Inlet it forms a low shrubland.

Table 6.41 Coastal dune vegetation found at Wilson, Irwin and Parry Inlets. (J.M. Chambers)

Colonisers:	Established dune:
*Arctotheca populifolia**	*Dryandra sessilis*+
*Euphorbia paralias**	*Pimelea ferruginea*
*Cakile maritima**	*Hibbertia cuneiformis*
Scaevola crassifolia	*Rhagodia baccata*
Carpobrotus sp.	*Sollya heterophylla*
*Ammophila arenaria**	*Pelargonium capitatum**
Established dune:	*Calocephalus brownii*
*Arctotheca populifolia**	*Anigozanthos flavidus*
*Euphorbia paralias**	*Stylidium* sp.
*Cakile maritima**	*Clematis* sp.
Scaevola crassifolia	*Cassytha* sp.
Carpobrotus sp.	*Lysinema ciliatum*
*Ammophila arenaria**	*Lepidosperma gladiatum*
Agonis flexuosa	*Lepidosperma striata*
Spyridium globulosum	*Lynginia barbata*
Acacia littorea	*Isolepis nodosa*
Olearia axillaris	*Lomandra micrantha* ssp *micrantha*
Olax phyllanthii	

* introduced species, + found at Wilson only.

Behind this coastal community there is generally a peppermint forest, which incorporates many of the coastal dune species and also a number of additional shrubs (Table 6.42).

Table 6.42 Peppermint forest found behind coastal communities at Wilson, Irwin and Parry Inlets. (J.M. Chambers)

Agonis flexuosa	*Astartea fascicularis*
Paraserianthes laphantha	*Acacia eglandulosa*
Acacia littorea	*Spyridium globulosum*
Hibbertia cuneiformis	*Bossiaea linophylla*
Olax phyllanthii	*Leucopogon parviflorus*
Leucopogon multiflorus	*Exocarpus sparteus*
Hakea sp.	*Oxylobium lanceolatum*
Gastrolobium biloba	*Rhagodia baccata*
Xanthorrhea preissii	*Macrozamia reidlei*
Anigozanthos flavidus	*Sollya heterophylla*
Isolepis nodosa	*Lepidosperma gladiatum*
Lyginia barbata	*Cyperus congestus*

The majority of the vegetation at Parry Inlet, and in large areas surrounding Wilson and Irwin Inlets, is a low shrubland/heath community containing many swamps and depressions. These heaths are dominated by species of *Agonis*, *Melaleuca*, *Kunzea* and *Astartea* and a large number of sedges and species of Restionaceae. Swamps in the depressions are dominated by *Melaleuca rhaphiophylla* and sometimes *Agonis juniperina* (Table 6.3).

7 ESTUARINE FAUNA

The composition of the aquatic fauna reflects the hydrological conditions of the three estuaries. Wilson Inlet with its brackish water (10 to 30 ppt) and large volume has a relatively rich fauna compared with other seasonally closed estuaries of the south coast. Fewer species of fish have been found in Irwin Inlet, but the invertebrate fauna appears to be as diverse as in Wilson Inlet, though probably more subject to periodic mass mortalities as a result of the lower salinities and exposure of the productive shallows sometimes in summer. Much fewer species of fish and invertebrates have been found in Parry Inlet where there are even greater salinity extremes and changes in water level. However to some extent this represents less thorough sampling.

Many of the species are 'estuarine'; species which are confined to estuaries, where they live and breed in a wide range of salinities from almost fresh to more salt than the sea. Other 'marine affinity' invertebrate species also live and breed in sheltered marine environments such as Princess Royal Harbour. Most such species probably do not long survive in water of less than about 10 ppt, and their estuarine populations are recruited from marine sources. Fish, being more mobile, can readily come and go. Most are 'estuarine marine' species that spawn in the sea and return to the estuaries as larvae or juvenile fish. A few are true 'estuarine' species and may be abundant, and a few 'marine' species sometimes invade the estuaries when the bars are open.

No study has been made of the abundant microfauna (Protozoa) and meiofauna (harpacticoid copepods and nematodes) of the surface sediments, but these play an essential role in making the bacteria of the decaying plant material available to the small invertebrates that in turn are the staple diet of most fish and birds.

7.1 PLANKTON

Three common estuarine copepods, *Acartia* sp., *Gladioferens imparipes*, *Oithona* sp. dominated the animal plankton of Wilson Inlet, the Denmark and Hay rivers and Irwin Inlet in samples taken in the early 1970s; a fourth, *Sulcanus conflictus*, was not recorded. No quantitative study has yet been made of them, but they are unlikely to be abundant in Wilson Inlet where the plant plankton is sparse.

Larvae of bivalve and gastropod molluscs, polychaete worms, barnacles and crabs, and harpacticoid copepods were also present in night plankton. Parry Inlet may be expected to have a similar, but sparser fauna.

7.2 BOTTOM FAUNA

Table 7.21 lists the bottom-living invertebrate fauna found in surveys made in Wilson Inlet in October 1976 and April 1987 and in Irwin and Parry inlets in

Table 7.21 The benthic invertebrate fauna of Wilson, Irwin and Parry Inlets, October 1976 (J.Wallace) and April 1987 (J. Shaw).

		Wilson Inlet	Irwin* Inlet	Parry* Inlet
POLYCHAETA:				
Phyllodocidae	- *Phyllodoce* sp.	+		
Nereididae	- *Ceratonereis aequisetes*	++	++	-
	- *Olganonereis edmondsi*	+		
	- *Neanthes vaalii*	+++		
	- *Neanthes* sp.	+		
Orbiniidae	- *Scoloplos simplex*	++	++	-
Spionidae	- *Prionospio* sp.	+	++	-
	- *Boccardia chilensis*	+		
Capitellidae	- *Capitella capitata*	+++	+	-
Arenicolidae	- *Abarenicola* sp.	+	-	-
Serpulidae	- *Ficopomatus enigmatica*	+	-	-
MOLLUSCA GASTROPODA:				
Hydrobiidae	- *Hydrobia buccinoides*	+++	++	-
	- *Tatea preissii*	+	+	-
Assimineidae	- *Assiminea* sp.	+	+	
Hydrococcidae	- *Hydrococcus brazieri*	+++	+++	-
Nassariidae	- *Nassarius burchardi*	++	-	-
Atyidae	- *Liloa brevis*	++		
Phylinidae	- *Philine* sp.	+		
Amphibolidae	- *Salinator fragilis*	+	+	
MOLLUSCA BIVALVIA:				
Mytilidae	- *Mytilus edulis planulatus*	++	-	-
	- *Xenostrobus securis*	++	+	-
Leptonidae	- *Arthritica semen*	++	++	+
Mactridae	- *Spisula trigonella*	++	+	-
Tellinidae	- *Macomona deltoidalis*	+	+	-
Sanguinolaridae	- *Sanguinolaria biradiata*	+	-	-
Trapeziidae	- *Fluviolanatus subtorta*	+	+	-
Veneridae	- *Irus crenata*	++		
	- *Katelysia scalarina*	+	+	-
CRUSTACEA:				
Mysidacea	- Mysid sp.	+	+	-
Amphipoda	- *Melita* sp.	++	+	+
	- *Corophium* sp.	++	-	-
	- *Paracorophium* sp.	+	+	-
Isopoda	- *Sphaeroma* sp.	+	++	-
Decapoda	- *Palaemonetes australis*	+++	++	+
	- *Macrobrachium intermedium*	++	+	-
	- *Ovalipes australiensis*	+		
INSECTA:				
Chironomidae	- *Pontomyia* sp.	++	+	-
	- *Chironomus* sp.	-	-	++

* Blanks in these columns indicate that the species may have been present but were not identified in the 1976 surveys. - not found, + present, ++ abundant, +++ very abundant.

October 1976, and includes a few other species listed by Wells and Bryce (1984). The Wilson and Irwin Inlet lists are similar, with some notable absences from the Irwin Inlet list. The blanks in the Irwin and Parry lists represent deficiencies in identifications in the 1976 survey. Many fewer species were recorded from Parry Inlet, which partly reflects the fact that sampling sites were uniformly muddy and *Ruppia* was sparse. More thorough surveys would doubtless show other less common species and give a somewhat different rating of the relative abundance and distribution of the species in the two Tables 7.21 and 7.22. The limited data do not allow a quantitative comparison of the fauna of the three estuaries, though again they suggest that Parry Inlet has a more impoverished fauna than the other two.

Table 7.22 Principal habitats of common species of benthic invertebrates in Wilson, Irwin and Parry Inlets. (J. Wallace, J. Shaw)

	Sand and silty sand	*Ruppia* on silty sand	Mud
POLYCHAETA:			
Ceratonereis aequisetes	+++	++	+
Scoloplos simplex	++	++	-
Capitella capitata	+++	+++	++
MOLLUSCA GASTROPODA:			
Hydrobia buccinoides	+	+++	-
Hydrococcus brazieri	++	+++	+
Nassarius burchardi	++	++	+
MOLLUSCA BIVALVIA:			
Mytilus edulis	++	++	-
Xenostrobus securis	+	++	-
Arthritica semen	+++	+++	-
Spisula trigonella	+++	++	++
Irus crenata	++	+	+
CRUSTACEA:			
Melita sp.	+	++	+
Palaemonetes australis	+	+++	-

Symbols as in Table 7.21.

Most of the common species, both estuarine and marine affinity species, are widely distributed throughout the Inlets, as is to be expected with the uniform salinities generally experienced. However the dominant faunas of the different bottom types do differ, as indicated by the necessarily subjective ratings in Table 7.22. The mud of the deep basins has a typically impoverished fauna. Rocks are sometimes colonised by tube worms (*Ficopomatus*), mussels (*Mytilus* and *Xenostrobus*) and barnacles (*Balanus*).

There is evidence of periodic high mortality of some of the marine affinity species; eg mussels (*Mytilus*) and venus shells (*Irus*) with low salinity in Wilson Inlet, and cockles (*Katelysia*) in Irwin Inlet by the retreat of water from the productive shallows when the bar is closed in summer. Repopulation is then dependant on recruitment of larvae from the few survivors or from marine sources such as Princess Royal Harbour. Oysters (*Ostrea angasi*) were also abundant in both Wilson and Irwin Inlets and are believed to have died out in the latter about 10 years ago, possibly as the results of floods and low salinity.

In addition to the many small sedentary invertebrates, a few more mobile species form part of the bottom fauna. Crabs (*Portunus* and *Ovalipes*) and King prawns (*Penaeus*) feed on the small invertebrates and microorganisms on and in the bottom sediment, as also do gobies, mullet and Cobbler. The shrimp (*Palaemonetes*) is listed with the bottom fauna, but it is free-swimming and is especially abundant among the seagrass. It is an important part of the diet of many species of fish.

No study has been made of the fauna of the estuarine reaches of the rivers. The small mussel-like bivalve *Fluviolanatus* may be expected to be abundant, attached to logs and other solid structures.

7.3 FISH

Table 7.3 presents the list of fish species recorded as having been caught in the three estuaries. The number from Wilson Inlet is large when compared with records from other estuaries of the south coast, though this is partly because the sampling effort has been greater there than in most. Fewer species are recorded from Irwin and Parry inlets, where the hydrological conditions are more extreme. The terminology is that of Hutchins and Thompson (1983).

The great majority of fish are marine species which enter the estuaries when the bars are open, and recruitment to estuarine populations depends on larvae and juveniles being present in nearby coastal waters. They may return to the sea to spawn when they reach maturity. Of the commercially important species only Anchovy, Black bream, Flathead and probably Cobbler can complete their life cycle within the estuaries if hydrological conditions are not too extreme; many gobies, pipefish and hardyheads also do so. Current studies by a group from Murdoch University will further elucidate the breeding habits of estuarine species and recruitment from marine populations.

Black bream are common in the estuarine reaches of the Hay River, but Inlet populations are reported to have decreased in recent years. Sea mullet are also common in the rivers. Lampreys pass through the estuaries on their way to the rivers, where they spawn and where the larvae develop until they are ready to return to the sea. Rainbow trout are present in the Denmark River above and below the dam and sometimes enter the estuarine reaches of the river.

Table 7.3 Commercial and non commercial species of fish caught in Wilson (W), Irwin (I) and Parry (P) Inlets. (WA Fisheries Department, Lenanton, 1974a & 1974b, WA Museum, Murdoch University, Hutchins & Thompson, 1983 and J. Brenton pers. comm.). + caught , - not caught.

Commercial		W	I	P
CLUPEIDAE:	Sandy sprat *Hyperlophus vittatus*	+	-	-
ENGRAULIDIDAE:	Australian anchovy *Engraulis australis*	+	+	-
PLOTOSIDAE:	Cobbler *Cnidoglanis macrocephalus*	+	+	+
SALMONIDAE:	Rainbow trout *Salmo gairdneri*	+	-	-
HEMIRAMPHIDAE:	Southern sea garfish *Hyporhamphus melanochir*	+	+	-
TRIGLIDAE:	Red gurnard *Chelidonichthys kumu*	+	-	-
PLATYCEPHALIDAE:	Flathead *Platycephalus* sp.	-	+	-
	Rock flathead *Platycephalus laevigatus*	+	-	-
	Southern sand flathead *Platycephalus bassensis*	+	-	-
	Blue-spotted flathead *Platycephalus speculator*	+	-	-
SILLAGINIDAE:	Yellow-finned whiting *Sillago schomburgkii*	-	+	-
	King George whiting *Sillaginodes punctata*	+	+	+
POMATOMIDAE:	Tailor *Pomatomus saltator*	+	+	-
CARANGIDAE:	Silver trevally *Pseudocaranx dentex*	+	-	-
	Sand trevally *Pseudocaranx wrighti*	+	-	-
	Skippy *Pseudocaranx* sp.	-	+	-
ARRIPIDAE:	Western Australian salmon *Arripis truttaceous*	+	+	+
	Australian herring *Arripis georgianus*	+	+	+
SPARIDAE:	Black bream *Acanthopagrus butcheri*	+	+	+
	Pink snapper *Chrysophrys auratus*	+	+	-
	Tarwhine *Rhabdosargus sarba*	+	+	+
SCIAENIDAE:	Mulloway *Argyrosomus hololepidotus*	+	+	-
MULLIDAE:	Goatfish *Mullidae*	+	+	-
MUGILIDAE:	Yelloweye mullet *Aldrichetta forsteri*	+	+	+
	Sea mullet *Mugil cephalus*	+	+	+
LABRIDAE:	Western blue groper *Achoerodus gouldii*	+	+	-
	Brown spotted wrasse *Pseudolabrus parilus*	+	-	-
SCOMBRIDAE:	Blue mackerel *Scomber australasicus*	+	+	+
BOTHIDAE:	Small toothed flounder *Pseudorhombus jenynsii*	+	+	-
PLEURONECTIDAE:	Long snouted flounder *Ammotretis rostratus*	+	+	+
CYNOGLOSSIDAE:	Southern tongue sole *Cynoglossus broadhursti*	-	+	-
MONACANTHIDAE:	Leatherjacket	-	+	-
	Spiny tailed leatherjacket *Bigener brownii*	+	+	-
	Six-spined leather-jacket *Meuschenia freycineti*	+	-	-

Non-commercial		W	I	P
GEOTRIIDAE:	Pouched lamprey *Geotria australis*	+	+	+
DASYATIDIDAE:	Smooth stingray *Dasyatis brevicaudatus*	-	+	-
ELOPIDAE:	Giant herring *Elops machnata*	+	+	-
CONGRIDAE:	Eel *Conger* sp.	+	+	-
OPHICHTHIDAE:	Serpent eel *Ophisurus serpens*	+	-	-
GALAXIIDAE:	Western minnow *Galaxias occidentalis*	+	-	-
GONORYNCHIDAE:	Beaked salmon *Gonorhynchus greyi*	+	-	-
MORIDAE:	Beardie *Lotella rhacinus*	+	-	-
NOTOCHEIRIDAE:	Surf sardine *Iso rhothophilus*	+	-	-
ATHERINIDAE:	Hardyhead Atherinid sp.	-	+	+
	Hardyhead *Atherinosoma elongata*	+	+	-
	Hardyhead *Allanetta mugiloides*	+	-	-
	Silverfish *Atherinosoma presbyteroides*	+	-	-
	Wallace's hardyhead *Atherinosoma wallacei*	+	+	-
SYGNATHIDAE:	Hairy pipefish *Urocampus carcinirostris*	+	-	-
	Sygnathid sp.	+	-	-
SERRANIDAE:	Gurnard perch *Neosebastes pandus*	+	+	-
TERAPONIDAE:	Striped trumpeter *Pelates sexlineatus*	+	+	-
SERRANIDAE:	Western Pigmy perch *Edelia vittata*	+	+	-
MONODACTYLIDAE:	Woodward's pomfret *Schuettea woodwardi*	+	-	-
KYPHOSIDAE:	Silver drummer *Kyphosus sydneyanus*	+	+	-
GIRELLIDAE:	Zebra fish *Girella zebra*	+	-	-
SCORPIDIDAE:	Sea sweep *Scorpis aequipinnis*	+	-	-
	Moonlighter *Tilodon sexfasciatum*	+	-	-
ENOPLOSIDAE:	Old wife *Enoplosus armatus*	+	-	-
APLODACTYLIDAE:	Rock cale *Crinodus lophodon*	+	-	-
CLINIDAE:	Southern crested weedfish *Cristiceps australis*	+	-	-
	Yellow crested weedfish *Cristiceps aurantiacus*	+	-	-
CHEILODACTYLIDAE:	Red lipped morwong *Cheilodactylus rubrolabiatus*	-	+	+
	Crested morwong *Cheilodactylus gibbosus*	+	+	-
URANOSCOPIDAE:	Fringed stargazer *Icthyscopus barbatus*	+	-	-
GOBIIDAE:	Long finned goby *Favonigobius lateralis*	+	+	-
	South west goby *Favonigobius suppositus*	+	+	+
	Blue spot goby *Pseudogobius olorum*	+	+	+
	Sculptured goby *Callogobius mucosus*	+	+	-
PLEURONECTIDAE:	Elongate flounder *Ammotretis elongatus*	+	-	-
TETRAODONTIDAE:	Prickly pufferfish *Contusus brevicaudus*	+	+	-
	Banded toadfish *Torquigener pleurogramma*	+	+	-
MONOCENTRIDIDAE:	Nightfish *Bostockia porosa*	+	-	-

The extent to which different species survive salinity extremes varies greatly. Resident species such as Anchovy, Black bream, Cobbler, flathead,gobies and hardyheads, can tolerate a wide range from almost fresh to 40 ppt or greater; they are 'euryhaline' species. So too do the common species, Yellow-eye mullet, Sea mullet and King George whiting. Most other species such as Australian herring, Tailor and Australian salmon do not survive the extremes that are often experienced in Irwin and Parry inlets, and are less able to tolerate the low salinities that occasionally occur in Wilson Inlet. The marine species show varying degrees of tolerance of low and high salinity; leatherjackets and sharks are mainly caught near the bars when they are open and salinity is close to that of sea water. They are 'stenohaline marine' species, and the higher salinities experienced in Irwin Inlet may explain why there are records of Stingray and blowfish (or Banded toadfish) there, but not for Wilson Inlet.

Few fish are herbivorous and of those that occur in these estuaries only sea garfish and some species of leatherjacket are known to eat seagrass and phytoplankton. Sea mullet extract microorganisms from the decaying matter in the mud, and the great majority of estuarine fish feed on the bottom fauna: worms, molluscs, shrimp and other small invertebrate animals living on and among the seagrass. Shrimp (*Palaemonetes*) are an important part of the diet of many species. Food is abundant and growth rates of fish in the estuaries are higher than for the same species found in the sea.

THE FISHERY The list of commercial fish in Table 7.3 includes 33 species, but the bulk of the catch is made up of only a few species: Cobbler, Yellow-eye mullet, Sea mullet, King George whiting, Blue-spotted flathead, Sea garfish, Australian herring. There was a big Black bream fishery in Irwin Inlet some years ago, but recently numbers have been small. The Kent and Bow rivers were seeded with juveniles in 1987. Amateurs fish for King George whiting, Pink snapper, Australian herring and a variety of marine species near the bar. Black bream is a popular fish caught by amateur fishermen in riverine areas.

Annual catches of commercial species have varied greatly from year to year with obvious peaks and a progressive increase in Cobbler catches (Figure 7.3). Annual catches of these and other commercial species are given by Lenanton (1984). It is not claimed that the data accurately represent the stock abundance of these species; catches are often influenced by other factors such as the fishing strategies of fishermen and market demand. However, catches of Cobbler and Whiting do substantially reflect the changing populations because these fish are always in demand as prime quality food items. To what extent the fluctuations can be attributed to particular environmental conditions is not clear; the causes are complex and affect the various species in different ways. The time and duration of bar opening must

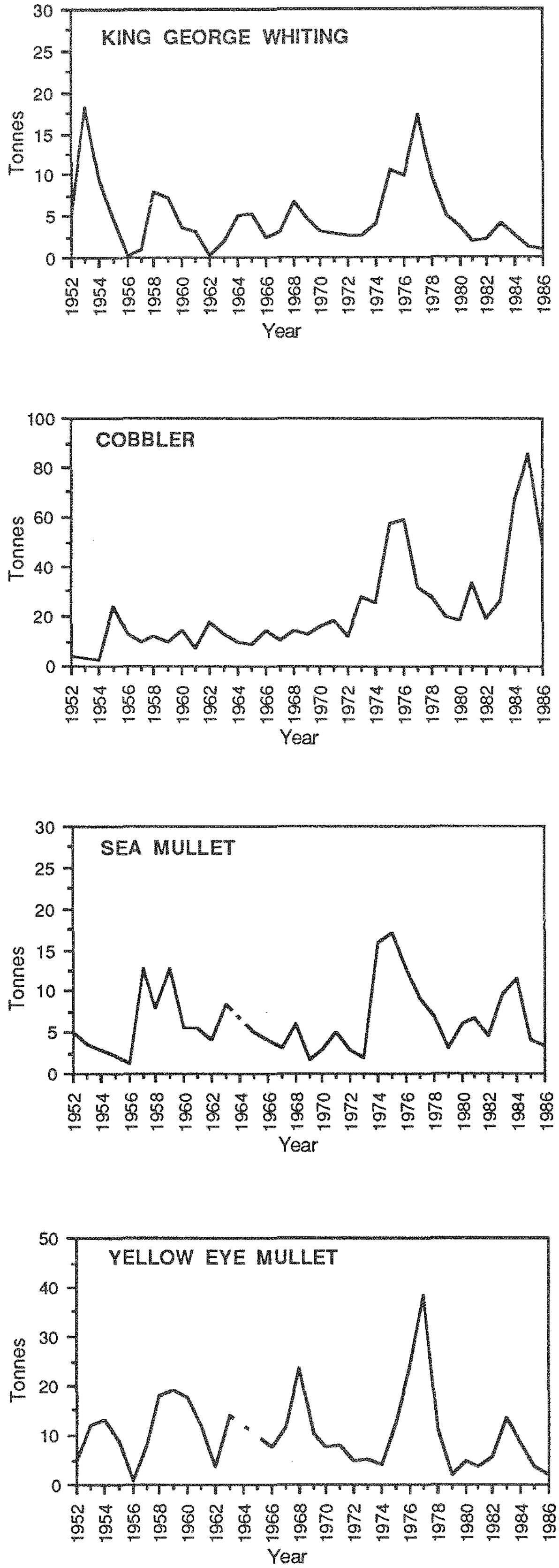

Figure 7.3 Catch in tonnes of the common commercial fish, King George whiting, Cobbler, Sea mullet and Yellow-eye mullet of Wilson Inlet between 1952 and 1986. (WA Fisheries Department)

affect recruitment of species which spawn at sea. Low winter salinities can cause mortality of fish and their prey, as does exposure of the shallows in summer. The abundance of seagrass appears to favour Cobbler especially and other species indirectly. The great increase in Cobbler catches in the 1970s and 1980s may be due to the reported increase in seagrass (Figure 7.3). However it must be remembered that it is only recently that Cobbler has been recognised as a good table fish. There is no evidence of overfishing of fish, though mud oysters are reported to have been scarce in Wilson Inlet ever since being overfished in the 1880s.

King prawns (*Penaeus latisulcatus*) are sometimes fished commercially. They vary greatly in abundance, probably because of erratic recruitment to estuarine populations. Small numbers of the Blue manna crab (*Portunus pelagicus*) are also present in summer, but is not fished commercially. The sand crab (*Ovalipes australiensis*) is sometimes so abundant in Wilson Inlet as to foul fishermen's nets. Some years ago an attempt was made to establish mussel culture in Wilson Inlet.

The Wilson Inlet fishery is usually operated by 6 to 10 persons, with 5 to 8 boats, most of whom now fish mainly for Cobbler. There are only one or two in Irwin Inlet and Parry Inlet is not regularly fished. Fishing is mainly with gill nets. Catches are sold locally or are freighted to the Perth market; Cobbler and Whiting for human consumption, but Mullet mainly as Rock lobster bait. The early history of the Wilson Inlet fishery is recorded by Lenanton (1984).

7.4 BIRDS

A total of 79 species of waterbirds have been recorded in Wilson, Irwin and Parry Inlets and in Owingup Swamp (Table 7.4). The most common species of waterbirds found at Wilson Inlet are Black Swan, Australian Shelduck, Pacific Black Duck and Grey Teal; they are seasonal visitors most abundant in winter and seldom seen in Irwin and Parry Inlets in summer. Banded Stilt and Red-necked Avocet have become abundant in Wilson Inlet in the last three years. The Fairy Tern is a summer visitor to Wilson Inlet and regularly attempts to breed at Ocean Beach but has failed because of human activities associated with cars, off road vehicles, trail bikes and dogs. Small numbers of Fairy Tern feed at Morley Beach. A considerable variety of waterbirds favour Owingup Swamp, but little is known of the waterfowl of Irwin Inlet. The RAOU made aerial surveys of the Inlet in March 1986 and 1987.

8 MANAGEMENT

Management of the bars is probably the major problem in all three estuaries, but for somewhat different reasons, and management strategies therefore need to be designed for each. So far Wilson Inlet is the only one to show signs of eutrophication, a problem which proper management of the bar can help to alleviate. The success of its rich fishery is also influenced by the way the bar is managed. Irwin Inlet has a relatively rich fishery considering its small size, but this is at peril from the salinity extremes experienced when the bar is closed. There is not much of Parry Inlet at any time, but when the bar is closed in summer it can lose almost all its water and become a salt pan of little interest to man, fish or waterbirds.

There is no longer the 'natural' situation in which the bars open when the water in the Inlets and storm waves on the beaches will break them. The pressure to prevent flooding of roads and low-lying agricultural land now largely dictates when the bars of all three estuaries are opened. And there are inevitable conflicts of interest as to exactly when, where and at what level they should be opened, especially at Wilson Inlet. These are contentious issues which have engendered much disagreement, lengthy correspondence and at times more heat than light. Further conflict arises because when the bars are open there is no vehicle access to beaches east of the mouths. These are human problems which it is not the purpose of this report to attempt to solve.

Judgments about management of the estuaries is further confused by the fact that Irwin and Parry Inlets are now well on their way to their eventual extinction as lagoonal systems, as indicated in Section 1.3 above. The estuaries are slowly filling with sediment from the catchment and from the beaches. While this is not an urgent matter in these estuaries it is important that nothing should be done to accelerate the process. It is regrettable that there is no information as to the current rate of sediment accumulation and the effect that clearing in the catchments may have had on it. The small catchment of Parry Inlet is in a high rainfall area, but the Inlet is already only half a metre deep. Owingup Swamp is a sediment trap on the Kent River, and will also trap nutrients. There are no such traps on the Denmark and Hay rivers, but Lake Saide also appears to be a nutrient trap.

It is especially regrettable that the natural vegetation has so often been cleared down to the stream channels, allowing stock access to them. This has resulted in erosion of the banks and increased runoff of water, sediment and nutrients. The banks of the estuarine reaches of the rivers are also stabilised by the vegetation and its destruction allows erosion of the generally sandy soils and slumping of the banks under high flow conditions in winter.

MANAGEMENT COMMITTEES It is a reflection of the concern of local people and Local Government for the welfare of the estuaries that management committees are now being established. Previously responsibility for management of the estuaries has been divided, various Government departments and the Shire being involved in particular aspects, with no coordination. In 1987 the Shire of Denmark established the Irwin Inlet Management Advisory

Table 7.4 Waterbirds observed by Lola Broadhurst, Geoff Rogerson, RAOU and Mary Bremner inWilson (W), Irwin (I) and Parry (P) Inlets and Owingup swamp (O). + observed, - not observed. Numbers indicate highest recorded.

	W	I	P	O
Great Crested Grebe *Podiceps cristatus*	12	-	-	-
Hoary-headed Grebe *Poliocephalus poliocephalus*	20	-	+	+
Australasian Grebe *Trachybaptus novaehollandiae*	25	-	-	+
Australian Pelican *Pelecanus conspicillatus*	350	+	+	+
Darter *Anhinga melanogaster*	+	-	-	+
Great Cormorant *Phalacrocorax carbo*	50	-	-	-
Pied Cormorant *Phalacrocorax varius*	+	-	+	-
Little Black Cormorant *Phalacrocorax sulcirostris*	1100	-	+	+
Little Pied Cormorant *Phalacrocorax melanoleucos*	1000	+	+	+
Pacific Heron *Ardea pacifica*	+	-	+	-
White-necked Heron *Ardea pictata*	-	1	-	-
White-faced Heron *Ardea novaehollandiae*	23	-	+	+
Cattle Egret *Ardeola ibis*	+	-	+	-
Great Egret *Egretta alba*	12	-	+	+
Little Egret *Egretta garzetta*	1	-	-	-
Eastern Reef Heron *Egretta sacra*	+	-	-	-
Mangrove Heron *Butorides striatus*	-	+	-	-
Rufous Night Heron *Nycticorax caledonicus*	+	-	-	-
Little Bittern *Ixobrychus minutus*	-	-	-	+
Australasian Bittern *Botaurus poiciloptilus*	-	-	+	+
Sacred Ibis *Threskiornis aethiopica*	12	-	+	+
Straw-necked Ibis *Threskiornis spinicollis*	+	-	+	-
Yellow-billed Spoonbill *Platalea flavipes*	2	-	+	+
Black Swan *Cygnus atratus*	3212	3204	+	+
Australian Shelduck *Tadorna tadornoides*	420	21	+	+
Pacific Black Duck *Anas superciliosa*	1368	2436	+	+
Grey Teal *Anas gibberifrons*	1336	316	50	+
Chestnut Teal *Anas castanea*	+	5	+	+
Australian Shoveler *Anas rhynchotis*	200	-	+	+
Pink-eared Duck *Malacorhynchus membranaceous*	+	-	-	+
Hardhead *Aythya australia*	12	-	-	-
Maned Duck *Chenonetta jubata*	+	-	+	+
Blue-billed Duck *Oxyura australis*	192	8	+	+
Musk Duck *Biziura lobata*	226	1	+	+
Osprey *Pandion haliaetus*	+	-	+	-
White-bellied Sea-Eagle *Haliaeetus leucogaster*	1	-	-	-
Marsh Harrier *Circus aeruginosus*	+	-	+	+
Australian Crake *Porzana fluminea*	-	-	-	+
Spotless Crake *Porzana tabuensis*	+	-	+	+
Black-tailed Native Hen *Gallinula ventralis*	+	-	+	+

	W	I	P	O
Dusky Moorhen *Gallinula tenebrosa*	+	-	+	+
Purple Swamphen *Porphyrio porphyrio*	+	-	+	+
Eurasian Coot *Fulica atra*	1500	-	+	+
Pied Oystercatcher *Haematopus longirostris*	+	-	-	-
Sooty Oystercatcher *Haematopus fuliginosus*	+	-	-	-
Grey Plover *Pluvialis squatarola**	+	-	+	-
Lesser Golden Plover *Pluvialis dominica**	+	-	-	-
Red-kneed Dotterel *Erythrogonys cinctus*	+	-	+	+
Hooded Plover *Charadrius rubricollis*	5	-	+	-
Large Sand Plover *Charadrius leschenaultii**	+	-	-	-
Red-capped Plover *Charadrius ruficapillus*	+	-	+	+
Black-fronted Plover *Charadrius melanops*	+	-	+	+
Black-winged Stilt *Himantopus himantopus*	30	-	+	+
Banded Stilt *Clador hynchus leucocephalus*	480	-	-	-
Red-necked Avocet *Recurvirostra novaehollandiae*	2750	-	-	-
Ruddy Turnstone *Arenaria interpres**	+	-	+	-
Wood Sandpiper *Tringa glareola**	+	-	+	+
Grey-tailed Tattler *Tringa brevipes**	+	-	-	-
Common Sandpiper *Tringa hypoleucos**	2	-	2	-
Greenshank *Tringa nebularia**	14	+	-	+
Marsh Sandpiper *Tringa stagnatilis**	+	-	+	+
Black-tailed Godwit *Limosa lapponica**	+	-	-	-
Bar-tailed Godwit *Limosa lapponica**	+	-	+	+
Red Knot *Calidris canutus**	+	-	+	-
Great Knot *Calidris tenuirostris**	+	-	-	-
Sharp-tailed Sandpiper *Calidris acuminata**	+	-	+	-
Red-necked Stint *Calidris ruficollis**	+	-	+	+
Long-toed Stint *Calidris subminuta**	-	-	-	+
Curlew Sandpiper *Calidris ferruginea**	+	-	-	+
Sanderling *Calidris alba**	+	-	-	-
Broad-billed Sandpiper *Limicola falcinellus**	1	-	-	-
Silver Gull *Larus novaehollandiae*	300	-	+	+
Pacific Gull *Larus pacificus*	+	-	+	-
Whiskered Tern *Chlidonias hybrida*	+	-	-	-
Caspian Tern *Hydroprogne caspia*	+	-	+	-
Fairy Tern *Sterna nereis*	+	-	-	-
Crested Tern *Sterna bergii*	+	-	+	-
Sacred Kingfisher *Halcyon sancta*	+	-	+	+
Yellow Wagtail *Motacilla flava*	+	-	-	-

* denotes migratory bird; present in greater numbers in spring and summer, most depart in autumn. All other birds are sedentary or vagrant.

Committee to monitor the Inlet and recommend management options. This Committee combines local knowledge and experience with advice from State Government departments — Conservation and Land Management, Environmental Protection Authority, Fisheries, Marine and Harbours and Waterways Commission. The Denmark Shire Council has now established a Wilson Inlet Management Advisory Committee which will include representation from the following State Government departments: Agriculture, Environmental Protection Authority, Fisheries, Marine and Harbours, Water Authority, Waterways Commission, and the Shire of Albany will also be represented because the eastern shores of the Inlet and the eastern catchments are in that Shire.

The draft plan for the management of the coastal zone of the Denmark Shire does not include recommendations for management of the estuaries (Anon, 1987).

8.1 WILSON INLET

There are three major problems, all related to management of the bar:

> flooding of low lying areas in winter; the present potentially eutrophic condition of the estuary and the perceived increase in weed accumulation on the shores; maintenance of fish populations.

Correct management of the bar is vital to keep the waters of the estuary healthy and to ensure good recruitment of fish stocks from the sea.

The channel from the Denmark River to the Inlet has had to be dredged from time to time, the last occasion appears to have been in 1966. The much wider bar across the mouth of the Hay River has not been dredged.

THE BAR For many years the former Public Works Department and the Shire Council had been involved in investigating problems related to management of the bar. Responsibility for timing the opening of the bar now lies with the Water Authority. The channel is dug by the Shire Council.

The present practice is to open the bar when Inlet water level reaches 1.01 m above MSL in order to prevent low-lying land being flooded. It is accepted that the best scouring of the channel and therefore the best flushing of the estuary is achieved by opening the bar when there is the maximum difference in level between Inlet water and the ocean; at the highest permissible level inside and the lowest obtainable level outside (ie low tide and low sea level). In practice: 'Time the opening to be in the week following the Inlet water level attaining a height of 1.1 m above AHD [MSL] and to be started 6 to 8 hours before predicted low water on the day within the week which is predicted to have the highest barometric pressure at Denmark' (PWD letter 1076/72 of 1.12.1976). The timing aims to have the greatest difference between Inlet and ocean water level when the channel cutting phase is nearing completion. This ensures that flow scours the biggest bar channel.

When the bar is opened the water level falls 1 m over 3 to 4 days (if the barometric pressure remains high), the flow scours a good channel through the bar and about one third of the water in the estuary is lost to the sea. In 1987 the bar was opened when the Inlet water level was 0.77 m above MSL and the barometric pressure was low. The water level only fell to 0.5 m. There was a much smaller loss of estuary water, poor scouring of the channel, and the bar only remained open for 71 days (Figure 3.21). This premature, low level opening of the bar was to enable potato farmers in the Lake Saide area to drain water off their paddocks to permit spring planting of the crops.

Where to open the bar. There has been a long standing controversy as to where the bar should be opened, whether at its eastern or western ends or in the middle. Since 1955 it has been opened variously between 50 and 440 m from the western cliff. The Shire generally favours a position near the cliff while some fishermen argue for the bar to be opened towards its eastern end, the location once favoured by the Drainage Authorities of PWD. Before 1929 the bar opened against the cliff and a channel followed the western shore to the cliff. This may have been the 'natural' position for the opening, as it is for many estuaries along the south coast, but there is no longer a natural situation. For the last 60 years the bar has been breached before it is ready to break, the old western channel has largely silted up and the main channel through the massive flood tide delta generally ends some 300 m to the east of the cliff.

Studies by PWD indicate that the best flushing of water from the Inlet, and maximum loss of sand, is gained by cutting the channel through the bar at the shortest point, even though the channel soon migrates close to the cliff. Measurements made during 1976 showed that the initial flush only cuts a channel through the sand of the ocean bar. It has no effect on the sill which was formed when the bar closed the previous year. The channel cuts itself westward from the initial excavation, for 60 to 80 m. Therefore, provided that the initial cut is located more than 100 m from the cliff, a full width channel will result. If the cut is made closer to the cliff it will open to the cliff, the energy of flow will be dissipated and a smaller channel will be excavated.

How long the bar remains open. This has also been a contentious issue, and is locally believed to be related to the location of the opening. A recent analysis examined the statistics of 'east' and 'west' openings (between 1954 and 1986) and showed that there was no difference in the average number of days the bar remained open when it was opened near the cliff or towards the eastern side of the bar: 182

days in either location (Riney, 1987). However this did not take into account the '100 metre' criterion nominated above. But it did show the overriding significance of rainfall, the greater the rainfall the longer the bar remained open (Figure 8.1). It seems reasonable to conclude that the length of opening is not influenced by the site of the opening cut, provided that the cut is made more than 100 m from the cliff.

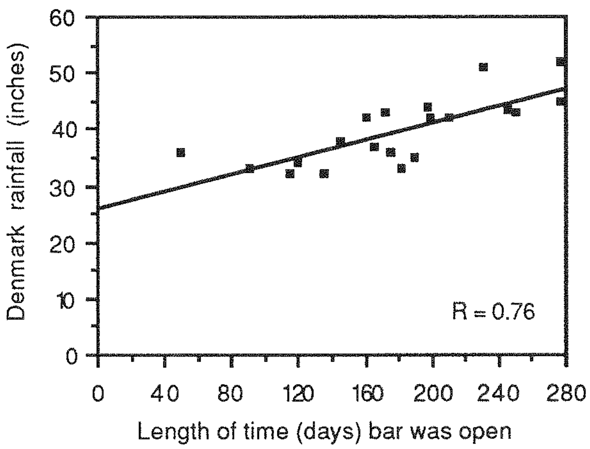

Figure 8.1 The relation between rainfall and length of opening of Wilson Inlet bar. (redrawn from Riney, 1987)

EUTROPHICATION The two perceived problems attributable to nutrient enrichment are the abundant seagrass, *Ruppia*, and some decaying weed on the shores. The *Ruppia* is a nuisance to boat owners and small quantities of rotting seagrass and algae are unpleasant for people using the shores in summer. These are human problems. The estuary is in a biologically healthy condition and it is the *Ruppia* that maintains it in this state. The plants take up most of the nutrients poured in by the rivers and drains and nutrient levels in the water are low. They also help to keep the water well oxygenated and so ensure that any excess of phosphorus is lost to the sediment. The sediment appears to have an almost unlimited capacity to store phosphorus under oxygenated conditions, and it is only released to the water when this lacks oxygen. Only then does phosphorus become more available to algae which, unlike *Ruppia*, must obtain their nutrients from the water.

However the estuary is potentially eutrophic. More nutrients enter it than are lost to the ocean, but under present conditions the *Ruppia* and the sediments combine to maintain low nutrient levels in the water. Some harvesting of seagrass may be desirable for the convenience of boat owners and to reduce accumulations on the shores. But major harvesting of the seagrass could be followed by depletion of oxygen and release of phosphate from the sediment. This could fertilize blooms of both large and microscopic algae, as happens in the Peel-Harvey estuary, and the estuary would then be eutrophic with a serious algal problem. At present algae only form a small part of the plant biomass and stranding of algae on the shores mainly occurs as the result of the lowered water level in summer.

There is always the risk that the present balance may be upset. For example if the *Ruppia* is overgrown by epiphytic algae and dies and decomposes using up the oxygen, as appears to have happened in Harvey Estuary. It is therefore important to ensure that there is no increase in nutrient input and if possible to reduce the amount now entering the estuary. This implies some measure of control of the application of phosphatic fertilizers in the catchment in accordance with the findings and recommendations of the two studies by Lukatelich *et al* (1984, 1986) and Yeates *et al* (1984).

Further clearing of native vegetation for agriculture is likely to increase nutrient input to the estuary because of the application of phosphatic fertilizers. Areas of sandy soils under high rainfall in the catchments of the Sleeman, White and Cuppup rivers, Lake Saide drain and the southern extremity of the Hay River catchment are especially prone to leaching phosphorus. Extension of the drainage network and increased urban development, with septic tanks, on such soils can also add to nutrient input.

Opening of the bar allows the escape of estuary water, and the amount of nutrient lost is determined mainly by the amount of water lost with the fall in water level at the time of opening. Subsequent tidal exchange between the estuary and the ocean is a less important mechanism for nutrient loss, because concentrations in ocean water are not very different from those in the estuary. Once the bar has closed any further water and nutrient input is retained within the Inlet. **This underlines the need to ensure the maximum possible loss of water when the bar is opened and to keep it open at least as long as there is any substantial river flow and nutrient input.**

FISH AND THE FISHERY Wilson Inlet has the largest estuarine fishery of the south coast, both amateur and professional. This is attributable to its present character as a seasonally closed estuary in which there is an abundance of food and a limited range of salinity (10 to 30 ppt) that favours a few estuarine species and excludes most marine predator species. The permanently open, more marine, Nornalup Inlet may have a more diverse fish fauna, with marine 'straggler' species such as Gummy shark, Trevally and Salmon trout, but the common Wilson Inlet species, such as King George whiting, appear to be less abundant there.

The productivity of the fishery depends to a large extent on an adequate supply of food for fish. This the abundant seagrass provides through the food chain, which involves microorganisms, worms, shrimps and the other small invertebrate animals on which the fish feed. Seagrass also provides cover for fish from predators, such as cormorants and other fish.

Most species are recruited to the estuaries from the sea and estuarine populations are dependant on the bars being open when eggs, larvae or juveniles are present in coastal waters. Successful recruitment probably also depends on there being deep, well scoured channels through which there is substantial tidal movement of marine water into the Inlets.

The Wilson Inlet fishery is a restricted entry fishery, new fishing licences are not being issued and when existing licenses expire they are only renewed with the permission of the Minister for Fisheries. Fish netting is not permitted in the vicinity of the bar or in the rivers and near their mouths (Figure 8.2). These areas are reserved for amateur line fishermen and to protect juvenile fish from netting pressure when they enter the Inlet. Amateur fishermen are only allowed to use one net, of 60 mm mesh and 60 m length. There is no limit on the length of nets used by professional fishermen, but there are minimum mesh sizes for particular species.

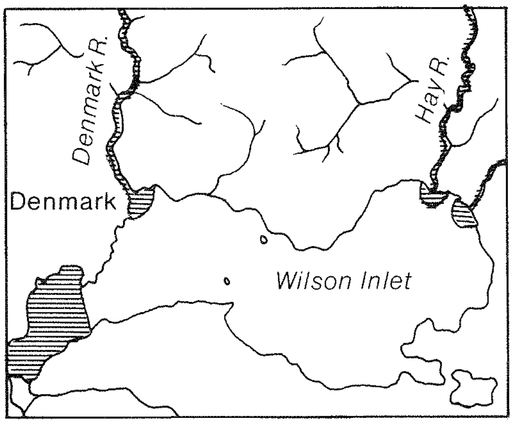

Figure 8.2 Areas closed to all net fishing in Wilson Inlet. (WA Fisheries Department)

SUMMARY There are obvious conflicts of interest with respect to the management of the estuary and compromises will no doubt have to continue to be made, especially with respect to the time and position of opening the bar. However, with respect to the welfare of the estuary and its flora and fauna, **the following appear to be the principal considerations for management:**

- **the bar should be opened at a time and place which will ensure that a deep channel is scoured through the flood tide delta and bar; this is in order to ensure maximum flushing of estuary water to the sea, the greatest loss of sand from the delta, and minimum input of sand to the delta from the sea;**
- **the bar should remain open while there is still flow in the rivers, and long enough for recruitment of fish;**
- **every effort should be made to reduce nutrient input to the estuary and especially to ensure that there is no increased input.**

Perhaps the most serious threat to the estuary is reduced rainfall and river flow. There has been a 20% reduction in rainfall since the turn of the century and damming of the Denmark River has further reduced flow from that source. The 1987 winter rainfall was one of the lowest on record and Inlet water had only risen to 0.77 m above MSL by mid October when the bar was opened and the water might never have reached the 1.1 m level. The bar was not well scoured, it only stayed open for 71 days and the Inlet was poorly flushed, though presumably it received less than the average load of nutrients. By coincidence, in 1988 the Inlet water level had reached 1 m by 31 May when the bar was breached, the earliest opening for 22 years.

8.2 IRWIN INLET

Management of the Irwin Inlet bar presents much the same problems as those of Wilson Inlet: when, where and at what level to open it in order to obtain a satisfactory compromise between flooding roads and agricultural land and ensuring a healthy estuarine ecosystem with a successful fishery. The mouth opens through unconsolidated dunes across an open beach and there is no fixed position for the opening, the height of the bar is set by waves and swell on the beach, and seasonal rainfall determines when the bar is ready to break, all unpredictable factors.

The same principles apply to opening the bar as at Wilson Inlet in order to scour the best possible channel. The water level in the Inlet should be as high as possible, the opening should be as far as practicable from the western shore consistent with getting a good flow, and it should be opened on a high pressure system so as to gain the maximum head of water.

Prolonged closure of the bar over summer, as in 1986-87 (Figure 4.2), can be catastrophic for the aquatic flora and fauna, and for the fishery. Clearly it is desirable to maintain free exchange with the sea as long as is possible to prevent evaporation seriously reducing water level in the Inlet. That is not to say that the bar should be kept open continuously, a situation that might greatly alter the character of the ecosystem.

Owingup Swamp is no longer part of the estuary, and it is unlikely that any significant amount of Inlet water backs up into it. It is however a sediment trap, as is evidenced by the delta of the Kent River where it discharges into the swamp. It is probably also a nutrient trap, though how significant this is will not be known until more samples have been taken from the tributaries.

Irwin Inlet and the Kent River are closed to net fishing from 1 November to the second Saturday in June. The Bow River is permanently closed to net fishing.

8.3 PARRY INLET

Parry Inlet also presents much the same problems as Wilson Inlet with respect to opening the bar, and the same principles apply to its opening in winter. However, if this shallow lagoon is to survive as a viable ecosystem, the main problem is not to release excess water in winter but to prevent its loss by evaporation in summer. It is beyond the scope of this study to assess whether there is any practicable and economic way to solve this problem or even to decide whether any attempt should be made to reverse the natural processes which have reduced the estuary to its present condition. The problem can only be solved with further study based on better data than are presently available, and a careful assessment of the priorities for the estuary.

There are no restrictions on fishing in Parry Inlet.

8.4 FURTHER INVESTIGATION

All three estuaries, especially Wilson Inlet, are of great social and economic value and it is important that they should be maintained as beautiful and healthy ecosystems which give pleasure to people and support a varied plant and animal life, with an abundance of fish. They are dynamic systems subject to constant change, both as the result of natural processes and the increasing impact of human activities on the estuaries themselves and in their catchments. These activities make them vulnerable to dramatic and unwelcome events such as the recent *Nodularia* (blue-green algal) blooms in the Peel-Harvey estuary.

The studies made by Lukatelich *et al* (1984, 1986) provide a valuable basis for understanding the condition of the waters of Wilson Inlet, but this is not directly applicable to Irwin and Parry Inlets. Moreover no two years are alike and major changes to the ecosystems can be precipitated by episodic floods and storms or by large deviations from previously experienced conditions. For example, 1987 was one of the driest years on record, with low river input to the Inlets, and 1988 has had the heaviest early rains for the last 25 years, probably carrying more plant nutrients into the Inlets than ever before.

This Study summarises existing knowledge and understanding of the processes involved in maintenance of the present condition of the estuaries, but if there is to be effective management this must be supplemented by up to date data on the current state of the estuaries. It is suggested that the waters of the estuaries should be sampled at regular intervals for plant nutrients, chlorophyll, dissolved oxygen, light penetration and salinity in order to be forewarned of any deterioration in the condition of the waters. The health of Wilson Inlet especially depends to a large extent on the ability of the seagrass *Ruppia* and the sediments to buffer the nutrients in the water, especially phosphorus, and the condition and distribution of the *Ruppia* should be monitored.

The source of the nutrients is in the catchments of the tributary rivers and drains and it is necessary to monitor the inputs from these sources on a similar basis to the 1982-1985 studies. This involves determining nutrient loads by measuring both concentrations of the nutrients and flows in the tributaries. It is known that there are high levels of pesticides, especially organochlorines, in the soils of the potato paddocks, but as yet there is no information as to the quantities being discharged to the estuaries or the effects they may have on the estuarine fauna. This requires investigation.

The health of the estuaries also depends on the bars and the channels through them functioning in such a way as to allow effective exchange between estuary and ocean water and free movement of fish in and out. There are conflicting views about where, when and how the bars should be opened and there will doubtless continue to be controversy. The suggestions made above about bar management were based on past observations and on limited studies by PWD. A detailed study of sand movements through the inlet channels would provide a more reliable basis for decisions about how the bars should be managed. Such a study should include an examination of the hydrodynamics of flow through the channels and of sand transport in the channels and along the adjacent shoreline, both by wind and by water.

The estuaries are slowly filling with sediment. This is probably not a matter of urgent concern in these three estuaries, but it would be valuable to have a measure of the present rate of sedimentation and of how much this has been accelerated following clearing in the catchments and along the river channels.

9 ACKNOWLEDGEMENTS

The data in this series of studies have been gleaned from a variety of sources - published reports, unplublished records of Government departments and personal observations. Much valuable information has come from fishermen and other local residents who have lived and worked in the area for many years, and it has been a privilege to learn from their memories and experience. There are obvious gaps in our knowledge of these and other estuaries of the south coast, studies of which are now being drafted in this Estuarine Studies Series. The authors will greatly appreciate the continued assistance of those who have contributed in any way to these studies and of anyone else who has relevant information on the estuaries.

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10 REFERENCES

Anon (1987). Draft Coastal Management Plan for the Shire of Denmark. Dept. Conservation and Environment. Bulletin 199.

Beard, J.S. (1979). Vegetation survey of Western Australia: Vegetation of the Albany and Mt Barker Areas. Veg. Map Publications, Perth. S1 50-11 and S1 50-15.

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).

Humphries, R.B., Robertson, J.G.M. and Robertson, F.E. (1982). A resource inventory and management information system for Wilson Inlet, W.A. Department of Conservation and Environment Bulletin 132.

Hutchins, B. and Thompson, M. (1983). The Marine and Estuarine Fishes of South-western Australia. W. A. Museum.

Lenanton, R.C.J. (1974a). Wilson Inlet - a seasonally closed Western Australian south coast estuary. Department of Fisheries and Fauna, W.A. Report 14.

Lenanton, R.C.J. (1974b). 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). The Commercial Fisheries of Temperate Western Australian Estuaries. Early Settlement to 1975. Department of Fisheries and Wildlife, W.A. Bulletin 62.

Lukatelich, R.J., Schofield, N.J. and McComb, A.J. (1984). The Nutrient Status of Wilson Inlet (1982-1983). Department of Conservation and Environment, W.A. Bulletin 159.

Lukatelich, R.J., Schofield, N.J. and McComb, A.J. (1986). The Nutrient Status of Wilson Inlet (1984-1985). Department of Conservation and Environment, W.A. Technical Series 9.

Lukatelich, R.J., Schofield, N.J. and McComb, A.J. (1987). Nutrient loading and macrophyte growth in Wilson Inlet, a bar built South western Australian estuary. *Estuarine, coastal and shelf science*. 24: 141-165.

Muhling, P.C. and Brakel, A.T. (1985). Mount Barker - Albany, Western Australia: West. Australia Geol Surv. 1 ; 250,000 Geol. Series Explan. Notes.

RAC (1986). Touring and accommodation guide book.

Riney, T. (1987). Comment on papers submitted to Denmark Council by Councillor M. Hockley regarding the most appropriate location for opening of Wilson Inlet bar. Unpublished manuscript.

Rochford, D.J. (1953). Estuarine hydrological investigations in eastern and south-western Australia, 1951. *C.S.I.R.O. Aust. Div. Fish. Oceanogr. Sta. List* 12.

Sheriff, G.F. (1951). The History of Denmark. Its exploration and early development. W.A. Historical Soc. Mss.

Spencer, R.S. (1952). Hydrological investigations in south-western Australia, 1944-50. *C.S.I.R.O. Aust. Div. Fish. Oceanogr. Sta. List* 8.

Treloar (1977). Southwest Coast Estuarine Study, Mss, Environmental Protection Authority, Perth Western Australia

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

Wells, F.E. and Bryce, C.W. (1984). A guide to the common Molluscs of South-western Australian estuaries. W. A. Museum. pp112.

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

Yeates, J.S., Deeley, D.M., Clark, M.F. and Allen, D. (1984). Modifying fertilizer practices. *J. Agric.W.A.* 25(3):87-91.

Irwin Inlet March 1988 Photo: Land Administration, WA

Parry Inlet January 1988 Photo: Ruth Clark