The Leschenault Inlet estuary: physical features and habitats for benthic fauna

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Abstract

The Leschenault Inlet estuary has a distinctive pattern of bathymetry, water salinity and sediment types. The estuary is a flat, elongate central basin, flanked to east and west by shallow, shore-parallel platforms. The central basin grades into a shallow-water flat in the north, and adjoins deltas in the south. The estuary is underlain by mud in the central basin and northern flat, sand and muddy-sand on the eastern platform, mud, muddy-sand, sandy-mud and sand on the western platform, and predominantly sand under the deltas. The estuarine waters undergo seasonal changes in salinity as a result of restricted oceanic exchange, freshwater inflow during winter and evaporation in summer. Various salinity fields were identified in this study, based on the mean and range of salinity values occurring within the annual hydrological cycle. Hypersaline to mesosaline waters occur to the north, and increasingly more hyposaline to mesosaline waters occur to the south. Each of the large-scale geomorphic units in the estuary can further be subdivided on the basis of water salinity, bathymetry, substrate and presence of macrophytes. Based on these physical features, nineteen small-scale habitats units were proposed for Leschenault Inlet. These smaller scale habitat units provide a framework within which to study the distribution and ecology of benthic fauna.

Keywords: estuarine habitat classification, Leschenault Inlet, estuary, south-western Australia.

Introduction

Leschenault Inlet (Fig 1) is one of many estuaries in south-western Australia (Hodgkin *et al.* 1979). However, it is unique in the region as it has developed behind Holocene barrier dunes some 8 000 years ago, and has remained an estuarine lagoon since then (Semeniuk 1985). During its history, the combination of evolving adjacent subaerial landforms, regional climate, fluvial input of fresh water and sediments and restricted oceanic exchange has generated a dynamic and heterogeneous estuarine system. As such, Leschenault Inlet provides an opportunity to investigate a small and well defined system that contains a variety of estuarine features.

Other estuaries in south-western Australia have been studied to varying detail (Spencer 1955; Ashman *et al.* 1969; Smith 1975; Wallace 1975; Chalmer *et al.* 1976; Brown *et al.* 1980; Wells *et al.* 1980; Wells & Threlfall 1981 1982 a,b,c; Lukatelich & McComb 1983; Chalmer & Scott 1984; Hodgkin 1984; Anon 1985a; Semeniuk & Semeniuk 1990, 1991), mostly concentrating on some aspect of biota, geomorphology, hydrology, sedimentation, peripheral vegetation habitats, or age structure of estuaries. Leschenault Inlet was briefly surveyed for benthic fauna in 1974 by Chalmer & Scott (1984), and other workers have reported incidentally on it for comparative biological work (Smith 1975; Wells & Threlfall 1981).

Most of the above studies have focused on the biology and occurrence of specific molluscs, or on the physical features of the Inlet. Previous studies have not generally integrated the information on the features of the estuary into descriptions of habitats for fauna. This study developed a more detailed description of the estuarine environment of Leschenault Inlet than has previously been undertaken. The description of physical features was then used to develop a framework of estuarine habitats within which to consider the distribution and ecology of biota such as molluscs, crustacea, polychaetes, echinoderms, peripheral vegetation, mangroves, and avifauna. Such a framework may also be useful for designing and implementing future sampling programs within the estuary.

Environmental setting of Leschenault Inlet

Climate

Climate has a major effect on Leschenault Inlet, particularly on salinity and wind-induced processes. Salinity changes are due to fresh water input during winter, evaporation during summer, and wind-induced circulation and mixing of water. Wind shapes the large-scale habitats within the estuary (*e.g.* dune encroachment along the west shore), and generates waves and currents which rework substrates, transport sediment, cause turbidity, disperse sand sheets, and form shoreline spits. The climate of this region is typified by mild wet winters and hot dry summers. Annual rainfall is 881 mm, falling mainly between April and August. Annual evaporation is approximately 1 300 mm, and is most extreme in summer. Mean maximum summer temperature is 27.9 °C, and mean minimum winter temperature is 8.3 °C (Anon 1975). Wind patterns are related to summer and winter seasons (Semeniuk & Meagher 1981a). Summer winds are dominated by sea breezes emanating from south-western sectors, and land breezes emanating from SE to NE sectors. Winter is characterized by mild winds usually from easterly sectors, and occasional storms.

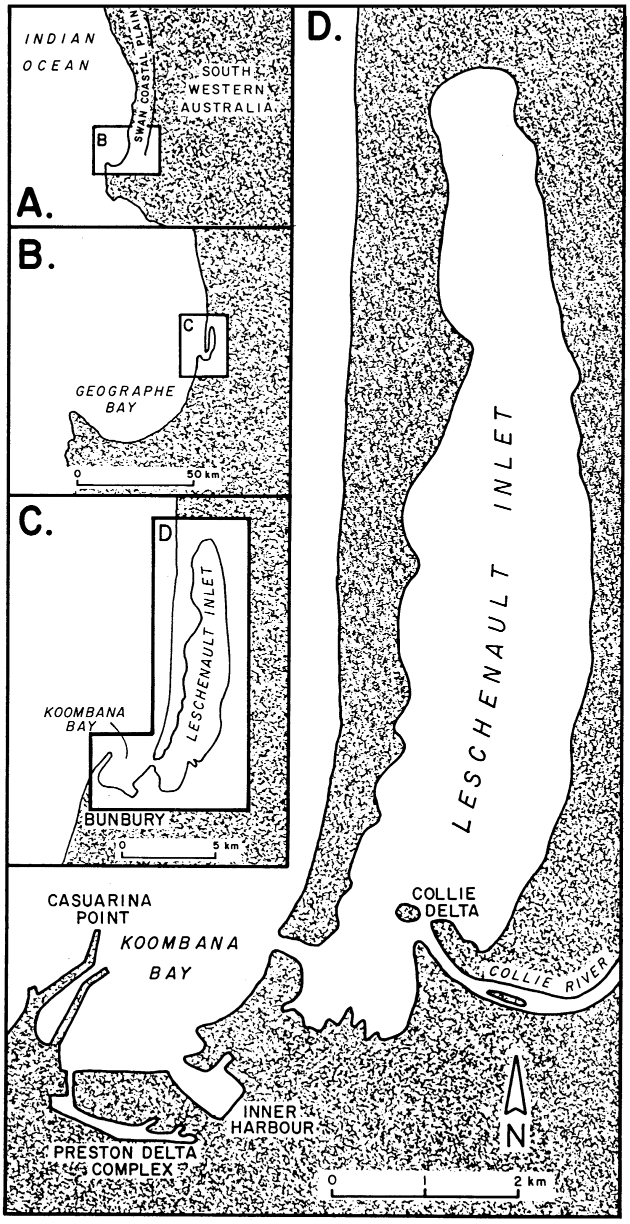

Figure 1. Location of the Leschenault Inlet.

Geomorphology

Leschenault Inlet is located at the junction of Yalgorup Plain, Mandurah-Eaton Ridge, and the Quindalup landform systems (McArthur & Bartle 1980, Semeniuk 1990, 1995, 1997), and is the receiving basin for the Collie and Preston rivers. The estuary is bordered to the west by a barrier of quartz and calcareous sand (Quindalup Dunes) of eastward migrating parabolic dunes. The shore along the barrier consists of alternating exposed sandy promontories and more sheltered embayments, due to the staggered dune migration into the estuary, and thus exhibits a heterogeneous suite of sediments (and, potentially, habitats). The eastern shore is bordered by a low lying plain underlain by quartz sand and limestone that flanks a linear quartz sand ridge (southern extremity of the Yalgorup Plain, and the Mandurah-Eaton Ridge). This shore is more linear than the west shore, and hence is less diverse in terms of shore types. To the north, the aquatic part of the estuary is bordered by supratidal samphire flats, and to the south by the Collie and Preston river deltas. High inter-tidal salt-marsh flats fringe the aquatic part of the estuary, particularly to the north and north-west. Shallow-water platforms and slopes comprise its aquatic periphery, and an elongate muddy basin occupies its central length (Semeniuk & Meagher 1981a). The platforms are mainly of sediment derived from the flanking dunes and have been developed by wave action, and modified through erosion and deposition by currents. The northern estuary is an extensive shallow-water flat, and along the north-eastern shore is a tidal to shallow sub-tidal limestone pavement.

The southern part of the estuary has been substantially modified in the last 40 years. This has included in-filling of the original estuary outlet to the sea, redirection of the Preston River and construction of an artificial exchange channel with the ocean ("The Cut"). Construction of "The Cut" has resulted in the development of a tidal delta within the estuary, and the partial destruction of the Collie River Delta (Semeniuk & Meagher 1981a; Anon 1985b; Pen 2000).

Sedimentology

Processes which determine the modern sediment distribution within the estuary are (Semeniuk & Meagher 1981a; Semeniuk 2000):

- landward movement of barrier dunes, resulting in parabolic dunes eventually encroaching into the western shore of the estuary, providing quartz and carbonate sand to the western platform;
- reworking of dune promontories along the western shore to develop sand sheets and shoreline spits;
- incorporation of quartz sand into the estuary by wind waves eroding the eastern shore;
- wave-building and current modification of sand, forming nearshore platforms;
- transport of fluvial mud and quartzo-felspathic sand into the estuary by the Collie and Preston rivers;
- re-suspension of mud by wind waves, and subsequent transport towards low energy environments of the central basin, the northern sector of the estuary and the sheltered embayments along the west shore; and
- autochthonous accumulation of organic and calcareous mud, and calcareous sand and gravel due to aquatic and marshland flora and estuarine fauna.

Leschenault Inlet thus is filling with sediment of aeolian, fluvial and biological origin. The habitats in the estuary therefore are locally dynamic in the short term (*e.g.* five to ten years), and evolving in the long term (*e.g.* hundreds to thousands of years).

Hydrodynamics and hydrochemistry

Tides of Leschenault Inlet are diurnal and micro-tidal, with a mean spring range of 0.5 m and a maximum range of 0.9 m. The estuary is classified as a micro-tidal barrier lagoon estuary (Hayes 1975). Barometric pressure has a greater influence on water level than astronomical tides (Hodgkin & DiLollo 1958), with high pressure systems in summer contributing to low tides, and low pressure in winter producing a general rise in mean sea level (Semeniuk & Meagher 1981a). Tides in the estuary also are dampened by the restricted exchange with the ocean through "The Cut" (McComb & Lukatelich 1986). As is typical of estuaries, the waters of Leschenault Inlet commonly are turbid (Day 1981) due to re-suspension of mud by wave action.

Prior to the major modifications to the south of the estuary, exchange between the estuary and the ocean took place via a 3 km-long, narrow, tidal-deltaic channel. This channel is now blocked or filled, and increased exchange with the ocean occurs through "The Cut". Fluctuations in water salinity of the estuary have stabilized, particularly to the south, by decreasing the effect of fresh water input from rivers, and by diluting with sea water the high salinity which develops with summer evaporation. Thus, the hydrodynamics, salinity fields and gradients within the estuary now are largely controlled by the interplay of a still relatively restricted exchange with the ocean, fresh water input during winter, and evaporation. Other developments that influenced hydrochemistry of the estuary include (Anon 1985b):

- the Wellington Dam, completed in 1960, which claims 2 830 km² of the total 3 600 km² of the Collie River catchment, and has reduced the flow of fresh water into the estuary;
- the Parkfield Drain, completed in 1977, which empties directly into the north of the estuary; and
- discharge of various effluents into water courses since 1983 which ultimately enter the estuary.

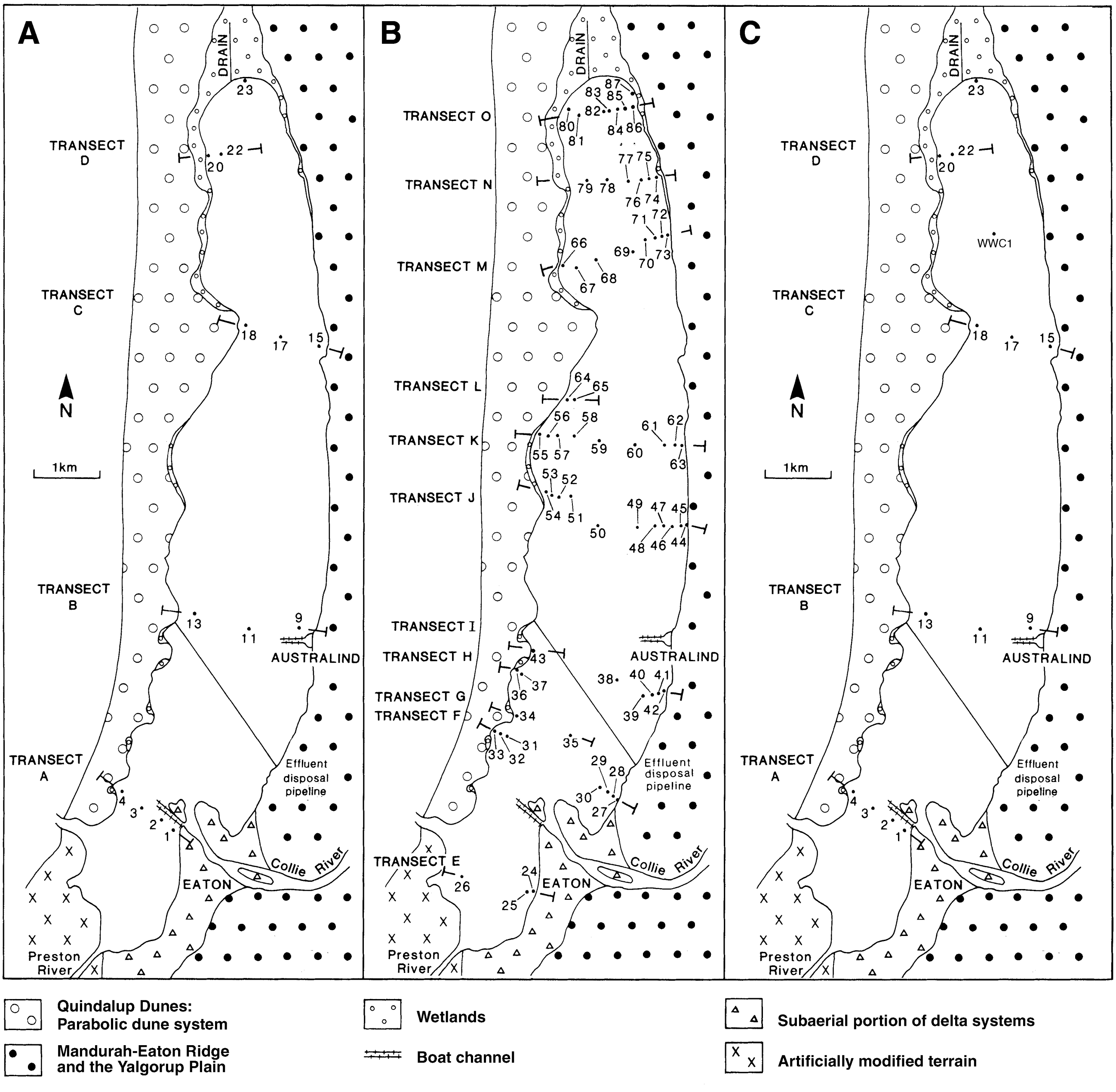

Figure 2. A: Sample sites along Transects A, B, C and D. **B:** Location of sites along Transects E to O for sampling of substrate, fauna, and flora. **C:** Water sampling sites.

Methods

This study of the physical features of Leschenault Inlet involved a range of sampling strategies, locations and times over five years between 1982 and 1987. Detritus and substrates were sampled and analysed once during this study. Macrophytes were sampled annually. During 1986/87, water quality parameters were monitored in blocks of weekly sampling during the seasonal peaks of either freshwater input during winter or evaporation during summer, separated by periods of monthly sampling. The geomorphology and bathymetry of the inlet were mapped by ground-truthing aerial photographs, and by probing the inlet floor from a boat. The study is confined to the area below the high inter-tidal to supra-tidal zone *i.e.* saltmarsh flats fringing the estuary (Semeniuk & Meagher 1981a).

A reconnaissance survey of the estuary was undertaken in February 1982 to identify the main habitat types, based on bathymetry, substrate, vegetation cover and hydrologic setting. This survey was the basis for selection of 22 sampling sites located along 4 main sampling transects oriented east-west across the estuary (Transects A-D; Table 1 and Fig 2A). Vegetation and selected physical and chemical features of habitats were monitored at these sites between 1982-1987.

A more wide-ranging survey was undertaken in December 1986 to extend the results of the 1982 survey, by quantitatively documenting bathymetry, substrates, macrophytes and fauna beyond that of the main transects (Transects E-O, Fig 2B). During this survey, substrates were sampled at the 87 sites in (Transects A-O), to determine grain size. Samples were sieved at 1 Æ intervals. The shallow stratigraphy was also determined at these sites by probing the substrate with a metal rod to 2 m. This method allowed identification of layers of mud, sandy-mud/muddy-sand, sand, shell gravel and rock.

During this survey, the presence/absence of macrophyte species was also recorded at the 87 mapping sites. Macrophytes were also quantitatively sampled annually at sites along Transects A-D, and distributions were also observed during aerial photo ground -truthing. Studies of the abundance and distribution of all species of macrophytes in the estuary have been undertaken by Lukatelich (1986) and Hillman *et al.* (2000). Macrophytes in this study are considered primarily as a component of habitat for fauna, and have only been studied from this perspective. The detritus content of the substrate was also determined at the 22 sampling sites (Transect A-D) in December 1986. Both macrophyte abundance and detritus content of the substrate were measured by collecting five replicate samples of substrate with *in situ* macrophytes, using a 25 cm x 25 cm x 25 cm box core. This sample was washed through a 1 mm mesh. Detritus and macrophytes were separated and then dried at 50 ^{o}C to a constant weight.

Table 1: Time of sampling for habitat parameters (A) water quality, and (B) other habitat variables.

A: Water quality

Data source	**Date**	**Sampling frequency**
Anon 1982-1984	From February 1982 to May 1984	every 12 weeks
(Waterways Commission of WA)		
	From June 1984 to March 1987	
	June to November	every week
	December to February	every 2 weeks
	March to May	every 6 weeks
Anon 1982-1983	December 1982 to January 1983	every 2 weeks
(State Energy Commission of WA)		
Anon 1982-1983 (LeProvost,	February 1982 to July 1983	every 6 to 8 weeks
Semeniuk & Chalmer,	May 1982 to September 1982	every 1 to 2 weeks
Environmental Consultants)		
	September 1982 to March 1983	every 6 weeks
This study	See Tables 2, 3 and 4	

B: Other habitat variables

Habitat variable	**Sampling date**
Transects A-D	
Bathymetry	December 1986
Subtrates	February 1982
Flora	February 1987
Transects E-O	
Bathymetry	December 1986
Subtrates	December 1986
Shallow stratigraphy	December 1986
Flora	December 1986

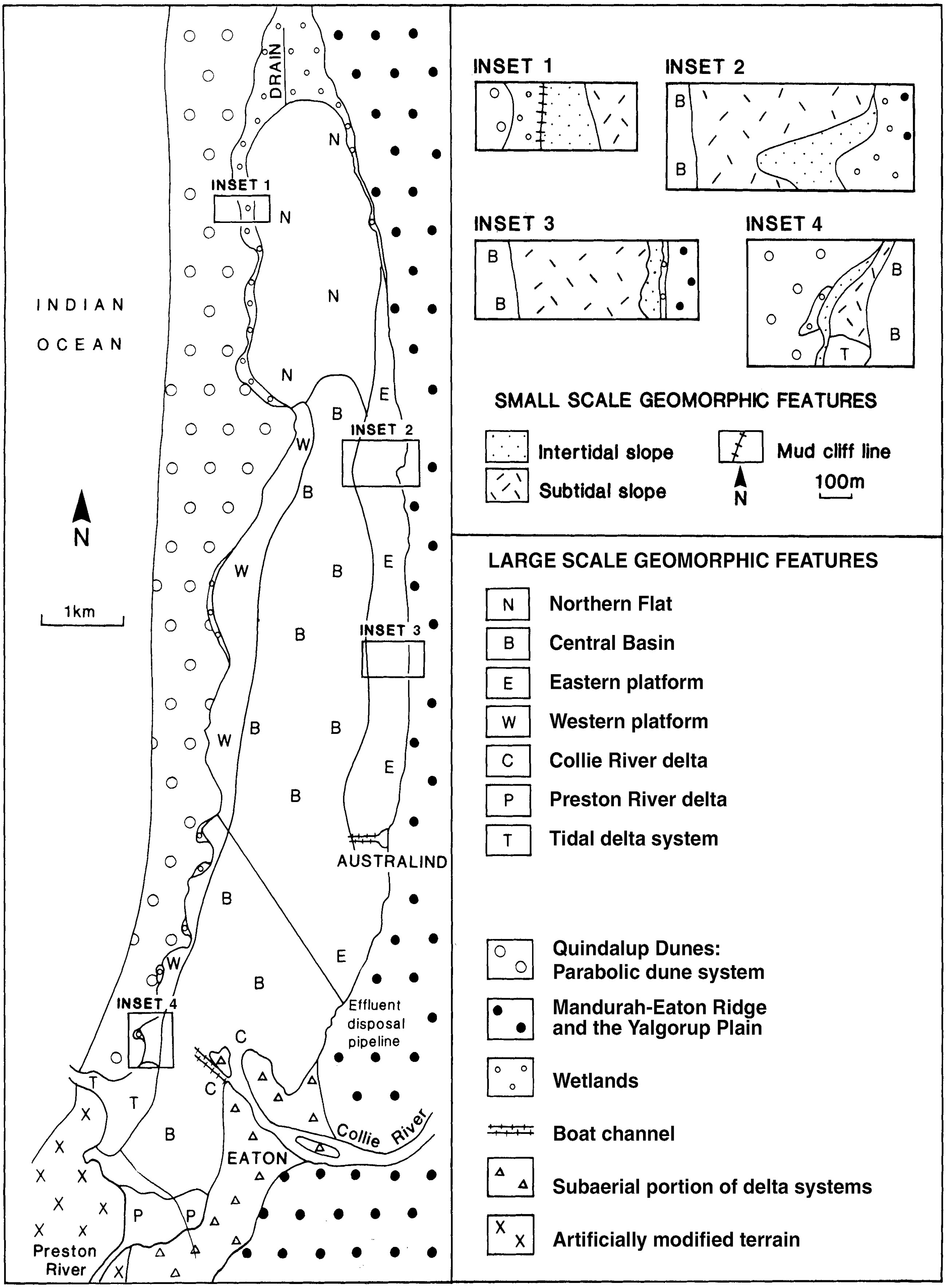

Figure 3. Map of the distribution of the large-scale geomorphic units of Leschenault Inlet.

Data on water quality were collected weekly, monthly, six-weekly and three-monthly at selected sites by Anon (1982a), Anon (1982b), Klemm, (1984, *pers comm*; information from Water & Rivers Commission)

Data collected prior to June 1986, also are considered in this study. However, these existing data were not totally adequate for this study, as the sampling programs had been designed for other objectives. Consequently, during 1986 and 1987 water salinity, temperature and oxygen concentration were sampled intensively, at selected sites along the monitoring transects (Fig 2C). These parameters were considered to be directly critical to the functions of benthos. Factors such as nitrogen and phosphorus concentration, turbidity and plant pigment concentration also can determine the water characteristics of habitats for benthic fauna, but were not included in this study. All water parameters and water samples were measured at the base of the water column, as this is the stratum directly affecting benthos. Salinity was determined using a TPS Model digital conductivity meter. Oxygen concentration initially was measured with two types of dissolved oxygen meters, a Beckman Model meter and a Hanna HI 8543 meter. Later, oxygen concentration was determined using the Winkler titration method (Riley & Chester 1971), with water samples acidified and fixed in the field to off-set plankton and detrital decay. Temperature was measured with a maximum-minimum toluene-mercury thermometer.

This study of the habitat features of Leschenault Inlet is part of a larger study that also described and monitored benthic fauna at sites used for habitat measurement and monitoring. These data are presented by Semeniuk & Wurm (2000) and Wurm (1987).

Results

Bathymetry and estuarine geomorphology

Leschenault Inlet is a long, narrow, estuarine lagoon, oriented north-south, approximately 13 km long and 1.5 km to 2.5 km wide. The estuary can be divided into five bathymetric and geomorphic units: central basin, northern flat, western platform, eastern platform, and the delta systems (Fig 3).

The central basin is approximately 10 km by 1 km, and has an average depth of 1.75 m, reaching a maximum of 2.5m. The bathymetrically deepest part is adjacent to the eastern platform. The contact between the basin and the eastern platform is abrupt, while along its western edge the basin slopes more gently into the western platform. The basin surface is very gently undulating to flat, and marked by centimeter-sized burrows.

The northern flat occupies the northern quarter of the estuary. An inter-tidal slope, approximately 200 m to 500 m wide, flanks the sub-tidal, central area of the flat, which has a maximum depth of approximately 50 cm. The inter-tidal surface has shallow, metre-sized depressions and channels that remain water-filled during low tides. The inter-tidal zone adjoins a low (10-30 cm) mud cliff at the edge of fringing marshlands. A limestone pavement appears locally in north-eastern parts of the flat, and meets a low cliff cut into limestone at the shoreline.

The eastern platform is approximately 500 m wide and slopes gently from the estuary shore to a steep contact with the basin at depths of approximately 1 m. Along the shore there is an inter-tidal slope of variable width but up to approximately 100 m wide, which is frequently exposed during periods of low water in summer. In front of the flanking marshlands, this platform adjoins low (10-20 cm) mud cliffs or very narrow beaches. The platform surface is hummocky to irregular due to wave scouring at the metre scale (Semeniuk & Meagher 1981a), and burrowing by crabs, fish and worms at the decimeter scale. The littoral zone is marked by cuspate shores, most probably developed by wind waves acting on the platform and sandy shore.

The western platform, approximately 200 m to 400 m wide, slopes gently from shore towards its contact with the central basin, where the water depth is approximately 1 m. It consists mostly of a gently inclined platform that laterally grades to a more inclined slope or ramp, depending on its disposition relative to adjoining, encroaching dunes. Its surface is marked by burrows and shallow metre-sized depressions, particularly in depths < 30 cm. An inter-tidal slope occurs as an irregular narrow (*ca* 50 m) zone which adjoins either narrow sandy beaches (where the shore is an encroaching dune) or low (10-20 cm) cliffs cut into mud (where the shore is salt marsh).

The Collie River delta protrudes from the shore as a subaerial and aquatic lobe in the south of the estuary. The delta has components of delta front sand, subaerial delta marshes, beach ridges and cheniers, abandoned channels, levees, distributary channels, and mid-channel islands. At its western edge the delta abuts the central basin relatively sharply, but grades more gently onto the eastern platform at its northern edge. Much of the delta front is inter-tidal, and it grades down to a maximum depth of 40 cm at its basin edge. The Preston River delta complex occurs in the extreme south of the estuary, and a dynamic tidal delta system has developed at the mouth of "The Cut". These latter two systems are not discussed further in this study.

Surface Substrate Types and Distribution

The type and distribution of substrates are significant in determining the distribution of the benthic fauna (Yonge 1976). For example, the distribution of deposit feeders can be largely determined by particle size, due to their feeding mechanisms (Tunnicliffe & Risk 1977). The predominant substrates in the Inlet, in order of increasing surface area, are mud, sand, muddy-sand and sandy-mud. The distribution of three most wide-spread sediment grain sizes (coarse sand, medium sand, and mud) are shown in Fig 4. Granulometry of sediments collected from the sampling sites along Transects A-D are shown in Figs 5-8. Diagrams for Transects E-O are presented by Wurm (1987), or are available from the authors. The estuary is underlain predominantly by mud in the central and northern sectors, sand and muddy-sand along the eastern platform, mud, muddy-sand, sandy-mud and sand along the western platform, and predominantly sand around the delta systems.

The central basin is underlain by muddy sediment

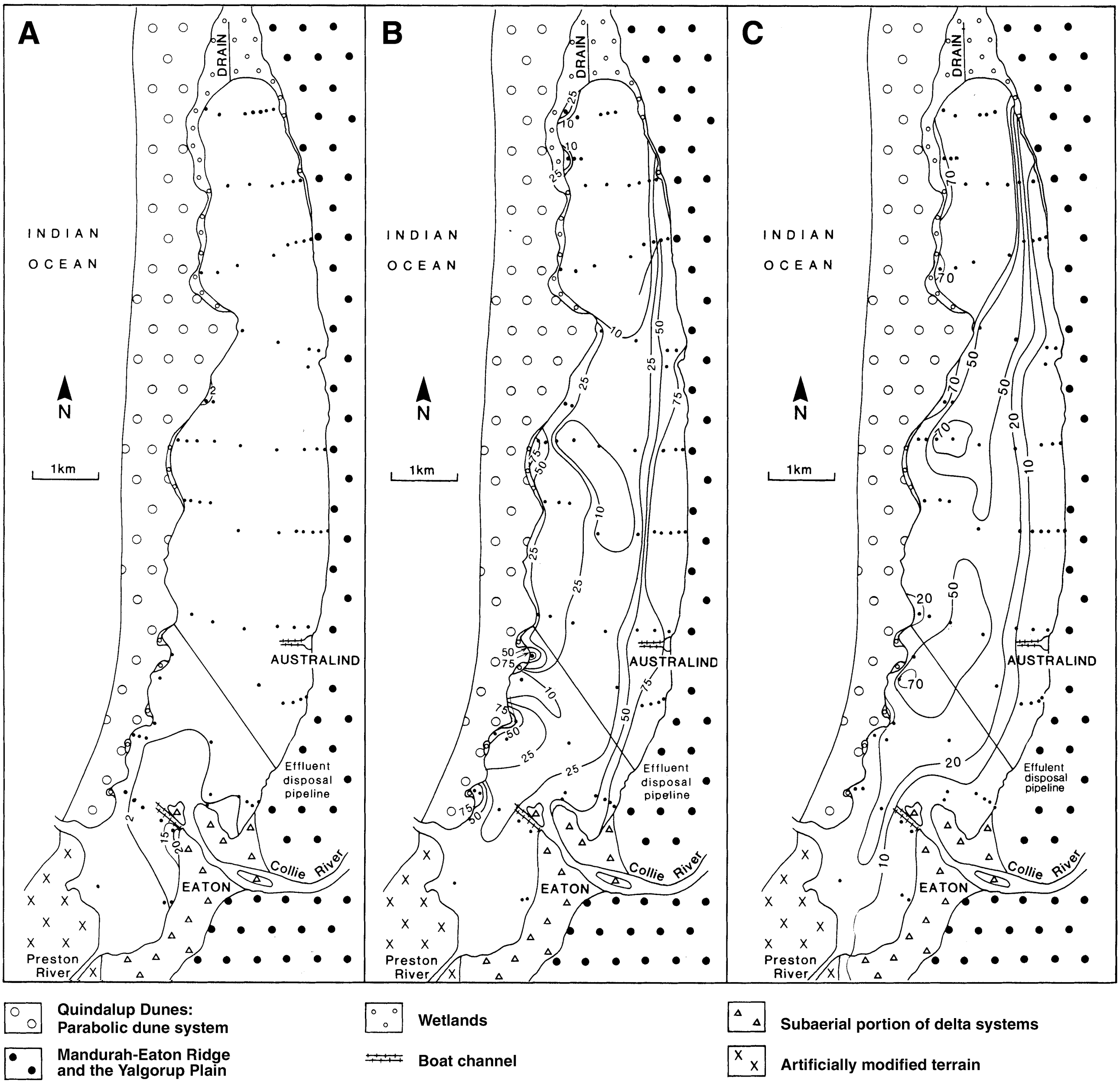

Figure 4. Contour maps of percentage content of selected grain sizes of substrates in Leschenault Inlet estuary. Dots indicate points from which substrate samples were collected. **A:** Distribution of coarse sand (> 500 mm - 1 mm particle diameter). **B:** Distribution of medium sand (>250 mm - 500 mm particle diameter). **C:** Distribution of mud (< 63 mm particle diameter).

(Figs 4B, 7, 8). Distribution of sediment types indicates that there has been local influx of sand from the reworking and incorporation of sand on flanking platforms (*e.g.* Fig 7, sites 10 and 13). Sandy-mud also occurs locally (*e.g.* Fig 5, site 3), where the sand fraction was primarily shell fragments, unlike the sand of the deltas and platforms, which was mainly quartz. The northern flat is underlain by muddy sediments (generally > 70% mud). However sand from the eastern platform extends into the muds of the northern flat along its eastern shore (Fig 4C; Fig 9F). Similarly, the patterns of heterogeneity along the western platform shore also are evident along the western shore of the northern flat (Fig 4B,C).

The eastern platform is underlain mainly by medium sand with < 10% mud (Fig 4B,C). Sand texture along the length of the eastern platform is relatively homogeneous, with an increase in mud content towards the central basin. This relative homogeneity reflects the origin of the platform (*i.e.* the reworking of a linear, sandy shore). The western platform substrates are more texturally heterogeneous, similarly reflecting their origin (*i.e.* the staggered encroachment of dunes into the estuary) (Fig 4B,C). At the tip of dune promontories sand sheets have developed as dunes are reworked at the shore. Distribution of substrate types indicates that muddy-sand and sandy-mud substrates develop over time as mud is mixed into what was formerly dune sand.

The Collie River delta system is underlain mainly by medium and coarse angular quartz and felspar sand, with some very coarse sand and granules (Figs 4A, Fig 5, 6). The northern edge of the delta lobe is underlain by mainly

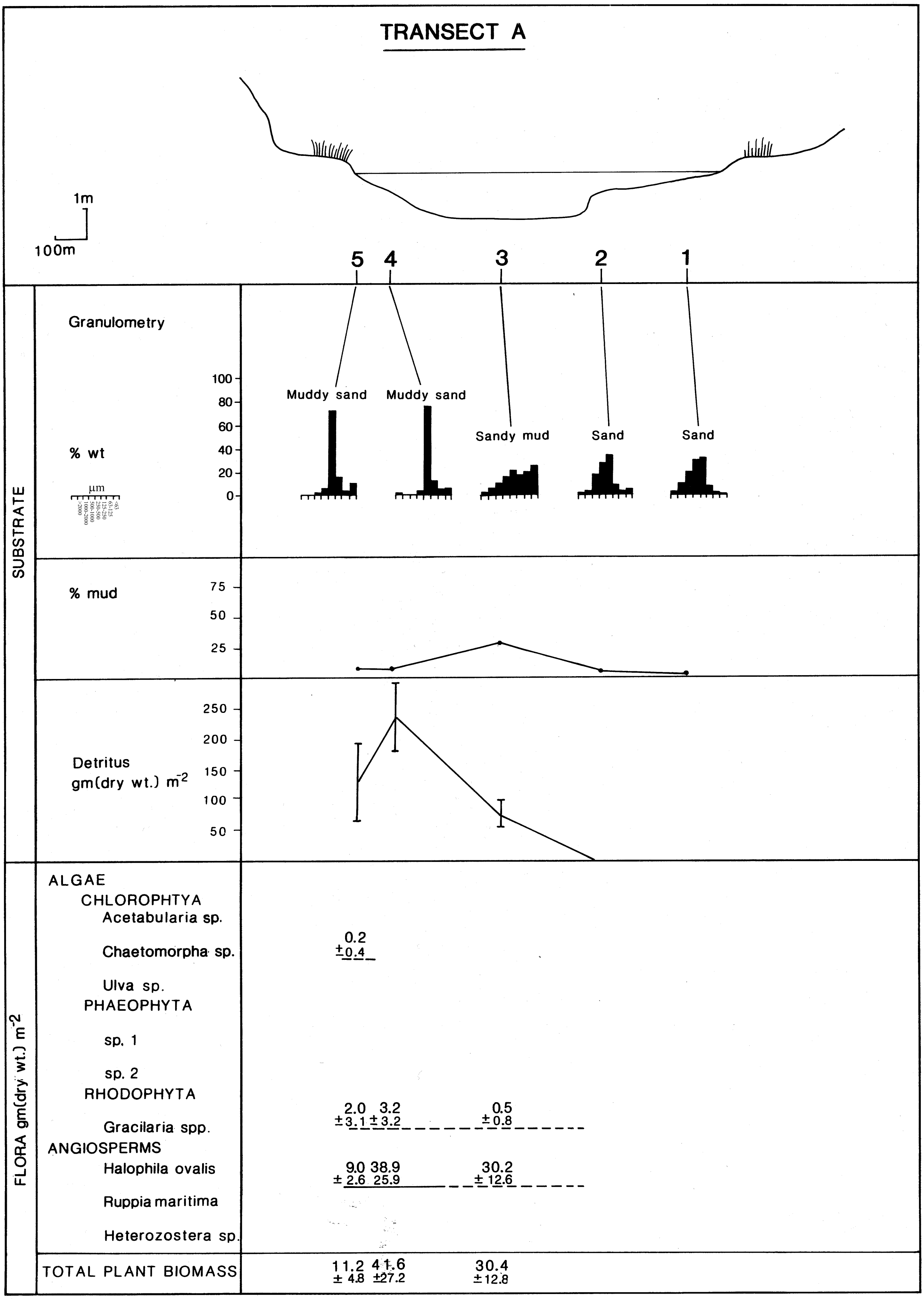

Figure 5. Geomorphic profile across Leschenault Inlet, showing substrate and macrophyte characteristics of sites along Transect A. Location of site is shown in Fig 2A.

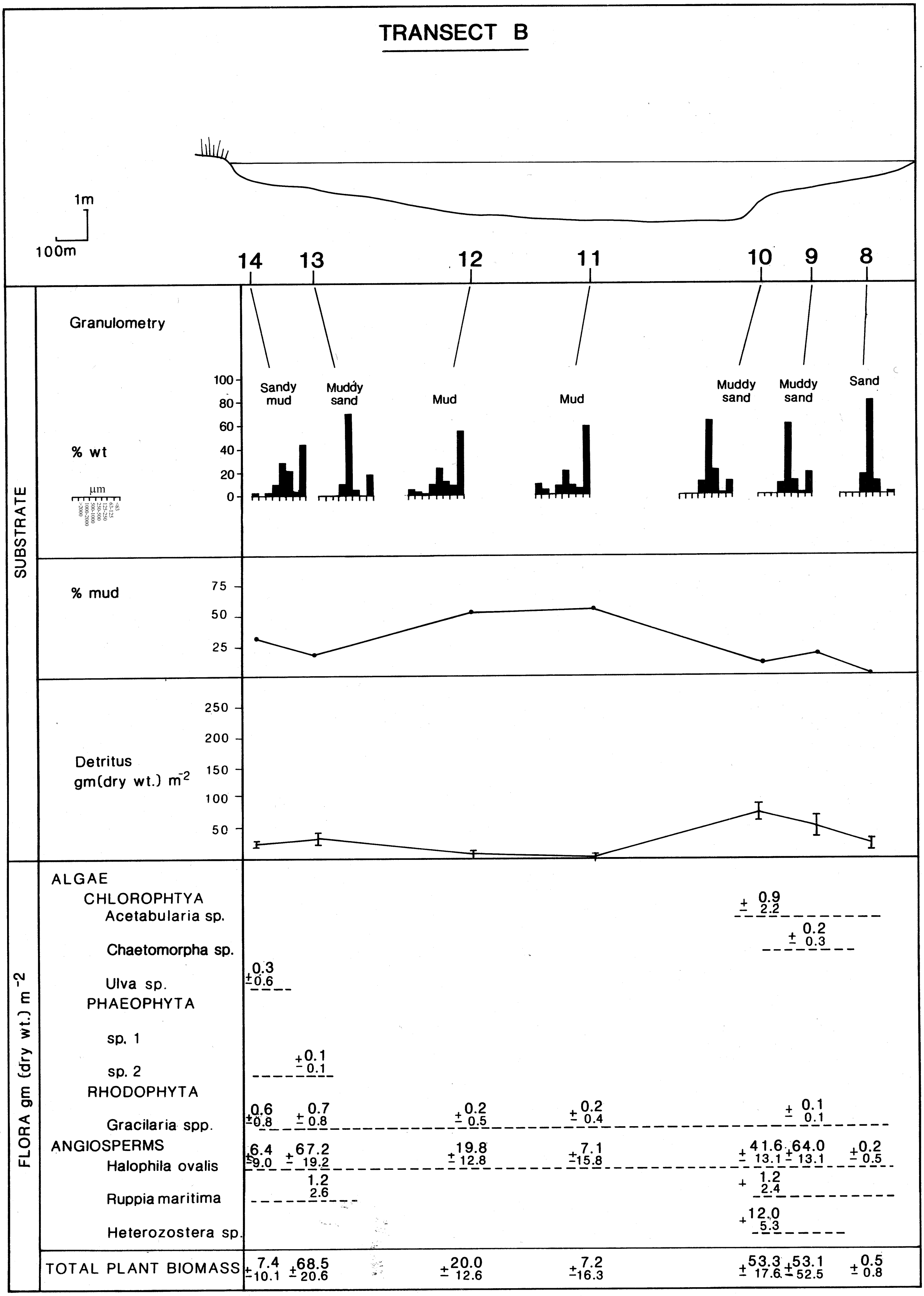

Figure 6. Geomorphic profile across Leschenault Inlet, showing substrate and macrophyte characteristics of sites along Transect B. Location of site is shown in Fig 2A.

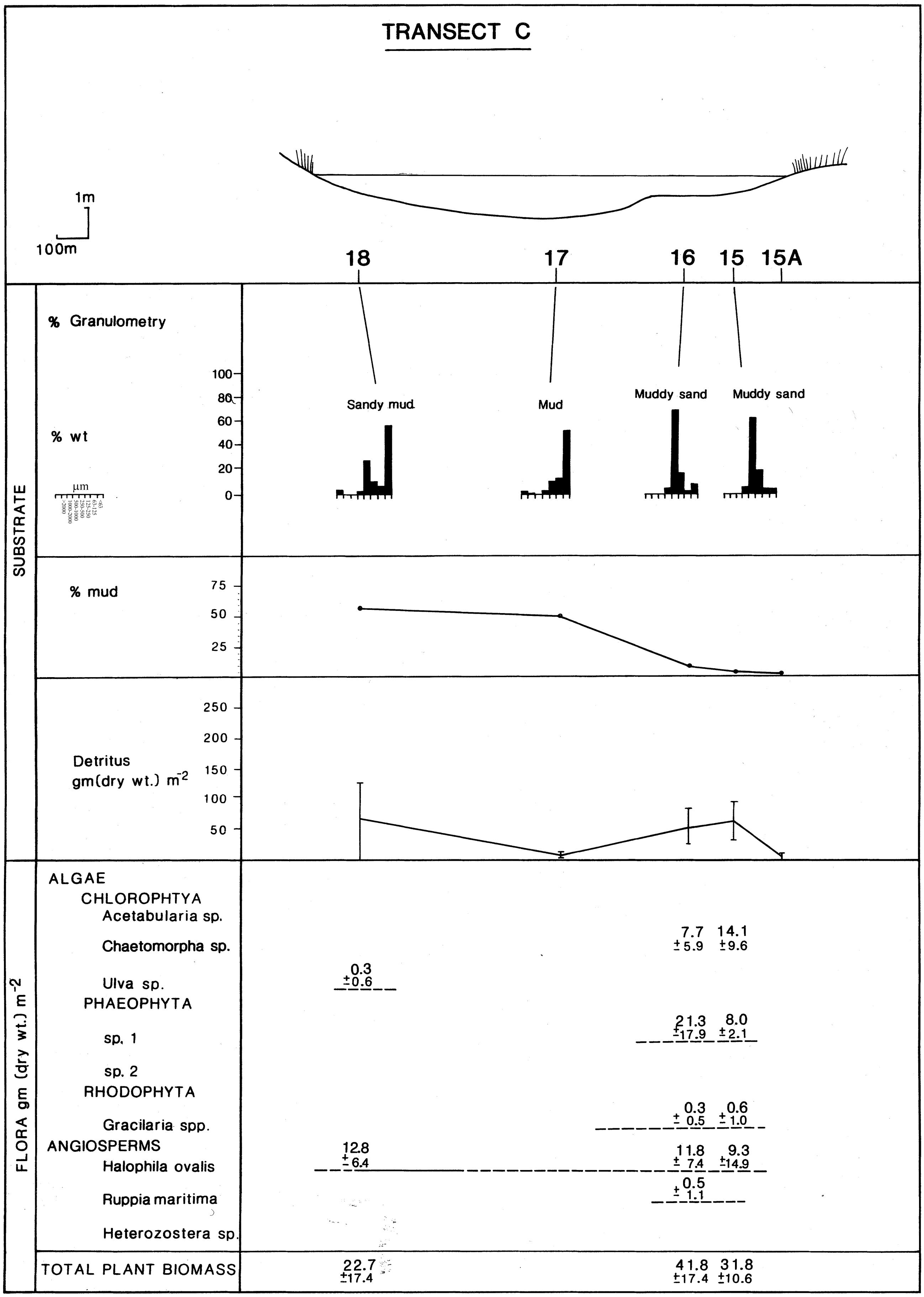

Figure 7. Geomorphic profile across Leschenault Inlet, showing substrate and macrophyte characteristics of sites along Transect C. Location of site is shown in Fig 2A.

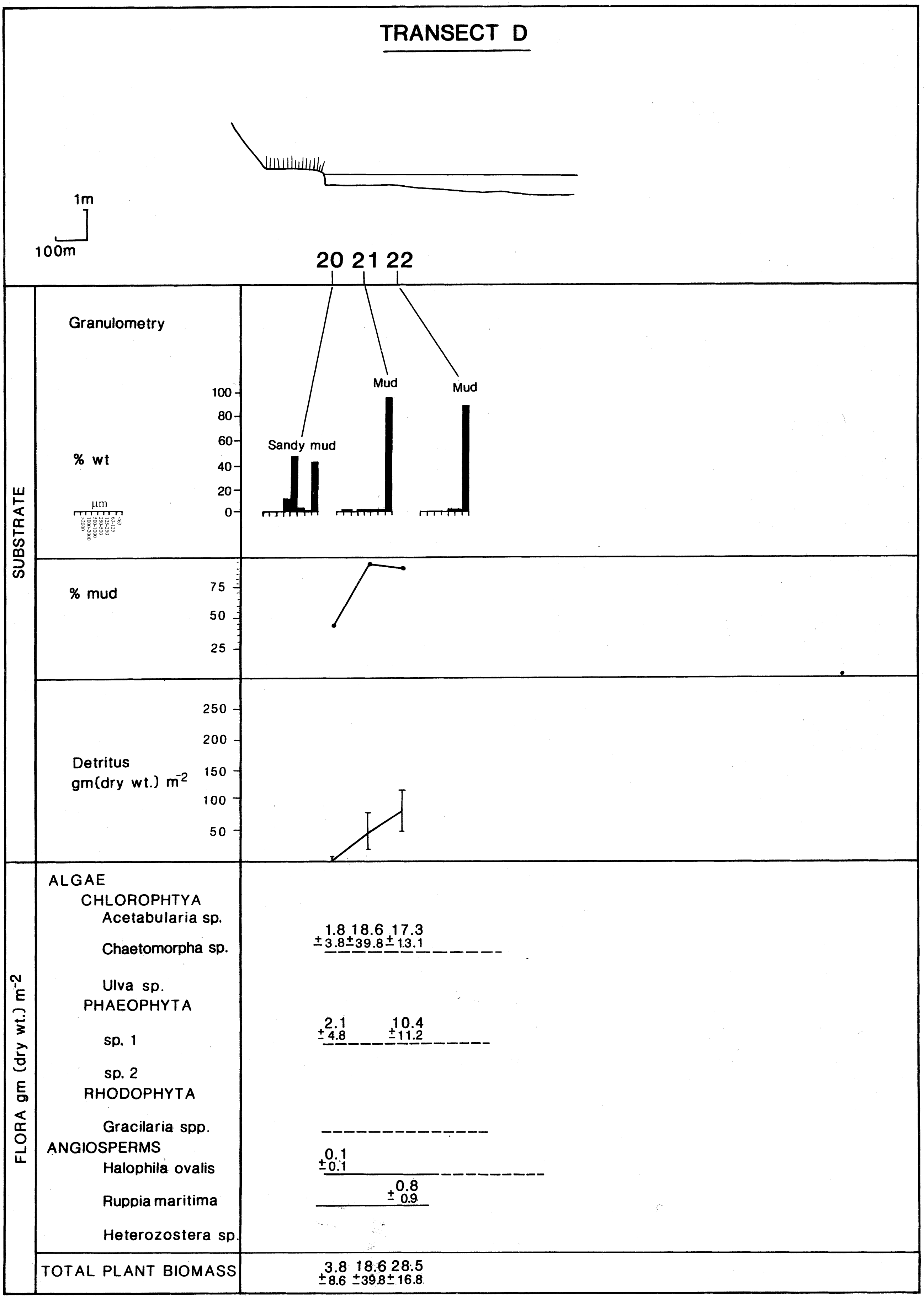

Figure 8. Geomorphic profile across Leschenault Inlet, showing substrate and macrophyte characteristics of sites along Transect D. Location of site is shown in Fig 2A.

medium sand with less coarse sand and little very coarse sand, probably due to the lower energy regime there. The delta is a dynamic system due to the continuing deposition of sediment by the Collie River and reworking of the delta at its seaward edge. For example, during this 5-year study, a 10 cm thick sheet of coarse sand encroached over south-western sites on the delta, and a 50 cm thick sheet of medium sand encroached over western and northern sampling sites on the delta.

Detritus occurs most abundantly in the substrates of the eastern and western platforms, where macrophytes are also most abundant (Figs 5-8). However, despite relatively minor macrophyte cover across the northern flat, the detritus content here also is relatively high (Figure 8). This may be due to drifts of floating algae washed in from marine sources (informally observed during the course of this study), and input from the marshes fringing its shore. Detritus is low in muds of the central basin, in unvegetated sands of the delta, and inter-tidal slopes of the eastern platform (Figs 5-8). Note, however that detritus was sampled only once during this study. It is likely that this substrate character may vary with seasonal variations in macrophytes.

Shallow stratigraphy

The shallow stratigraphy provides information on the homogeneity of substrata with depth, and the extent of interlayering of sediment types due to burial of previous substrates. This in turn provides information on the origin and development of substrate types, and an indication of the evolution and dynamics of habitats and associated biota. Shallow stratigraphy also influences deep burrowing fauna and rooted vegetation. Information on shallow stratigraphy is also presented in Semeniuk & Meagher (1981a), Wurm (1987) and Semeniuk (2000).

The northern flat is generally underlain by homogeneous mud, though a more complex stratigraphy occurs along its north-eastern shore indicating dynamic short-term habitat variations (Fig 9 Transects J, K). Limestone also crops out at the north-north-eastern shore and forms an undulating surface, periodically buried under a thin cover of mud and interlayered muddy and sandy sediment. The muddy-sand and sand substrates of the eastern platform and the mud of the central basin are homogeneous at depth, indicating relative long-term stability in habitats (Fig 9 Transect F sites 44-48, Fig 9 Transect G sites 61-63). The western platform, in contrast, has a complex shallow stratigraphy indicating a dynamic environment: dune encroachment alternating with mud deposition has resulted in the interlayering of muddy-sand, mud, and sandy-mud at shallow depths (Fig 9 Transect F sites 51-54). Mud also accumulates in the more protected environments between sand promontories (Fig 9 Transect B, sites 31-33, Fig 9 Transect H, sites 36-37). Interlayering of muddy-sand and sandy-mud also occurs in the delta system due to alluvial input from the rivers and the constant wave reworking of the delta front (Fig 9 Transect E).

Water chemistry

Data on salinity, oxygen and temperature of estuarine water between 1982 and 1986 from Anon (1982a) and Anon (1982b) sampled in localities close to sites in the central basin of this study are presented in Tables 2-4 and Fig 10. Data for sites other than those in the central basin are not available prior to 1986. Data on water sampled during this study are presented in Fig 11.

The extremes of hydrochemistry may be more significant in determining the long term distribution of biota, than are the mean conditions prevailing in a given habitat. Ranges of values for water parameters, as well as means, at each sampling site are presented in Table 5. These data form the basis for the identification of categories of water types in the estuary.

Salinity. Waters along the length of the estuary are poikilosaline *i.e.* undergo fluctuating salinity (Table 2; Figs 10 & 11). Patterns of variation indicate that salinity changes both within and between years (Fig 10). For example, at site A3 in the lower estuary, there was a marked drop in salinity in 1983. This was not recorded again at this site during subsequent years of monitoring. However, at sites C17 and D23, located in the mid and upper estuary respectively, a similar decrease in salinity was recorded in each subsequent year of monitoring. This may reflect the damping effect on salinity, due to the input of sea water through "The Cut". This influence does not appear to extend to the north of the estuary during the times of maximum freshwater input (winter).

In the north, salinity varies from hyposaline to hypersaline throughout the year (salinity terms after Hammer 1986). For example, during the 1986-1987 study period, water salinity in the north of the estuary (Transect D sites 20 and 21) varied from 21 - 62 ‰ (Table 2). In the mid estuary, salinity fluctuated within a range of mesosaline values. For example, on Transect B at site 9, salinity varied between 23.5 - 45.0 ‰ (Table 2). At the Collie River delta, salinity varies from hyposaline to mesosaline. For example, during the 1986-1987 study period, salinity varied from 4.7 - 42.5 ‰ (Table 2, Transect A site 3).

The north-south differences in fluctuation patterns are illustrated in a plot of water salinity at sites along the north-south axes of the central basin and western platform (Fig 12). This graph illustrates a more stable, year-round salinity to the south of the estuary (sites A3, A4), a more variable salinity in the middle of the estuary (*e.g.* sites C17 and C15) and the most variable salinity in the northern end of the estuary.

Oxygen. Estuary waters are generally well oxygenated throughout the year. Dissolved oxygen concentrations even in summer are generally > 5 mg L^{-1}. Highest oxygen concentrations were recorded at well-vegetated sites in shallow water. Even though the solubility of oxygen decreases with temperature (Gross 1972), high oxygen concentrations frequently occurred with high water temperature at shallow sites. This is possibly due to increased plant metabolism under warm conditions, resulting in greater oxygen release into the water (bubbles of oxygen were observed adhering to vegetation during some surveys). Overall, there was no clear correlation between variation of oxygen concentration and other water parameters, and oxygen concentration in the estuary appeared to vary independently of temperature and salinity (Figs 9 & 10).

Temperature. The temperature of a relatively shallow water body, such as Leschenault Inlet, is typically determined

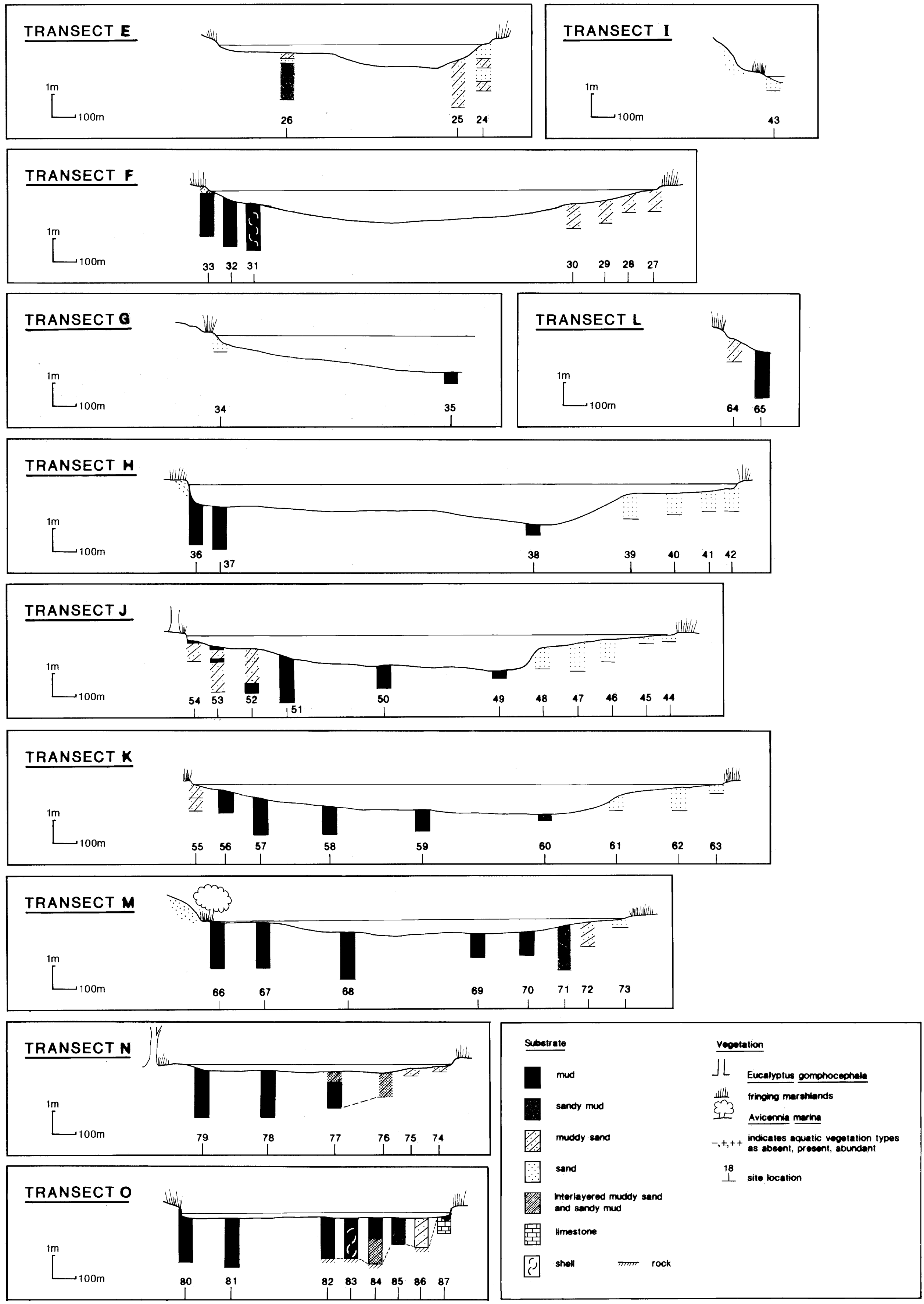

Figure 9. Shallow stratigraphy at sites along Transects E-O. Location of sites is shown in Fig 2.

Table 2. Water salinity (‰) recorded in Leschenault Inlet at sites along Transects A-D during this study.

SITE	TRANSECT A							TRANSECT B							TRANSECT C					TRANSECT D			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Week 1 5/10/1986	24.0	31.0	34.0	35.0	35.0	24.0	25.0	32.0	33.5	33.5	33.5	33.5	32.5	32.5	29.5	30.5	29.5	30.0	30.0	28.5	29.0	30.0	ns
Week 2 14/10/1986	27.0	33.5	35.5	34.0	35.0	34.5	32.5	33.5	33.5	33.5	33.5	33.5	34.0	33.5	31.0	30.0	30.5	31.5	32.0	31.0	30.0	31.0	3.5
Week 3 21/10/1986	ex	15.0	33.5	32.0	ex	ex	ex	ex	32.5	33.5	34.0	29.5	32.0	ex	34.0	32.0	ex	32.0	33.5	35.5	ns	34.5	315.0
Week 4 29/10/1986	17.5	33.0	35.5	34.5	34.5	32.0	21.5	34.5	34.5	34.5	34.5	34.5	34.0	35.0	34.0	34.0	33.5	33.0	33.0	35.0	35.0	35.0	4.5
Week 5 4/11/1986	ex	21.0	35.5	36.0	36.5	ex	ex	35.5	35.5	35.5	35.5	35.5	35.5	36.0	36.0	36.0	ex	35.5	35.5	35.5	35.5	36.0	ns
Week 6 13/11/1986	31.5	35.0	37.0	37.0	36.5	29.5	29.5	36.5	36.0	36.0	36.0	36.0	36.5	36.0	36.0	36.5	37.0	36.0	36.0	36.5	36.5	36.5	235.0
Week 7 20/11/1986	33.5	35.0	36.0	36.0	36.5	ex	ex	36.0	36.0	36.0	36.0	36.0	36.0	36.5	37.0	37.0	38.0	36.5	36.5	41.5	35.0	39.0	440.0
Week 8 27/11/1986	41.5	39.5	42.5	43.5	41.5	ex	ex	45.5	45.0	44.5	44.5	44.5	46.0	45.5	48.5	47.0	48.0	46.0	47.0	53.0	53.0	52.0	ns
Week 9 2/12/1986	17.5	32.5	34.0	35.5	36.0	ex	ex	36.0	36.0	36.0	36.5	35.5	36.0	36.0	37.0	37.0	40.5	39.0	37.0	45.0	44.0	43.0	5.0
Week 13 26/12/1986	36.5	36.0	34.5	36.0	ns	ns	ns	37.0	37.0	37.0	ns	38.0	35.0	36.5	39.0	42.5	ns	46.0	36.5	47.5	48.0	47.5	115.0
Week 17 29/01/1987	ns	36.0	37.0	38.0	ns	ns	ns	ns	43.0	ns	44.0	ns	ns	ns	47.5	ns	ns	46.0	ns	62.0	ns	62.0	350.0
Week 18 5/02/1987	36.0	36.5	37.0	36.5	ns	ns	ns	ns	41.5	ns	38.5	ns	37.0	ns	44.0	ns	ns	42.5	39.5	53.0	ns	53.0	465.0
Week 19 12/02/1987	32.5	35.0	36.0	35.5	ns	ns	ns	ns	38.0	ns	38.0	ns	36.5	ns	43.0	ns	ns	42.5	41.0	59.0	ns	56.0	575.0
Week 20 19/02/1987	36.5	36.0	36.0	36.0	ns	ns	ns	ns	39.5	ns	39.5	ns	36.5	ns	45.5	ns	ns	41.5	41.0	50.0	ns	50.5	595.0
Week 21 25/2/87	36.0	36.0	37.5	38.5	ns	ns	ns	ns	42.0	ns	39.8	ns	39.0	ns	48.0	ns	ns	45.0	44.0	53.0	ns	52.0	535.0
Week 23 9/3/87	35.5	36.1	36.5	36.5	ns	ns	ns	ns	39.5	ns	37.5	ns	38.0	ns	44.5	ns	ns	42.0	43.5	56.0	ns	52.0	ns
Week 27 30/03/1987	35.5	36.0	36.0	36.0	ns	ns	ns	ns	39.5	ns	36.0	ns	37.5	ns	43.5	ns	ns	39.0	41.5	47.0	ns	46.0	480.0

Footnotes: 1. "ex" indicates that a site was exposed at that time. 2. "ns" indicates that a site was not sampled at that time.

Table 3. Oxygen concentrations (mg.1.-1) recorded at all sites during the water quality monitoring programme.

SITE	TRANSECT A							TRANSECT B							TRANSECT C					TRANSECT D		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Week 1 5/10/1986	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Week 2 14/10/1986	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Week 3 21/10/1986	ex	10.2	8.5	7.0	ex	ex	ex	ex	10.0	9.0	9.3	8.3	7.0	ex	10.8	12.3	12.5	19.0	ex	7.8	ns	8.0
Week 4 29/10/1986	9.3	8.4	9.4	9.1	8.7	11.9	9.7	8.7	8.3	8.5	8.2	9.0	8.8	10.6	10.1	10.9	9.3	17.0	10.7	9.2	9.4	9.0
Week 5 4/11/1986	ex	6.0	6.0	6.3	11.6	ex	ex	10.5	9.8	6.8	5.7	5.9	8.0	11.6	12.9	11.0	9.8	15.5	ex	8.3	8.3	10.6
Week 6 13/11/1986	11.2	11.0	11.0	12.1	12.5	12.0	13.8	9.1	8.8	9.9	9.6	9.0	10.0	10.5	9.8	9.8	9.9	10.5	10.3	ns	ns	ns
Week 7 20/11/1986	ns	ns	ns	ns	ns	ns	ns	12.8	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	10.5	12.5	13.5
Week 8 27/11/1986	9.9	9.9	9.8	8.5	10.9	ex	ex	14.5	12.6	9.7	10.8	10.2	11.1	14.8	15.0	11.3	11.0	16.5	11.9	11.2	13.3	14.6
Week 9 2/12/1986	14.2	10.2	10.0	10.1	13.3	ex	ex	15.3	12.1	9.5	9.9	10.1	9.9	11.8	19.0	14.8	10.1	19.3	10.6	8.5	8.9	9.5
Week 13 26/12/1986	11.8	10.1		9.3	11.8	ex	ex	10.6	7.0	11.6	ns	9.6	11.8	11.8	11.8	11.8	7.2	11.7	ex	ns	ns	ns
Week 17 29/01/1987	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Week 18 5/02/1987	7.6	7.3	6.5	6.2	ns	ns	ns	ns	20.0	ns	6.2	ns	8.8	ns	11.0	ns	10	20.0	ns	11.8	ns	10.5
Week 19 12/02/1987	10.9	10.8	10.0	12.2	ns	ns	ns	ns	11.0	ns	9.3	ns	8.1	ns	13.5	ns	8.5	12.0	ns	16.2	ns	16.6
Week 20 19/02/1987	8.0	7.2	7.0	6.7	ns	ns	ns	ns	9.3	ns	7.4	ns	10.2	ns	9.6	ns	6.9	12.0	ns	8.5	ns	9.6
Week 21 25/2/87	8.2	7.7	7.0	7.7	ns	ns	ns	ns	12.2	ns	7.7	ns	11.5	ns	9.4	ns	8.5	12.5	ns	6.6	ns	6.7
Week 23 9/3/87	8.0	8.5	7.7	7.7	ns	ns	ns	ns	9.3	ns	8.0	ns	9.8	ns	9.8	ns	8.3	10.7	ns	9.0	ns	9.1
Week 27 30/03/1987	8.2	8.3	8.0	8.0	ns	ns	ns	ns	8.5	ns	7.5	ns	8.2	ns	9.9	ns	8.5	11.1	ns	7.2	ns	7.5

Footnotes: 1. "ex" indicates that a site was exposed at that time. 2. "ns" indicates that a site was not sampled at that time.

Table 4. Water temperature (degrees ºC) recorded in Leschenault Inlet at sites along Transects A-D during this study.

SITE		TRANSECT A							TRANSECT B							TRANSECT C					TRANSECT D		
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Week 1	5/10/1986	17.0	17.0	17.5	18.0	19.5	24.0	20.0	17.5	17.5	18.3	18.5	16.9	18.8	19.8	18.0	17.5	17.0	20.5	19.5	17.5	17.5	17.0
Week 2	14/10/1986	17.0	17.0	15.0	16.5	16.5	17.5	15.5	16.5	16.5	16.5	16.0	16.0	17.0	17.0	17.5	17.5	17.0	17.0	16.5	17.0	17.5	17.0
Week 3	21/10/1986	ex	20.0	18.0	18.5	ex	ex	ex	ex	20.5	18.5	18.5	17.5	21.0	ex	22.0	20.0	20.0	20.5	ex	21.5	ns	21.5
Week 4	29/10/1986	17.5	17.0	17.0	17.5	20.0	23.5	21.5	19.5	19.5	18.8	20.0	19.5	17.8	19.5	21.5	20.0	20.0	19.0	19.5	19.0	20.5	20.5
Week 5	4/11/1986	ex	21.5	18.5	19.0	ex	ex	ex	22.5	21.0	20.5	20.5	20.5	21.0	27.0	24.0	23.5	21.5	25.5	ex	18.0	15.0	19.0
Week 6	13/11/1986	19.5	20.5	20.0	20.0	20.0	23.0	23.0	21.5	21.5	21.5	21.5	21.0	22.0	22.5	23.0	22.0	22.5	23.0	22.5	24.5	24.0	23.4
Week 7	20/11/1986	29.5	24.5	24.0	24.5	28.5	ex	ex	30.0	27.0	24.5	25.0	25.5	29.5	33.0	31.0	31.0	27.5	32.0	29.5	27.5	27.5	27.5
Week 8	27/11/1986	23.5	22.0	21.5	22.0	23.0	ex	ex	26.5	24.5	21.5	21.5	21.5	25.0	28.0	27.0	26.0	22.0	27.5	24.0	30.0	29.0	2*9
Week 9	2/12/1986	23.5	21.0	21.0	22.0	22.5	ex	ex	24.0	22.0	20.5	21.0	21.0	23.0	31.0	26.0	24.0	21.5	27.0	29.0	24.0	25.0	26.0
Week 13	26/12/1986	30.0	27.0	ns	23.5	23	ex	ex	18.5	24.0	24.0	ns	24.5	26.0	29.0	26.5	27.0	22	27.0	ns	30.0	32.0	31.0
Week 17	29/01/1987	ns	26.5	24.0	22.0	ns	ns	ns	ns	24.0	ns	22.5	ns	ns	ns	29.0	ns	24.0	ns	ns	24.5	ns	23.0
Week 18	5/02/1987	25.0	25.0	22.5	23.0	ns	ns	ns	ns	26.0	ns	24.0	ns	26.0	ns	28.5	ns	25	28.5	ns	30.0	ns	30.0
Week 19	12/02/1987	25.5	24.5	22.0	22.5	ns	ns	ns	ns	27.0	ns	23.0	ns	25.0	ns	31.5	ns	24	31.0	ns	26.5	ns	26.0
Week 20	19/02/1987	20.5	19.5	21.5	20.5	ns	ns	ns	ns	21.5	ns	20.5	ns	20.5	ns	22.5	ns	21	22.5	ns	19.5	ns	20.0
Week 21	25/2/87	22.5	22.0	20.5	21.0	ns	ns	ns	ns	24.0	ns	21.5	ns	23.5	ns	26.5	ns	22	27.0	ns	19.0	ns	20.5
Week 23	9/3/87	22.0	22.5	22.0	22.5	ns	ns	ns	ns	24.0	ns	23.0	ns	23.0	ns	23.5	ns	23	23.0	ns	22.0	ns	21.0
Week 27	30/03/1987	21.0	21.0	21.0	21.0	ns	ns	ns	ns	21.0	ns	20.5	ns	22.0	ns	21.0	ns	20.5	22.0	ns	19.0	ns	19.0

Footnotes: 1. "ex" indicates that a site was exposed at that time. 2. "ns" indicates that a site was not sampled at that time.

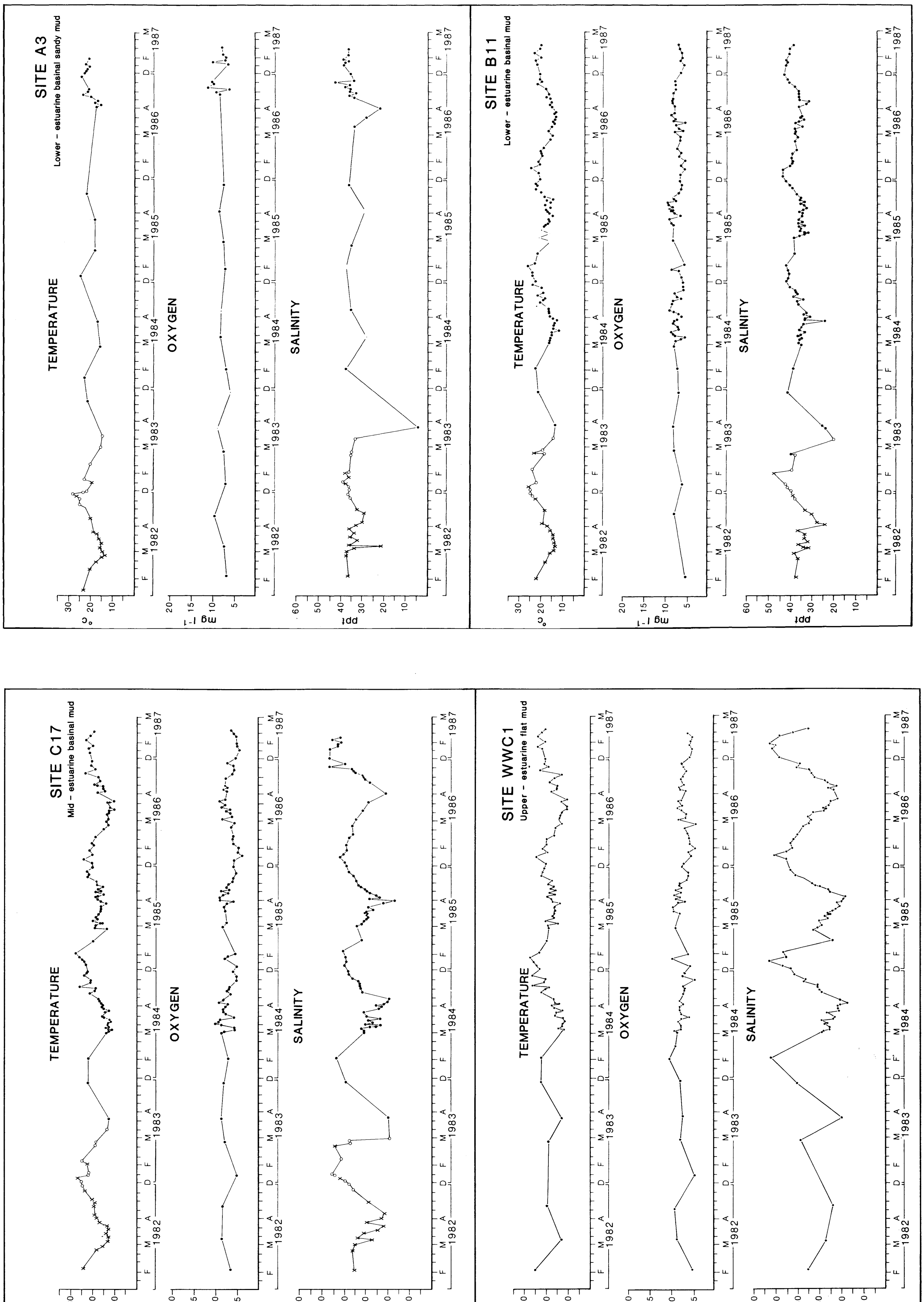

Figure 10. Water quality data for selected sites collected (Anon 1982a, b; Anon 1985b; Klemm 1984)

by air temperature and wind. Winter temperatures in deep water were frequently below 15 °C, while summer temperatures are frequently at or above 25 °C, but typically around 22 °C (Table 4 & Fig 10). The deep water of the central basin has a temperature range of approximately 10 °C, and maintains a generally lower temperature than shallower sites. Shallower water sites, located on eastern and western platforms, Collie delta and the northern flat have winter water temperatures of approximately 15 °C, and summer temperatures of approximately 30 °C. Shallow water sites, with dark muddy substrates (*e.g.* D20, D21, D22, C18 and B14) experienced the highest temperatures. A temperature of 32 °C was recorded in one shallow pool on the northern flat during the 1986 survey (fine, dark mud absorbs more solar radiation than lighter coloured and coarser grained sandy substrates; see Hasse & Dobson 1986, p15). It also was observed in the field that muddy substrates become heated to a depth of at least 10 cm during summer.

Distribution of Macrophytes

A total of 3 species of seagrass and at least 7 species of algae were recorded in the Leschenault Inlet estuary during this study. The seagrass species were *Halophila ovalis*, *Ruppia megacarpa* and *Heterozostera tasmanica.* Algae species were *Chaetomorpha* sp, *Gracilaria* spp., *Ulva* sp, *Acetabularia* sp and two species of Phaeophyta (including *Hormophysa triquetta; cf* Hillman *et al.* 2000). *Halophila ovalis* is the most widespread species of seagrass in the estuary, and contributes the greatest biomass to the macrophytes.

Turbidity limits seagrass distribution (McComb *et al.* 1981), and in Leschenault Inlet at depths > 1.5 m seagrass is restricted and patchy in distribution (Fig 5-8; data for survey transects is available in Wurm 1987 or from the authors).

The greatest biomass of macrophytes generally occurred on mud, sandy-mud and muddy-sand of the western platform, where *Halophila ovalis* dominated (*e.g.* Fig 5 sites 4; Fig 7 site 13). *Gracilaria* spp. also occurred more commonly in the south of the estuary. *Ruppia megacarpa* occurred occasionally, and mainly in shallow inter-tidal depressions that retain water at low tide. Some *Chaetomorpha* and *Gracilaria* also occurred in these pools. Minor occurrences of *Ulva* sp were noted, and *Heterozostera tasmanica* occurred on sandy substrates at the tip of encroaching dunes.

Sandy substrates of the eastern platform supported a relatively dense cover of *Halophila ovalis* (*e.g.* Fig 7 sites 9, 10). A sparse cover of *Ruppia megacarpa* typically occurred at the more sandy shoreward edge of the platform in a few centimetres of water but also extended into the *Halophila* zone (*e.g.* Fig 7, site 9). *Gracilaria* spp also occurred in the *Halophila* zone. *Heterozostera tasmanica* was recorded in the mid estuary zone of the platform (*e.g.* Fig 7 sites 8,9,10). Toward the north of the eastern platform, *Chaetomorpha* and a phaeophyte species became more common (*e.g.* Fig 8 sites 15,16).

Sandy substrates of the eastern shore of the northern flat supported mainly *Acetabularia* sp. Subtidal muddy sites of the northern flat supported *Halophila ovalis* meadows with varying degree of cover. Shallower mud substrates were variously covered by *Chaetomorpha* which locally forms dense mats. *Ruppia megacarpa* occurred in small water-retaining inter-tidal depressions and undulations. Drift of *Gracilaria* spp was present on otherwise bare mud in most peripheral and inter-tidal portions of the northern flat. The muddy floor of the central basin was mostly devoid of vegetation, but a sparse or patchy cover of *Halophila ovalis* occurred locally. The sand sheets environments in the Collie delta sites were generally devoid of vegetation.

Discussion

Most of the estuary comprises the flat, deep and elongate central basin, flanked to east and west by shallow, shore-parallel platforms that are related to the upslope features of relict and active dunes respectively. To the north, the central basin grades into a shallow water northern flat, and to the south deltas intrude into the estuary.

Substrate type reflects proximity to sediment source, extant processes, and grain size availability. Consequently, Leschenault Inlet is underlain by:

- mud in the central basin and northern flat;
- sand and muddy-sand on the eastern platform, where there is local reworking/winnowing of shore materials in this wave dominated environment;
- sandy-mud, mud, muddy-sand and sand on the western platform where dune sand encroaches into and contributes sand to the estuary, and where more mud accumulates than on the eastern platform because of its more sheltered nature; and
- sand in the deltas.

The estuary is generally of marine salinity and vertically well mixed. The hydrochemistry is dominated by daily

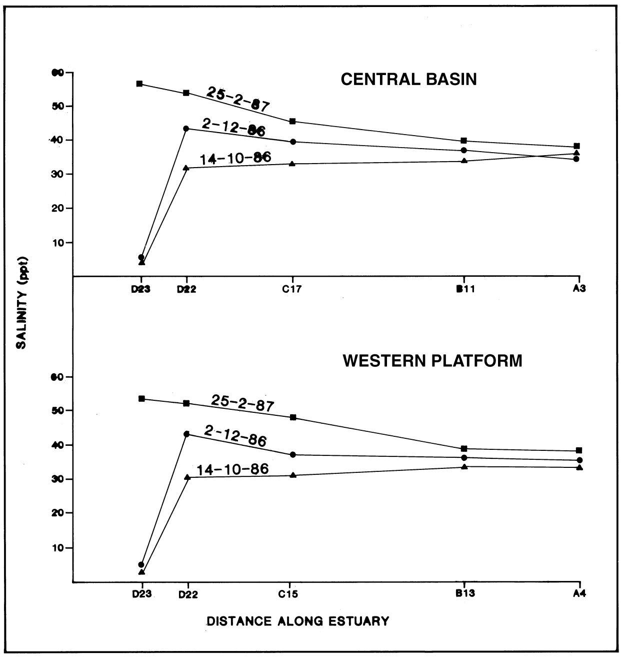

Figure 11. Graph of salinity along the length of the Leschenault Inlet, at three sampling times during this study, for sites on the a) Central Basin; b) Western Platform.

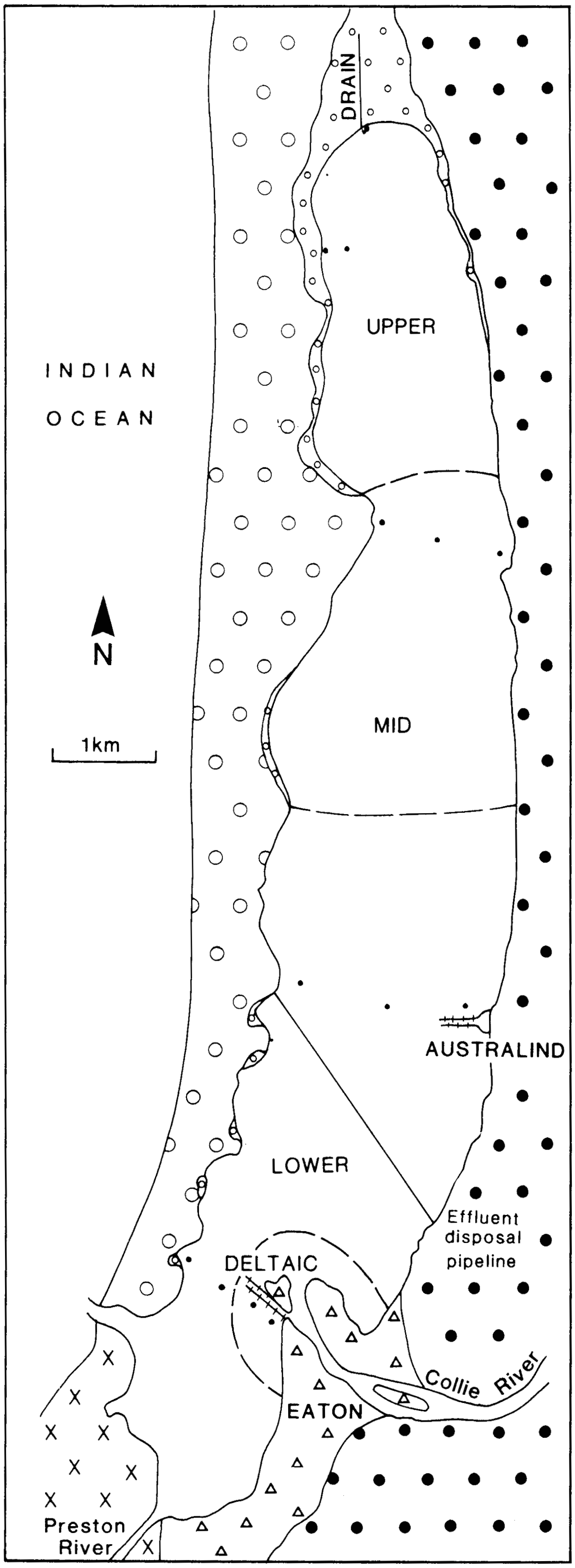

Figure 12. Proposed estuarine salinity fields of Leschenault Inlet, based upon values for the range and mean (± sd) of water salinity data at water quality monitoring sites during this study (See also Table 5). The location of monitoring sites is shown in Fig 2.

exchange through the artificial channel and wind- and tide-forced circulation. However, the estuary is still poikilosaline, due to freshwater inflow during the winter in the south, and restricted oceanic exchange and summer evaporation in the north. In this respect Leschenault Inlet is similar to estuaries elsewhere in south-western Australia.

In winter, salinity of the estuary decreases with fresh water input, from rivers, drains, run-off from adjoining terrain, and groundwater seepage from upland aquifers (*e.g.* dunes; Semeniuk & Meagher 1981b) and deltas. These studies indicate that after the cessation of fresh water input, evaporation (induced by summer temperatures and wind), and the continued limited exchange with the ocean become important determinants of water salinity to the north, away from "The Cut", which may become hypersaline. There is a salinity gradient from south to north for most seasons.

Values of the mean and standard deviation of water salinity (Table 5) can be used to describe salinity fields within the estuary. As data were collected at only 4 transects along the length of the estuary, and because it is expected that the salinity trends are gradational, the boundaries between fields can only be interpolated. However, the Leschenault Inlet water body may be divided into 4 gradational salinity fields, based on mean salinity values and the variation in the salinity developed throughout the year (Table 5). These are (Fig 12):

- the deltaic field which has a mean salinity value of slightly less than sea water but a large variation about the mean (*e.g.* Transect A sites 1,2; Table 5);
- the lower estuarine field in which a mean salinity value slightly greater than sea water is maintained, with a small variation about the mean (*e.g.* Transect A sites 3,4,5,6,7; Table 5);
- the mid estuarine field in which a mean salinity value higher than sea water is maintained, with a large variation about the mean (*e.g.* Transect B& C sites, Table 5); and
- the upper estuarine field in which a mean salinity value much greater than seawater is maintained, with a very large variation about the mean (*e.g.* Transect D sites, Table 5).

Habitat types

Nineteen (19) small-scale habitat types within Leschenault Inlet are proposed (Fig 13). These have been determined by interactions between the 5 large-scale geomorphic units (Fig 3) and large-scale estuarine salinity patterns (Fig 12). The habitats are named, and further differentiated, according to large-scale geomorphic setting, substrate, presence of macrophytes and salinity field. A description of the 22 monitoring sites in terms of the habitats is presented in Table 6.

The northern flat lies within the upper estuarine salinity field, where there are four small-scale habitats (Table 6, Sites D20, 21, 22; Fig 9 Transects M, N & O). These are: 1. inter-tidal mud; 2. inter-tidal sandy mud; 3. vegetated flat mud; and 4. vegetated flat sandy-mud.

The central basin spans the mid and lower estuarine

Table 5. Ranges and mean + sd of water temperature (°C), oxygen concentration (mg L^{-1}) and salinity (‰) in Leschenault Inlet at sites along Transects A-D. Only data from sites sampled during the 1986-87 study period were used to calculate mean and standard deviation. For maxima and minima, all available data, including Anon 1982a, Anon 1982b, and Anon 1985b, were used from locations used in this study (Refer to Table 1a for information on sampling times).

		Temperature (°C)		Oxygen (mg L^{-1})		Salinity (‰)	
		Max & Min	**Mean ±sd**	**Max & Min**	**Mean ± sd**	**Max & Min**	**Mean ± sd**
Transect A	1	17.5 - 30.0	22.4 ± 4.1	7.6 - 14.2	9.8 ± 2.1	17.5 - 41.5	31.5 ± 7.3
	2	17.0 - 27.0	21.7 ± 3.1	6.0 - 11.0	8.9 ± 1.6	15.0 - 39.5	33.1 ± 6.1
	3	14.0 - 28.5	20.4 ± 2.5	6.0 - 1.0	8.4 ± 1.6	4.7 - 42.5	36.1 ± 2.0
	4	16.5 - 24.5	20.8 ± 2.3	6.2 - 12.2	8.5 ± 2.0	20.5 - 43.5	36.3 ± 2.4
	5	16.5 - 28.5	-	8.7 - 13.3	-	33.5 - 41.5	-
	6	17.5 - 24.5	-	11.9 - 12.0	-	24.0 - 34.5	-
	7	15.5 - 23.0	-	9.7 - 13.8	-	21.5 - 34.5	-
Transect B	8	16.5 - 30.0	-	8.7 - 15.3	-	32.0 - 45.5	-
	9	16.5 - 27.0	22.4 ± 3.0	7.0 - >20	10.7 ± 3.3	23.5 - 45.0	37.8 ± 3.6
	10	16.5 - 24.5	-	6.8 - 11.6	-	32.5 - 44.5	-
	11	12.5 - 26.5	21.1 ± 2.2	5.0 - 10.8	8.3 ± 1.5	17.0 - 45.4	37.3 ± 3.3
	12	16.0 - 25.5	-	5.9 - 10.2	-	29.5 - 44.5	-
	13	17.0 - 29.5	22.6 ± 3.3	7.0 - 11.8	9.4 ± 1.5	32.0 - 46.0	36.4 ± 3.2
	14	17.0 - 33.0	-	10.5 - 14.8	-	31.5 - 45.5	-
Transect C	15	17.5 - 31.5	24.6 ± 4.1	9.4 - 19.0	11.7 ± 2.8	28.5 - 48.5	39.9 ± 6.1
	16	17.5 - 31.0	-	10.9 - 14.8	-	30.0 - 47.5	-
	17	11.0 - 27.5	21.8 ± 2.6	3.9 - 12.5	9.3 ± 1.5	17.0 - 46.0	39.0 ± 5.4
	18	17.0 - 32.0	24.6 ± 4.3	10.5 - >20	14.4 ± 3.5	30.0 - 47.0	38.0 ± 4.8
	19	16.5 - 29.5	-	10.3 - 11.9	-	25.5 - 48.0	-
Transect D	20	17.0 - 30.0	22.9 ± 4.6	6.6 - 16.2	9.6 ± 2.6	21.0 - 62.0	45.2 ± 10.2
	21	17.5 - 32.0	-	8.3 - 13.3	-	21.0 - 48.0	-
	22	17.0 - 31.0	23.0 ± 4.5	8.0 - 14.6	10.4 ± 3.0	21.0 - 62.0	44.5 ± 9.6
	23	10.5 - 27.0	-	5.0 - 11.0	-	18.4 - 53.6	-

Table 6. Habitat features of sites on Transects A-D.

Site	Habitat unit	Large-scale geomorphic unit	Substrate	Flora	Salinity field
A1	Deltaic inter-tidal sand	Collie River Delta	Medium & coarse sand	None	Deltaic
A2	Deltaic sand	Collie River Delta	Medium & coarse sand	None	Deltaic
A3	Lower estuarine basinal sandy mud	Central Basin	Sandy mud	Patchy *Halophila*	Lower
A4	Lower estuarine platform	Western Platform	Muddy medium sand	*Halophila*	Lower
A5	Lower estuarine inter-tidal muddy sand	Western Platform	Muddy medium sand	Patchy algae & *Halophila*	Lower
A6	Deltaic inter-tidal sand	Collie River Delta	Medium & fine sand	Patchy algae & *Halophila*	Lower
A7	Deltaic inter-tidal sand	Collie River Delta	Medium & fine sand	Patchy algae & *Halophila*	Lower
B8	Lower estuarine platform sand	Eastern Platform	Medium sand	Patchy *Halophila* & algae	Lower
B9	Lower estuarine platform muddy sand	Eastern Platform	Medium sand	*Halophila*	Lower
B10	Lower estuarine platform muddy sand	Eastern Platform	Medium sand	*Halophila*	Lower
B11	Lower estuarine basinal mud	Central Basin	Mud	Patchy *Halophila*	Lower
B12	Lower estuarine basinal mud	Central Basin	Mud	Patchy *Halophila*	Lower
B13	Lower estuarine platform muddy sand	Western Platform	Muddy medium sand	*Halophila* & algae	Lower
B14	Lower estuarine platform sandy mud	Western Platform	Sandy mud	Patchy algae & *Halophila*	Lower
C15	Mid estuarine muddy sand	Eastern Platform	Muddy medium sand	*Halophila* & algae	Mid
C16	Mid estuarine muddy sand	Eastern Platform	Muddy medium sand	*Halophila* & algae	Mid
C17	Mid estuarine basinal mud	Central Basin	Mud	Patchy *Halophila*	Mid
C18	Mid estuarine platform sandy mud	Western Platform	Mud	*Halophila* & algae	Mid
C19	Mid estuarine inter-tidal sand	Eastern Platform	Medium sand	None	Mid
D20	Upper estuarine inter-tidal sandy mud	Northern Flat	Sandy mud	Patchy algae	Upper
D21	Upper estuarine inter-tidal mud	Northern Flat	Mud	Patchy algae	Upper
D22	Upper estuarine inter-tidal mud	Northern Flat	Mud	Patchy algae	Upper

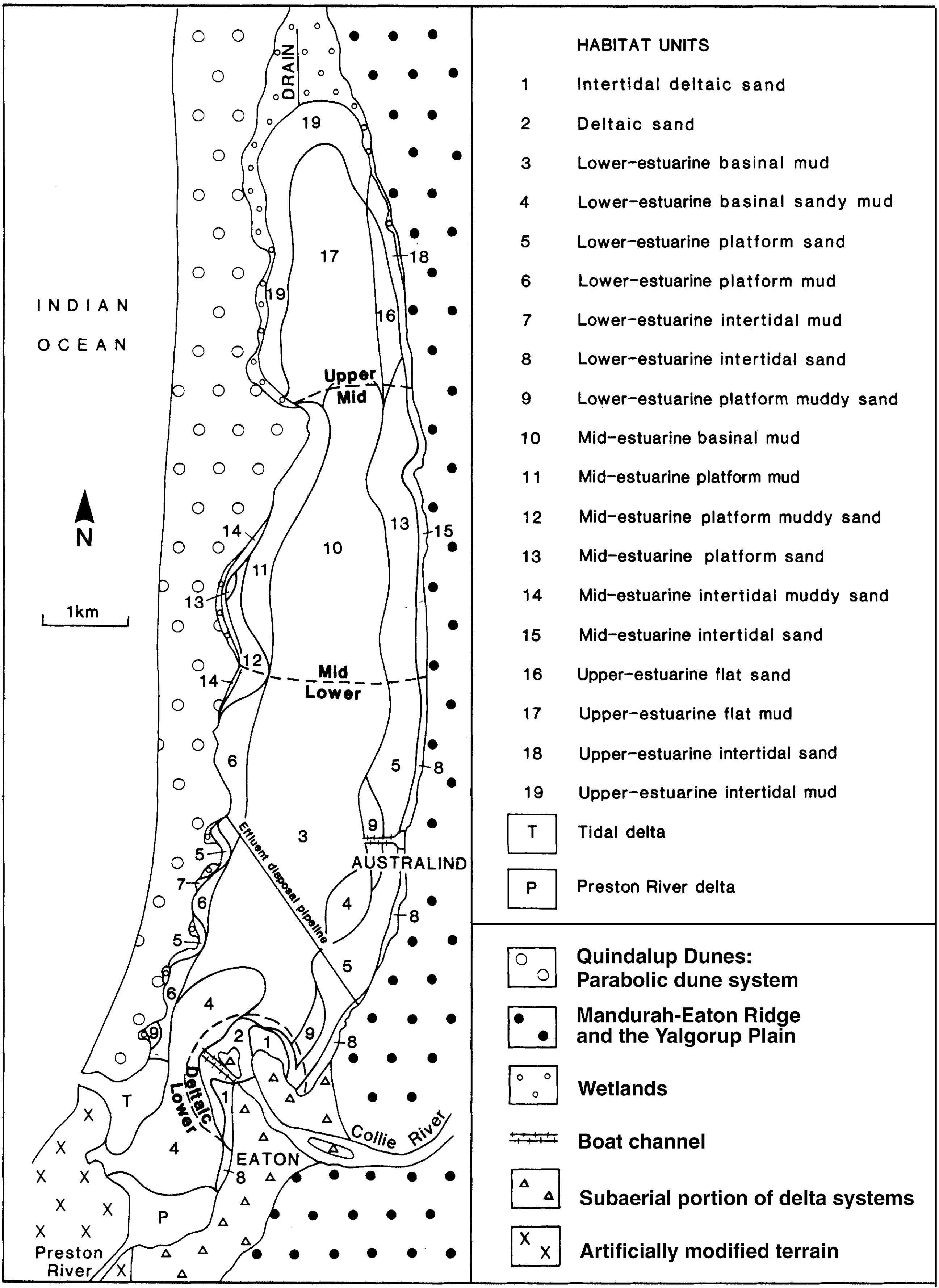

Figure 13. Map of proposed benthic habitat units in Leschenault Inlet.

salinity fields, and two small-scale habitats occur here (Table 6, sites BA3, B11, B12, C17; Fig 9 Transects E, F, G, H, I J, K, L): 1. sparsely vegetated basinal mud; and 2. sparsely vegetated basinal sandy-mud.

The western platform spans the mid and lower estuarine salinity fields, and contains the following small-scale habitats (Table 6, site A5, Fig 9 Transects E, F, G, H, I J, K, L): 1. inter-tidal sand; 2. inter-tidal mud; 3. inter-tidal muddy-sand; 4. inter-tidal sandy-mud; 5. vegetated platform muddy-sand; 6. vegetated platform mud; and 7. vegetated platform sand.

The eastern platform spans the mid and lower estuarine salinity fields and contains the following small-scale habitats (Table 6 Sites B8, B9, B10, C15, C16 C19; Fig 9 Transects E, F, G, H, I, J, K, L): 1. inter-tidal sand; 2. vegetated platform sand; and 4. vegetated platform muddy-sand.

The Collie River delta lies within the deltaic hydrochemistry field and contains (Table 6 Sites A1, A2): 1. inter-tidal sand; and 2. shallow water sand.

The intersection of geomorphology, substrate texture and detritus content, presence of macrophytes, and water salinity, has the potential to generate a variety of habitat types in Leschenault Inlet. A given environmental parameter (such as temperature, water depth, salinity) may vary gradually through space. The division between adjacent habitats may lie arbitrarily within the gradient of one or more of these parameters (*e.g.* the bathymetric junction between adjoining geomorphic units, transition between substrate types or the division between adjacent salinity fields are gradational).

This habitat classification is a first step towards linking habitat distribution and diversity with that of fauna. This framework may also be used to undertake more detailed studies of inlet attributes, and to stratify future fauna sampling programs.

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