

Contemporary and sub-recent pollen record for the Leschenault Inlet estuary: towards a palynological baseline

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Abstract

Palynological analysis of contemporary and sub-recent sediments from Leschenault Inlet, an estuarine lagoon on the south-west coast of Western Australia, has determined if a contemporary palynological baseline can be established to interpret the sub-recent pollen assemblages, and was used to determine the mangrove *Avicennia marina* was a component of the vegetation in the recent past. Leschenault Inlet is a relatively simple estuarine system with north-south trending sedimentary environments and parallel vegetation complexes, and with both easterly and westerly winds and two fluvial sources contributing to the pollen influx. Using predominantly family groupings (*e.g.* Chenopodiaceae, Myrtaceae, Casuarinaceae, Gramineae, Restionaceae) and several species prominent in the vegetation (*Frankenia pauciflora*, *Olearia axillaris*, *Lepidosperma gladiatum*), preliminary results indicate that the major sedimentary environments have characteristically different pollen assemblages. In transects across the sedimentary environments, individual species show relative abundance gradients that can be explained in terms of proximity to vegetation source and potential transport systems. Conversely, these serve to distinguish specific environments and the nature of the immediate upland source vegetation. *Avicennia marina* pollen is a minor component of the contemporary sediments near sites of mangrove habitation. It is absent from sub-recent samples in comparative environments, implying that it is a recent arrival to Leschenault Inlet. A late Holocene change in climate may be responsible for an intensification of the Leeuwin Current and subsequent delivery of *Avicennia* propagules from tropical regions. Leschenault Inlet is an excellent site to study the effect on palynological assemblages of proximity to vegetation source, wind directions, dispersal via estuarine currents, and taphonomy. It also presents an ideal setting from which to develop pollen assemblage baselines for the different estuarine sedimentary environments. From a geoheritage perspective, the Leschenault Inlet estuary probably ranks as significant at a national level.

Keywords: estuarine palynology, palynology, Leschenault Inlet, south-western Australia.

Introduction

Leschenault Inlet is a north-south trending estuarine lagoon situated on the southwest coast of Western Australia. It is barred by a long barrier dune system, the Leschenault Peninsula, and has a range of depositional (accretionary) environments and pollen-source habitats (both oriented north-south), an east-west to southwesterly aeolian delivery system, and two southerly located fluvial delivery systems. The estuarine sedimentary fill is entirely Holocene in age, and in the context of a retrograding barrier a complete estuarine sedimentary record from *ca* 8 000 yrs BP to the present is preserved (Semeniuk 1985). Considering its depositional setting, Leschenault Inlet estuarine lagoon potentially contains a valuable palynological record of Holocene environments.

The diverse range of habitats that border the estuarine system supports a mosaic of vegetation complexes that range from saltmarsh to freshwater terrestrial associations. Of particular interest is the presence of the mangrove

Avicennia marina, a species that is otherwise not known south of Houtman Abrolhos. *Avicennia marina* is a potential indicator of past Holocene climates and environments, and it has been suggested anecdotally that this isolated stand of a normally tropical species represents a relict population. However, it is also possible that *A. marina* is a recent arrival, its propagules having been transported by an intensified Leeuwin Current.

To adequately interpret the sub-recent pollen record in the estuarine sediments, a baseline of pollen assemblages in the various contemporary sedimentary suites or facies is required. This paper provides a preliminary account of the pollen record preserved in contemporary (surface) sediments and the upper parts of the Holocene sedimentary sequence (= sub-recent *viz* from 150 yrs BP to 500-1500 yrs BP) in Leschenault Inlet (Fig 1).

The specific objectives of this paper are: to characterise the pollen record in the surface sediments of the five main sedimentary suites (or facies) in the estuary, and from these interpret the pre-modern Holocene stratigraphic record; to determine the extent and mode of pollen trans-

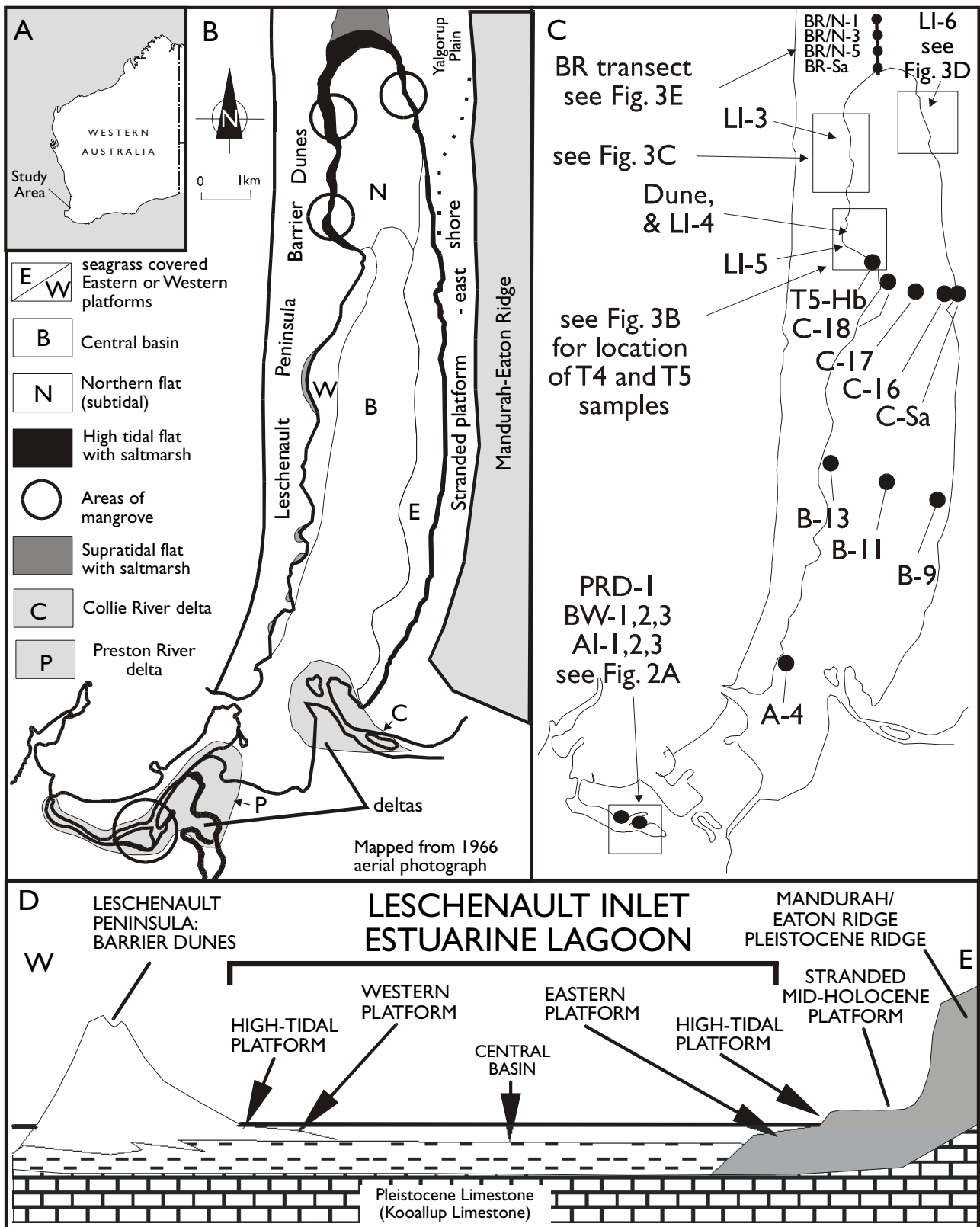


Figure 1. Leschenault Inlet showing location of main sedimentary/ geomorphic units, sampling sites, locations of detailed study areas, and Holocene stratigraphic framework.

port from its source, and to determine if *Avicennia* pollen is present in the sub-recent stratigraphic record. The general patterns in the contemporary and sub-recent pollen assemblages will provide preliminary conclusions and point the way for future more detailed studies of the pollen record and factors that influence its composition.

Setting

Estuarine sedimentary environments

Leschenault Inlet is an estuarine lagoon located along the Western Australian coast within the southern part of the Swan Coastal Plain (Fig 1; Semeniuk & Meagher 1981a). The lagoon is separated from the Indian Ocean by a barrier dune system, the Leschenault Peninsula (Semeniuk 1985). To the east, it overlaps the Mandurah-Eaton Ridge and the Yalgorup Plain (Semeniuk 1997).

The Leschenault Peninsula is a linear, north-south oriented dune barrier 0.5 to 1.0 km wide, and is comprised of east-west oriented mobile to vegetated parabolic dunes (Semeniuk & Meagher 1981a; Semeniuk *et al.* 1989). The Mandurah-Eaton Ridge is a high ridge of quartz sand and limestone, oriented north-south and bordering the eastern margin of the Holocene estuarine complex (Semeniuk 1997). Leschenault Inlet is an elongate, narrow, north-south oriented estuarine lagoon approximately 1.5 to 2.5 km wide, and 13 km long (Wurm & Semeniuk 2000). Bordering its eastern shore is a stranded sand platform 1-2 m above sea

Table 1. Description of geomorphic/sedimentary units in Leschenault Inlet selected for study in this paper

Geomorphic/ sedimentary unit	Description
central basin	long, shore-parallel relatively deep water mud-floored depression, generally 1.5-2.0 m deep
eastern platform	shore-parallel narrow, shallow water sand platform (low tidal to 1.0 m deep), vegetated by the seagrass <i>Halophila ovalis</i>
western platform	shallow water muddy sand platform or ramp (low tidal to 1.5 m deep), also vegetated by <i>Halophila ovalis</i>
high-tidal platform	high-tidal platforms located on the east and west shores of the estuarine lagoon; width varies from narrow (5-10 m) to wide (>500 m); mainly saltmarsh-vegetated
supratidal flat	broad flat, nearly horizontal, to very gently inclined towards the estuary, emergent by progradation, underlain by mud, and colonised by samphire; borders the northern estuary
Preston River delta	complex of linear, tidal-current-aligned shoals and emergent islands, with intervening shallow channels

level, formed earlier in the Holocene as a sub-aqueous estuarine sand platform. The depositional units of interest in this paper are the central basin, the eastern and western platforms, the high-tidal platform, the supratidal flat, and the Preston River delta. The characteristics of these units are described briefly in Table 1. The main estuarine geomorphic and sedimentary units within Leschenault Inlet, and the Quaternary stratigraphy of the area (after Semeniuk 1983, 1997), are illustrated in Fig 1D.

Vegetation contributing pollen

There are nine main categories of vegetation that may act as pollen sources for the estuarine sediments: barrier dune vegetation; Mandurah-Eaton Ridge vegetation; Yalgorup Plain vegetation; supratidal vegetation on emergent deltaic shoals; freshwater vegetation on the east shore of the estuary; saltmarsh vegetation fringing the shore of the estuary; mangrove vegetation along the shore of the estuary; seagrass vegetation; and exotic vegetation. The locations of these pollen sources are shown in Fig 2.

The barrier dunes are comprised of a mosaic of habitat types and vegetation (Semeniuk & Meagher 1981a,b; Trudgeon 1984; Cresswell & Bridgewater 1985; Smith 1985; Semeniuk *et al.* 1989). Semeniuk & Meagher (1981b) categorised the vegetation on the barrier in relation to the main landforms (or habitats), recognising four broad assemblages: 1. *Olearia* scrub assemblage, with *Olearia axilaris*, *Rhagodia bacatta*, *Spyridium* sp, *Acacia rostellifera*, and *A. cyclops* inhabiting recently fixed dunes; 2. *Acacia* scrub assemblage, with *Acacia rostellifera*, *A. cyclops*, and *Agonis flexuosa* inhabiting older fixed dunes; 3. the peppermint low forest assemblage, with *Agonis flexuosa*, inhabiting geomorphically degraded dunes; and 4. the tuart woodland assemblage with *Eucalyptus gomphocephala*, *Agonis flexuosa*, *Hakea prostrata*, *Acacia rostellifera*, and *A. cyclops* inhabiting swales in the dunes. Other species generally occurring in the dunes include *Hibbertia cuneiformis*, *Jacksonia furcellata*, *Trachyandra divaricata*, *Acacia saligna*, *Isolepis nodosa*, *Apium prostratum*, and *Lepidosperma gladiatum*.

On the quartz sand high ground of the Mandurah-Eaton Ridge the vegetation comprises a mosaic of assemblage types (Heddle *et al.* 1980). Key species in this system include *Eucalyptus calophylla* and *E. marginata*, *Allocasuarina fraseriana*, Proteaceae (various species of *Banksia* and *Isopogon*, *Stirlingia latifolia*, *Xylomelum occidentale*), *Kunzea ericifolia*, *Macrozamia reidleyi*, and *Hibbertia hypericoides*. On the low limestone and quartz sand plain of the Yalgorup Plain, key species include *Eucalyptus gomphocephala*, *E. calophylla*, *Allocasuarina fraseriana*, *Banksia attenuata*, *Macrozamia reidleyi*, and *Hibbertia hypericoides*. Vegetation on the emergent supratidal deltaic shoals in the Preston River delta complex (Semeniuk 2000), equivalent to the sandy rise complex of Pen *et al.* (2000), may be comprised of *Jacksonia furcellata*, *Casuarina obesa*, *Hakea prostrata*, *Acacia saligna*, *A. cyclops*, *A. cochlearis*, *Viminaria juncea*, *Hibbertia cuneiformis*, *Sporobolus virginicus*, and *Isolepis nodosa*.

Freshwater vegetation inhabits the broad wetland complex on the eastern shore of the estuary. This zone is a low level platform, formed as a stranded mid-Holocene subtidal

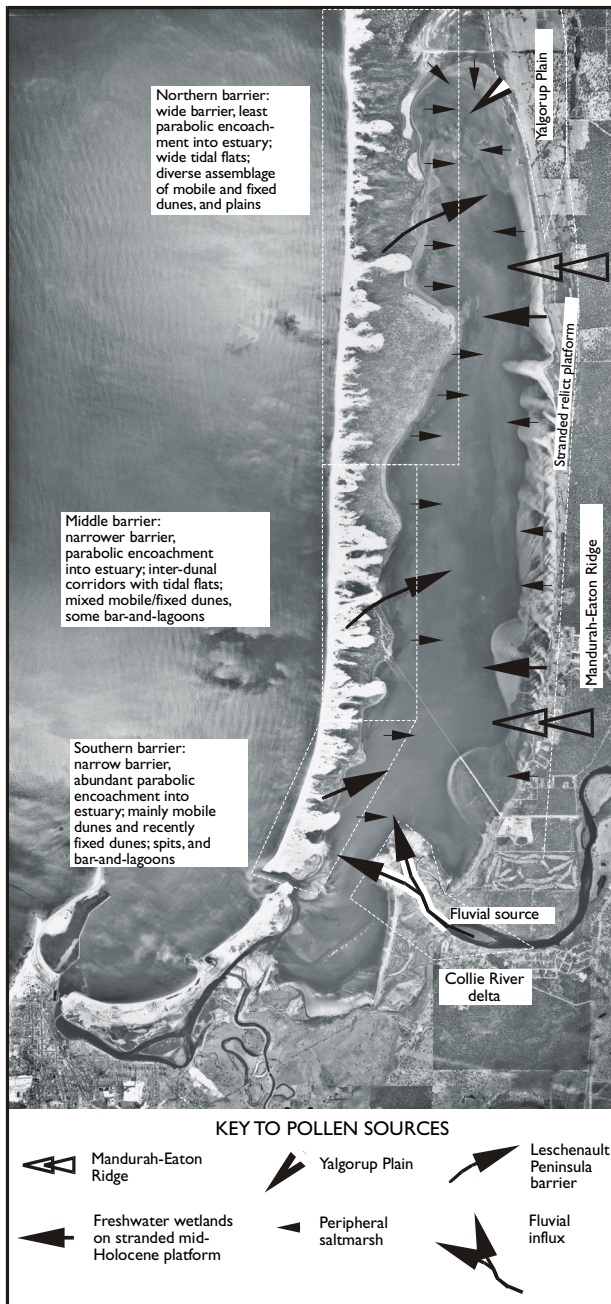


Figure 2. Aerial photograph of the Leschenault Inlet area showing main vegetation systems and the pollen sources.

estuarine platform (Pen *et al.* 2000; Semeniuk 2000). The most widespread and dominant species is *Melaleuca raphiophylla*. Also occurring in this habitat are *Eucalyptus rudis*, *Baumea juncea*, *Agonis flexuosa*, *Acacia saligna*, *Hemarthria uncinata*, *Baumea articulata*, *Lepidosperma longitudinale*, *L. gladiatum* and *Juncus pallidus*. Towards its contact with the present estuarine shore, the wetland complex surface is inhabited by *Melaleuca cuticularis*, *M. viminea*, and *Casuarina obesa*. Local areas emergent above the watertable support *Eucalyptus gomphocephala*.

Saltmarsh vegetation occurs as low herbland formations around the periphery of Leschenault Inlet. The species that comprise these formations include. *Halosarcia indica*

bidens, *Halosarcia halocnemoides*, *Salicornia quinqueflora*, *Suaeda australis*, *Polypogon monspelliensis*, *Sporobolus virginicus*, *Samolus repens*, *Sarcocornia quinqueflora*, *Bulboschoenus caldwellii*, and *Frankenia pauciflora* (Pen *et al.* 2000). The white mangrove *Avicennia marina* forms scrub and heathland (following Specht 1970) in local areas around the shores of the estuary (Fig 3). Seagrass vegetation (*i.e.* aquatic estuarine/marine vegetation) forms shallow water meadows in Leschenault Inlet, and includes *Halophila ovalis*, *Heterozostera megacarpa*, and *Ruppia tasmanica*.

Exotic vegetation (*i.e.* alien species) in the region that may contribute pollen to the Leschenault Inlet estuary include. pine plantations (*Pinus radiata* and *P. pinaster*), blue gum plantations (*Eucalyptus globulus*), crop, horticultural, and garden plants (*e.g.* *Lupinus*), and weeds such as couch grass (*Cynodon dactylon*), kikuyu (*Pennisetum clandestinum*), Paspalum grass (*Paspalum vaginatum*), and pigface (*Carpobrotus edulis*). Generally, the pines, blue gums, and crop, horticultural, and garden plants are located to the east of Leschenault Inlet, so that the occurrence of their pollen in estuarine sediments signals transport from eastern sources. Weeds also are mainly located to the east of Leschenault Inlet in residential areas, pasture land, and on the Collie River delta.

Given this range of contributing vegetation there are a number of mechanisms that result in anemophilous (rather than entomophilous) pollen being emplaced in the estuarine environment. These are: transport by wind, (by seabreezes transporting pollen from the western barrier dune vegetation, saltmarsh, and mangrove formations, and by landbreezes transporting pollen from the eastern Mandurah-Eaton Ridge, saltmarsh vegetation, and from peripheral freshwater vegetation; and locally from the emergent deltaic shoals); transport within the estuary by currents, including later re-working of previously deposited pollen; transport by wind and/or rivers from the east from a variety of hinterland vegetation formations, and delivered to the estuary by fluvial current within and proximal to the deltas; transport by avifauna (this may be a minor transport mechanism); and *in situ* accumulations.

The range of source species, transporting media, and transportation directions would appear to complicate the palynological records. However, the large-scale geomorphic units in the area have diagnostic vegetation assemblages, and thus a single species or group of species can signal derivation from a particular habitat. For instance, *Banksia* does not occur on the dune barrier, nor on the saltmarshes; *Olearia* does not occur on the Mandurah-Eaton Ridge or on the saltmarshes; and *Halosarcia* spp specifically inhabit only the saltmarshes. In this context, there are key species that are diagnostic of source environment (Table 2).

Pollen vectors: wind, currents and runoff

The three main vectors for transporting pollen in the Leschenault Inlet system are wind, estuarine currents, and fluvial run-off. Estuarine currents in the Leschenault Inlet estuary are driven by wind and tides. Wind waves rework the muddy sediment of the platforms, and under the effect of a northward net current, deposit mud in the deep water

of the central basin or in the northern parts of the estuary (Semeniuk 2000). Any pollen delivered to the platforms potentially can be reworked under these conditions, and redeposited along with mud particles in the sites of mud accumulation.

The Collie River and the Preston River discharge freshwater into the estuary, and their drainage basins potentially draw on pollen material delivered by *in situ* fall from riparian vegetation, eroded from soils in the hinterland that support a variety of vegetation types, and reworked wind-delivered material (e.g. pine pollen raining down on the drainage basin and floodplains of the rivers). All such pollen, through fluvial reworking and transport, can find its way into the Leschenault Inlet estuary.

Wind patterns, and their strength and direction in relation to anemophilous plant flowering times, are critical factors in determining the types of pollen and the amount of pollen that is delivered to the depositional environment. The Leschenault Inlet area is characterised by three wind patterns (Semeniuk & Meagher 1981a). a summer pattern of landbreezes and seabreezes, a prevailing winter pattern, and a winter-storm pattern. The pattern in spring is transitional between winter and summer patterns, with easterlies and the landbreeze/seabreeze system progressively intensifying. The wind patterns of interest are those that occur during the flowering season, from August to November, and for some species progressing to February.

It is important to note that other factors may contribute to the composition of a pollen assemblage. For example, prolific anemophilous plants on the Mandurah-Eaton Ridge, flowering at a time of calm or weak easterly winds in say, August, may not deliver as much pollen to the sedimentary repository as a less prolific pollen-producing plant flowering at a time of strong easterly winds in summer. Also, there may be prolific entomophilous pollen production, which may be preserved *in situ*, but this would have a negligible contribution via winds. A full analysis of the flowering times of anemophilous and entomophilous plants, their location, their abundance, the wind speeds and direction at times of plant flowering, and the abundance of their pollen within Leschenault Inlet, however, is beyond the scope of this study.

The saltmarsh plants *Frankenia pauciflora*, *Halosarcia indica bidens*, *H. halocnemoides*, *Sarcocornia quinqueflora*, and *Suaeda australis* flower at various times of the year (Marchant *et al.* 1987). In addition to wind dispersal *in situ* accumulations of pollen on the tidal flat are dispersed by estuarine currents to sub-aquatic platforms and the central basin. For *Avicennia marina*, which commences flowering in March-May (Semeniuk *et al.* 1978), *in situ* accumulation and subsequent estuarine current dispersion are significant factors.

Methods

Samples were collected from the undisturbed sedimentary surface of estuarine and saltmarsh environments, and from stratigraphic profiles (Fig 3). Sampling sites were selected from the 22 sites of Wurm & Semeniuk (2000), across the estuary to illustrate across-estuary trends. Contemporary environments sampled include the mangrove zone,

Table 2. Diagnostic key species of the source environment for Leschenault Inlet

Large scale habitat setting	Key species diagnostic to the setting
Barrier dunes	<i>Acacia cyclops</i> , <i>A. rostellifera</i> , <i>Eucalyptus gomphocephala</i> , <i>Olearia axillaris</i> , <i>Rhagodia bacatta</i>
Mandurah-Eaton Ridge	<i>Banksia</i> spp, <i>Eucalyptus calophylla</i> , <i>Eucalyptus marginata</i> , <i>Isopogon</i> spp, <i>Kunzea ericifolia</i> , <i>Stirlingia latifolia</i>
Yalgorup Plain	<i>Eucalyptus gomphocephala</i> , <i>Eucalyptus calophylla</i>
emergent deltaic shoals	<i>Casuarina obesa</i> , <i>Hakea prostrata</i> , <i>Viminaria juncea</i>
freshwater to saltwater wetlands, east shore	<i>Baumea articulata</i> , <i>Baumea juncea</i> , <i>Melaleuca cuticularis</i> , <i>M. raphiophylla</i> , <i>M. viminea</i>
saltmarsh	<i>Frankenia pauciflora</i> , <i>Halosarcia indica bidens</i> , <i>H. halocnemoides</i> , <i>Juncus kraussii</i> , <i>Salicornia quinqueflora</i> , <i>Suaeda australis</i>
mangrove	<i>Avicennia marina</i>
seagrass	<i>Halophila ovalis</i> , <i>Heterozostera</i> , <i>Ruppia megacarpa</i> , <i>Zostera muelleri</i>
exotic plants	<i>Pinus radiata</i> , <i>P. pinaster</i> , <i>Eucalyptus globulus</i> , <i>Lupinus</i> spp, <i>Cynodon dactylon</i> , <i>Pennisetum clandestinum</i> , <i>Paspalum vaginatum</i> , <i>Carpobrotus edulis</i>

sub-aquatic estuary platform (B9, 13, and C16, 18), estuarine basin (B11, C17), and saltmarsh zone. Pen *et al.* (2000), Wurm & Semeniuk (2000), and Semeniuk (2000) provide general descriptions of the settings of these sites.

The stratigraphic samples, collected to investigate the sub-recent (very late Holocene) occurrence of *Avicennia marina*, were obtained from (Fig 3): 1. the Preston River delta, where mangroves are currently extant; 2. the sub-surface muds in the vicinity of mangroves at Site LI-4B; 3. the sub-surface muds in the vicinity of mangroves at Site LI-6; and 4. along a north-south oriented transect across supratidal flats in northern Leschenault Inlet. The sampling strategy for these sub-recent stratigraphic settings was designed to target the zone of most likely occurrence of mangrove pollen, if indeed mangroves were present at that time.

Pollen and spore assemblages were recovered from the sediments following the extraction techniques of Phipps & Playford (1984). Residue strew mounts from thirty two samples in total were microscopically examined. All samples were scanned for the presence of *Avicennia marina* pollen, 12 samples were counted to characterise the pollen assemblages from different contemporary depositional environments, and nine of the sub-recent samples were counted for comparison with the contemporary assemblages. Table 3 lists all samples, their stratigraphic location/

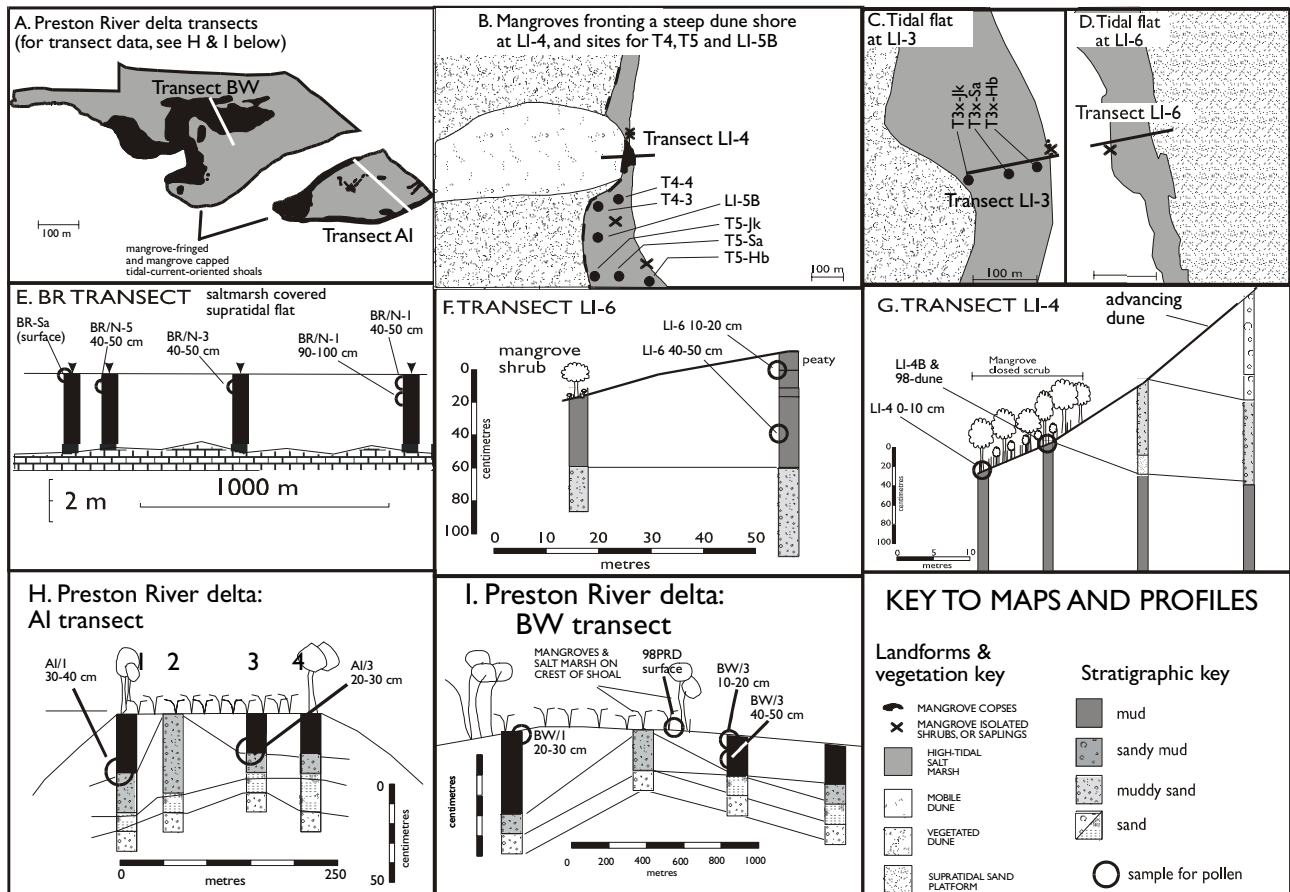


Figure 3. Location of transects and study sites in study areas, and stratigraphic setting and location of pollen samples.

environment, rationale for sampling, type of palynological analysis, and the presence or absence of *Avicennia marina* pollen.

Modern pollen reference slides were prepared from acetolysed pollen samples collected from fourteen critical species in the local flora, and *Avicennia marina* pollen was obtained from specimens mounted on herbarium sheets held at the Western Australia Herbarium. A range of pollen which are thin-walled did not survive the acetolysis process *i.e.* *Juncus kraussii* (Juncaceae) and the seagrasses *Halophylla ovalis*, *Heterozostera* sp, *Ruppia megacarpa*, and *Zostera muelleri*, and consequently are not recorded in the pollen assemblages.

Pollen counts

In the pollen counts, species identification was carried out where possible and critical, but the majority of specimens were identified only to the generic or family level. Pollen from the five species of Chenopodiaceae sampled from the local vegetation were grouped together because their differing preservation in the samples made it difficult to reliably differentiate between species. Similarly, pollen of Myrtaceae are grouped together in the analysis, but the dominance of *Eucalyptus* over the *Melaleuca/Agonis* group in particular samples is referred to where appropriate. *Pinus* was the main exotic palynomorph readily identified in the samples. Other potential exotic pollen, from

Eucalyptus globulus and grasses such as *Cynodon dactylon*, *Pennisetum clandestinum*, and *Paspalum vaginatum* were not differentiated from native species. The total percent occurrence of taxa counted in each sample is listed in Table 4. To characterise and compare the pollen assemblages from each site, *Pinus* pollen was removed and minor taxa further grouped. Note that in these analyses the data are presented as relative percentages, and not as absolute numbers for a given volume of sediment.

Scans for *Avicennia marina* pollen

For each sample, one to two strew slides were scanned for the presence of *Avicennia marina* pollen. For samples rich in palynomorphs, up to 15 000 pollen grains were included in the scan. For the rare samples depauperate in palynomorphs, only several hundred grains were scanned.

Avicennia marina pollen grains are tricolporate and oblate spheroidal with distinct colpi and circular pores averaging 10 µm in diameter. Colpi terminate sharply and have a distinctive psilate colpal membrane. Grains are sculpturally reticulate with prominent but short columellae, the expanded heads of which are fused to form the 1 µm wide muri; lumina are irregular and as thick as, or thinner than, the muri. Pollen of *A. marina* has an average polar diameter of 26 µm and an average equatorial diameter of 29 µm.

The tricolporate/colpate pollen group listed in the rela-

tive percent occurrence of species (Table 4) includes several types that, without close examination, could be mistaken for *A. marina* pollen. The large pores, prominent colpal membranes, and distinctive reticulum of *A. marina* pollen serve to differentiate it from the other tricolporate types in the Leschenault Inlet samples.

Results

Pollen groups and species identified in this study are as follows: 1) identification to Family level: Casuarinaceae, Chenopodiaceae, Compositae, Gramineae, Liliaceae, Myrtaceae, Proteaceae (excluding *Isopogon* and *Stirlingia*), and Restionaceae; 2) identification to genus level: *Gonocarpus*, *Isopogon*, *Ligularia?*, *Pinus*, and *Stirlingia*; 3) identification to species level: *Acacia cyclops*, *Aprum prostratum*, *Avicennia marina*, *Frankenia pauciflora*, *Lepidosperma gladiatum*, and *Olearia axillaris*; and 4) inde-

terminate identification: Dicotyledons, Tricolporate/colpate gen indet, Dicotyledon Gen. *et sp* indet, Cryptogam spores, Hepaticae (?*Phaeoceros*), Selaginellaceae, and Gen *et sp* indet. The results of the pollen counts are presented in Table 3 to 5.

Pollen assemblages

Gramineae and Casuarinaceae pollen are relatively consistent and show no trends in relative abundance in the main sedimentary environments (*viz* the saltmarsh, the western platform, the central basin, and the eastern platform).

Pollen assemblages in the saltmarsh environment on the western shore are dominated by Chenopodiaceae. The native pollen assemblages from the sub-aquatic western platform, central basin, and sub-aquatic eastern platform environments are similar in being dominated by Myrtaceae,

Table 3. Samples studied, rationale for study, pollen counts (NB. all samples were scanned), and presence of mangrove (*Avicennia marina*) pollen.

Sampling rationale	Samples (environment)	Pollen count	Mangrove pollen present
Contemporary samples			
Presence of mangrove pollen; typify pollen assemblage	LI-4B 10 cm (mangrove zone)	Yes	Yes
	98-dune surface (mangrove zone)		Yes
	98 PRD surface (mangrove zone)	Yes	Yes
Typify pollen assemblages across estuary; presence of mangrove pollen	A4 (subaquatic estuary platform)		No
	C9 (subaquatic estuary platform)	Yes	No
	C11 (estuarine basin)	Yes	No
	C13 (subaquatic estuary platform)	Yes	No
	B16 (subaquatic estuary platform)	Yes	No
	B17 (estuarine basin)	Yes	Yes
	B18 (subaquatic estuary platform)		No
Typify saltmarsh pollen assemblages; presence of mangrove pollen	C-Sa (saltmarsh)	Yes	No
	Br-Sa (saltmarsh)	Yes	No
	T3x-5C (saltmarsh)		No
	T3x-Hb (<i>H. indica</i> bidens zone)		No
	T3x-Jk (<i>Juncus kraussii</i> zone)		Yes
	T4-3 (saltmarsh)		Yes
	T4-4 (saltmarsh)		No
	LI-5B 10 cm (saltmarsh)		No
	T5-Sa (saltmarsh)		No
	T5-Hb (<i>H. indica</i> bidens zone)	Yes	No
T5-Jk (<i>Juncus kraussii</i> zone)		No	
Stratigraphic samples			
Determine if mangrove pollen present in subrecent sediments under extant mangrove sites, or nearby	AI/1 30-40 cm (Preston River delta)		No
	AI/3 20-30 cm (Preston River delta)	Yes	No
	BW/1 20-30 cm (Preston River delta)	Yes	No
	BW/3 10-20 cm (Preston River delta)	Yes	No
	BW/3 40-50 cm (Preston River delta)	Yes	No
determine if mangrove pollen present in subrecent sediments under extant mangrove sites or nearby	LI-6 10-20 cm (saltmarsh, NE inlet)		No
	LI-6 40-50 cm (saltmarsh NE inlet)	Yes	
	BR/N-1 40-50 cm (northern supratidal flat)	Yes	No
	BR/N-1 90-100 cm (northern supratidal flat)	Yes	No
	BR/N-3 40-50 cm (northern supratidal flat)	Yes	No
BR/N-5 40-50 cm (northern supratidal flat)	Yes	No	

Table 4. Pollen counts for species/groups found in sites sampled in Leschenault Inlet estuary (250 grain count).

TAXA	SITES	A4	B9	B11	B13	G16	G17	G18	Br-9a	T5-Hb	PRD surf	A1/3	20-30	BW/1	20-30	BW/3	10-20	LI-4B	0-10	LI-5B	0-10	BR/N/3	40-50	BR/N/5	40-50	BR/N/1	90-100	LI-6	40-50
Casuarinaceae		20	19	33	26	16	30	15	1	7	11	-	-	-	-	-	-	-	4	7	4	4	4	13	4	29	15		
Myrtaceae		52	114	103	52	87	65	86	16	46	69	2	14	12	11	23	10	102	23	11	23	10	102	10	102	95	23		
Gramineae		29	58	54	40	33	41	36	12	15	39	-	9	7	20	10	25	7	22	20	10	25	7	22	22	5			
<i>Pinus</i>		73	8	4	31	17	33	21	9	10	11	-	-	-	137	5	3	1	2	5	3	1	3	1	2	2	0		
<i>Avicennia marina</i>		-	-	-	-	-	3	-	-	4	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0		
Chenopodiaceae		19	29	20	24	86	36	59	201	152	94	238	194	231	52	200	140	20	39	52	200	140	20	20	39	183			
<i>Lepidosperma gladiatum</i>			2		6	1	7	1	-	-	-	-	-	-	2	-	50	10	10	2	-	50	10	10	10	10	6		
Restionaceae		10	3	7	6	3	11	8	5	2	-	-	1	-	4	1	1	7	15	4	1	1	7	15	1	1			
Compositae		6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0		
<i>Olearia axillaris</i>		7	1	6	10	2	10	2	2		6	3	-	-	4	1	1	73	3	4	1	1	73	3	4	4			
<i>Ligularia?</i>		-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0		
<i>Frankenia pauciflora</i>		1	4	1	-	-	1	1	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0		
<i>Aprum prostratum</i>		-	-	1	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	3	-	-	-	-	-	0		
<i>Gonocarpus</i>		2	-	4	5	-	-	2	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	4	0			
<i>Isopogon</i>		-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0		
Proteaceae		-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0		
<i>Acacia cyclops</i>		-	-	-	1	-	-	1	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1		
Gen et sp indet		11	-	6	9	-	3	4	4	4	1	1	1	1	6	-	-	4	8	6	-	-	4	8	8	3	3		
Tricolporate/colpate gen. indet.		5	4	3	10	2	4	4	-	8	8	-	26	-	2	3	8	-	8	2	3	8	-	-	8	8	8		
<i>Stirlingia</i>		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0		
Liliaceae		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	4	0		
CRYPTOGAM SPORES																													
Hepaticae (?Phaeoceros)		7	-	4	14	1	2	7	-	-	2	-	-	-	1	-	2	1	1	1	-	2	1	1	1	0			
Selaginellaceae		-	1	-	-	-	1	-	-	-	1	-	-	-	-	-	-	10	1	-	-	-	-	10	1	0			
Gen et sp indet		8	7	2	14	2	3	3	-	1	2	-	4	-	3	-	5	2	7	3	-	5	2	7	7	1			

Table 5. Percentage occurrence of pollen of species/groups sampled in Leschenault Inlet estuary.

TAXA	SITES	A4	B9	B11	B3	C6	C7	C8	Br-Sa	T5-Hb	PRD surf	A1/3	BW/1	20-30	BW/3	10-20	LI-4B	0-10	LI-5B	0-10	BR/N/3	40-50	BR/N/5	40-50	BR/N/1	90-100	LI-6	40-50	
Casuarinaceae		8	7.6	13.2	10.4	6.4	12	6	0.4	2.8	4.4	0	0	0	0	0	0	2.8	1.6	1.6	1.6	5.2	5.2	11.6	11.6	6	6	6	
Myrtaceae		20.8	45.6	41.2	20.8	34.8	26	34.4	6.4	18.4	27.6	0.8	5.6	0.8	4.8	4.8	4.4	4.4	9.2	4	4	40.8	40.8	38	38	9.2	9.2	9.2	
Gramineae		11.6	23.2	21.6	16	13.2	16.4	14.4	4.8	6	15.6	0	3.6	0	2.8	2.8	8	8	4	4	10	2.8	2.8	8.8	8.8	2	2	2	
<i>Pinus</i>		29.2	3.2	1.6	12.4	6.8	13.2	8.4	3.6	4	4.4	0	0	0	0	0	54.8	2	2	2	1.2	0.4	0.4	0.8	0.8	0	0	0	
<i>Avicennia marina</i>		0	0	0	0	0	1.2	0	0	1.6	2.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Chenopodiaceae		7.6	11.6	8	9.6	34.4	14.4	23.6	80.4	60.8	37.6	95.2	77.6	92.4	20.8	20.8	80	80	80	80	56	8	8	15.6	15.6	73.2	73.2	73.2	
<i>Lepidosperma gladiatum</i>		0	0.8	0	2.4	0.4	2.8	0.4	0	0	0	0	0	0	0.8	0.8	0	0	0	0	20	4	4	4	4	2.4	2.4	2.4	
Restionaceae		4	1.2	2.8	2.4	1.2	4.4	3.2	2	0.8	0	0	0.4	0	0.4	0	1.6	0.4	0.4	0.4	0.4	2.8	2.8	6	6	0.4	0.4	0.4	
Compositae gen. et sp. indet		2.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Olearia axillaris</i>		2.8	0.4	2.4	4	0.8	4	0.8	0.8	0	2.4	1.2	0	0	0	0	1.6	0.4	0.4	0.4	29.2	29.2	1.2	1.2	1.2	1.6	1.6	1.6	
<i>Ligularia?</i>		0	0	0.4	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Frankenia pauciflora</i>		0.4	1.6	0.4	0	0	0.4	0.4	0	0	0	2.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Apium prostratum</i>		0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.2	0	0	0	0	0	0	0	0	0	
<i>Gonocarpus</i>		0.8	0	1.6	2	0	0	0.8	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0	0	1.6	1.6	0	0	0	
<i>Isopogon</i>		0	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Proteaceae gen. indet.		0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Acacia cyclops</i>		0	0	0	0.4	0	0	0.4	0	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0.8	0.4	0.4	
Gen et sp indet		4.4	0	2.4	3.6	0	1.2	1.6	1.6	1.6	0.4	0.4	0.4	0.4	0	0	2.4	0	0	0	0	1.6	1.6	3.2	3.2	1.2	1.2	1.2	
Tricolporate/colpate gen. indet.		2	1.6	1.2	4	0.8	1.6	1.6	0	3.2	3.2	0	10.4	0	0.8	0.8	1.2	1.2	1.2	3.2	3.2	0	0	3.2	3.2	3.2	3.2	3.2	
<i>Stirlingia</i>		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Liliaceae		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0	1.6	1.6	0	0	
CRYPTOGAM SPORES																													
Hepaticae (?Phaeoceros)		2.8	0	1.6	5.6	0.4	0.8	2.8	0	0	0.8	0	0	0	0	0	0.4	0	0	0	0.8	0.4	0.4	0.4	0.4	0	0	0	
Selaginellaceae		0	0.4	0	0	0	0.4	0	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0.4	0	0	
Gen et sp indet		3.2	2.8	0.8	5.6	0.8	1.2	1.2	0	0.4	0.8	0	1.6	0	1.2	0	1.2	0	0	0	2	0.8	0.8	2.8	2.8	0.4	0.4	0.4	

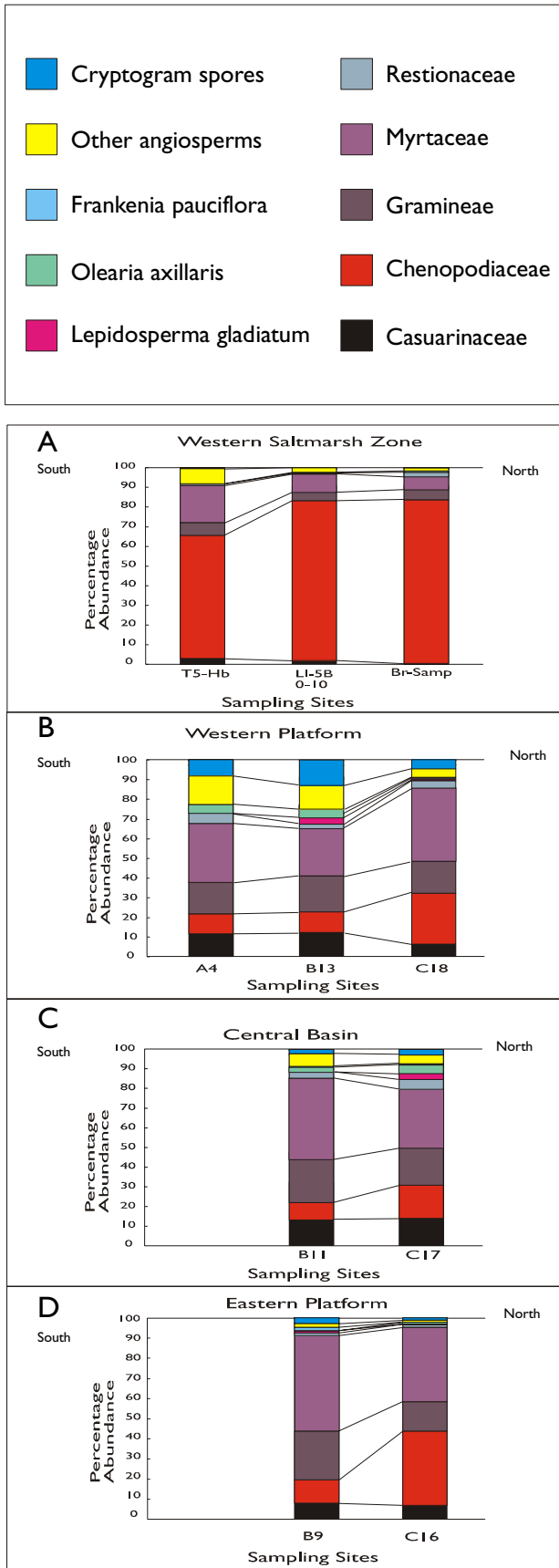


Figure 4. Occurrence of pollen of selected/species groups from the contemporary surfaces of the western saltmarsh zone, western platform, central basin, and eastern platform.

Chenopodiaceae, Gramineae, and Casuarinaceae (Fig 4). In each of these environments Chenopodiaceae pollen show a south to north increase in abundance, reflecting the increase in abundance of parent plants towards the northern tidal saltmarsh flats. *Olearia axillaris* pollen is most common in the southern and central sites on the western sub-aquatic platform and in the central basin, but is rare in the eastern sub-aquatic platform environment. This distribution reflects the proximity of the mobile and recently fixed dune habitats in the southern and middle Leschenault Peninsula barrier, a habitat that *Olearia axillaris* prefers. The relative prominence of this species in the central basin pollen assemblage suggests it is widely dispersed or re-worked by wind and water.

Patterns across transects

Trends in the relative abundance of pollen across the different estuarine environments are best illustrated by Transect C, incorporating Sites T5-Hb, C18, C17, C16, and C-Sa (Fig 5). These sites respectively occur in the western saltmarsh, sub-aquatic western platform, central basin, sub-aquatic eastern platform, and eastern saltmarsh environments. Chenopodiaceae pollen dominate the western saltmarsh environment, decrease in abundance towards the central basin, increase again on the eastern platform, and become dominant again on the eastern saltmarsh. Gramineae pollen, away from the saltmarsh environments where they are overshadowed by the over-representation of Chenopodiaceae pollen, show a fairly consistent relative abundance across the estuary. Casuarinaceae, Restionaceae, *Olearia axillaris* and *Lepidosperma* pollen are most abundant in the central basin and decrease in abundance towards the eastern and western shores. This pattern may signal transport and deposition by currents as well as wind. Pollen of the Myrtaceae are relatively consistent across the basin, being similarly prominent on the eastern and western platforms; their lower relative abundance in the saltmarsh is likely related to the over-representation of Chenopodiaceae pollen.

In Transect B, which incorporates Sites B13, B11 and B9 (Fig 5), some species/groups have a similar pattern of distribution as in Transect C (Fig 5), whereas others are quite different. From west to east, Chenopodiaceae pollen are slightly more abundant on the platforms than in the central basin, reflecting proximity of the platforms to adjoining saltmarsh environments. Gramineae pollen is relatively consistent across the estuary, and Casuarinaceae pollen is slightly more abundant in the central basin compared to the sub-aquatic platforms, suggesting transport and deposition by currents as well as wind. *Olearia axillaris* and *Lepidosperma gladiatum* pollen show comparable trends - they are more abundant in the western platform sites close to their source, and decrease in abundance from west to east. The pollen of Myrtaceae show a trend of decreasing abundance from east to west across the estuary.

Patterns of distribution

From the transects, consistent patterns of pollen distribution can be seen for the major plant groups discussed above. Chenopodiaceae pollen decreases in abundance away from its source; Gramineae is fairly consistent across

the estuary, suggesting its occurrence is relatively uniform in the surrounding vegetation; and Casuarinaceae pollen is more abundant in the central basin, possibly due to a combination of local input, currents, and long-distance aerial and fluvial delivery. Other taxa that provide insights into dispersion of pollen within the estuary are *Acacia cyclops*, *Eucalyptus* spp and the *Melaleuca/Agonis* group, *Lepidosperma gladiatum*, *Olearia axillaris*, and *Pinus*.

Acacia cyclops is restricted to specific habitats on the dune barrier. Its pollen only occurs in very low numbers adjoining its source. *Acacia* produces relatively large heavy pollen that is rarely transported far from its source. While the pollen counts presented in Table 4 refer to generalised Myrtaceae pollen (see Methods), differentiation between the pollen of *Eucalyptus* spp and the *Melaleuca/Agonis* group was attempted. The results of pollen counts show that along Transect B the pollen record is dominated by *Melaleuca/Agonis*, indicating probable derivation from *Melaleuca raphiophylla* wetland forests and *Agonis* scrub from the western and eastern shores; *Eucalyptus* pollen along this transect is most prominent in the central and eastern platform sites, indicating that its source is the *Eucalyptus* species (*E. gomphocephala*, *E. rudis*, *E. calophylla*, *E. marginata*) that inhabit the eastern shore. The shore and barrier to the west of Transect B is not dominated by *Eucalyptus* vegetation. In Transect C, *Eucalyptus* pollen is more prominent on the platforms and *Melaleuca/Agonis* dominates the central basin. *Eucalyptus* woodland occurs on the western barrier, and in the east, *Melaleuca raphiophylla* wetland forests, *Agonis* scrub, and the *Eucalyptus* species noted above, occur.

The patterns for *Lepidosperma gladiatum* and *Olearia axillaris* are similarly variable. Near Transect B, these species occur on both sides of the basin, but are most common on the dune barrier adjoining the western platform. Although pollen numbers are low for these species, their relative abundance across Transect B does reflect the distribution of the parent plants. Along Transect C, pollen of both species is most abundant in the central basin, indicating a possible high aerial delivery that by-passes the western platform, or a water current delivery from southern areas of the barrier dune.

Pollen of *Pinus* is ubiquitously present in low to moderate abundance (<1-12%) in most of the estuary environments. Pine plantations occur both locally and distally to the north-east of the Leschenault Inlet estuary, but there appears to be no pattern of pollen dispersal across the estuary with respect to source and wind patterns. Of interest are two samples with a particularly high pine pollen occurrence. Site A4, which contains 28% pine pollen, is the most southerly of the sub-aquatic western platform samples and the most distant from the forest source. However, this site is opposite the Collie River delta, suggesting fluvial delivery of pine pollen that has been transported to the Collie River drainage basin via wind and run-off. The most abundant occurrence of pine pollen is in a mangrove zone (Site LI-4B) where it comprises almost 55% of the pollen count. A replicate sample collected a metre away (Site 98-dune surface), and adjoining and more open saltmarsh environments (Sites LI-5B and T5-Hb), contain less than 5% pine pollen. The high relative abundance of pine pollen at Site LI-4B is inexplicable at this stage, and illustrates

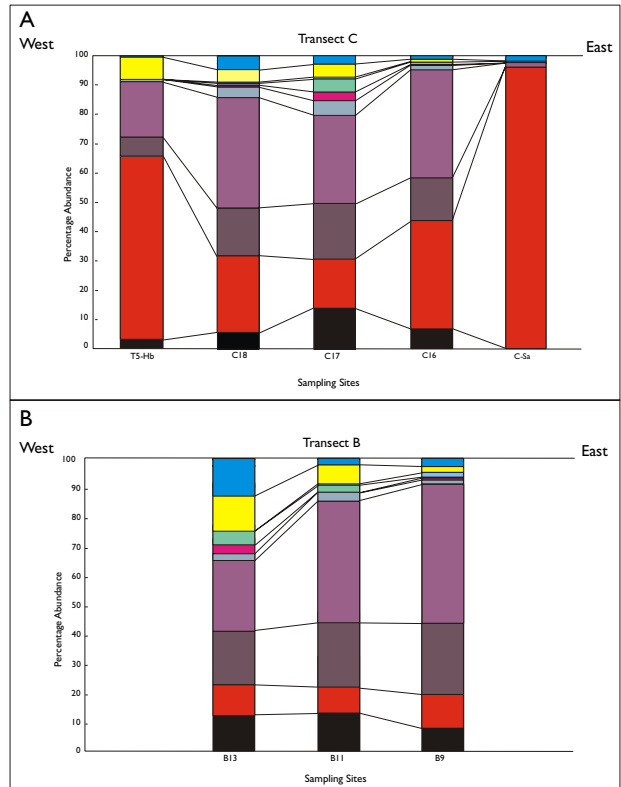


Figure 5. Occurrence of pollen of selected species/group from the contemporary surface along the east-west transects viz Transects B and C. Pine pollen has been excluded.

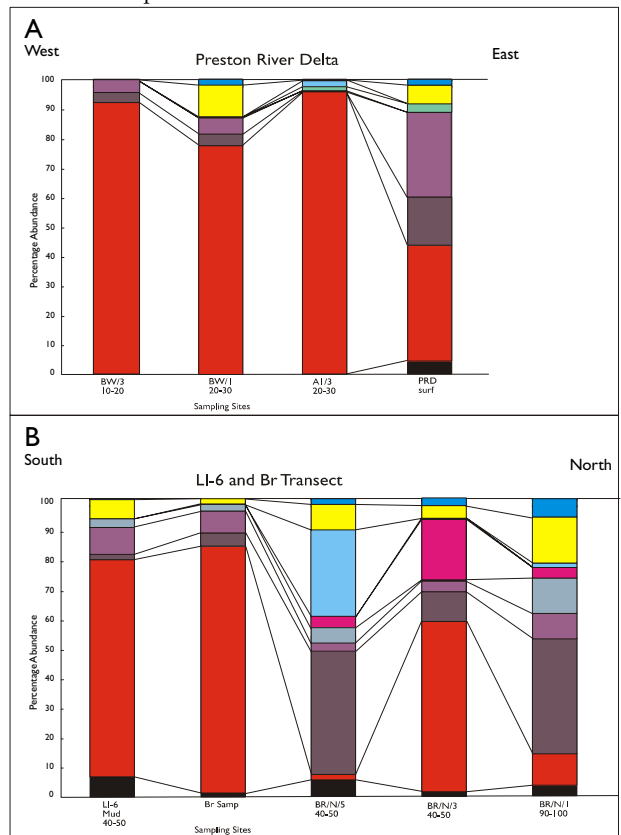


Figure 6. Comparison of occurrence of pollen of selected species/groups in the modern and sub-recent for the Preston River Delta transect and the LI-6 and BR/N transects. Pine pollen has been excluded.

well the problems posed by local over-representation of regional pollen when interpreting fossil pollen assemblages from single boreholes.

Stratigraphic results

Preston River delta (Fig 6). In the Preston River delta the contemporary sample (98 PRD surface) contains a variety of pollen types, including, in order of abundance, Chenopodiaceae (near 40%), Myrtaceae (near 30%), Gramineae, Casuarinaceae, *Pinus*, and *Frankenia pauciflora*. The three sub-recent samples (AI/3, BW/1, BW/3) are generally similar to each other in composition, but differ from the contemporary sample in being dominated by Chenopodiaceae (80-90%), with Myrtaceae and Gramineae together totalling about 10%; pollen of *Pinus* and Casuarinaceae are not present.

Northern estuary (Fig 6). In the north-eastern estuary the contemporary saltmarsh sample (Site Br-Sa) is dominated by Chenopodiaceae, with a < 20% aggregate of Myrtaceae, Gramineae, Restionaceae, *Olearia* and *Pinus*. The stratigraphic samples (Sites BR/N-1, BR/N-3, BR/N-5, and LI-6) are variable, but differ from the contemporary sample in containing markedly less Chenopodiaceae, comparatively common to abundant *Lepidosperma gladiatum*, and consistent Casuarinaceae pollen. Locally, they contain a higher percentage of Gramineae pollen, and Myrtaceae and Restionaceae pollen are more abundant in two of the samples.

Stratigraphically, the BR/N series of samples are located in the southern 1 km part of a former muddy tidal flat to shallow water mud basin setting that prograded some 4 km in the last *ca* 3 000 years (see Semeniuk 1985 and 1995a for radiocarbon dates in this region with respect to the sea level history and the evolution of Leschenault Inlet). This places the samples collected within a time frame of the last 1 000 years.

Mangrove pollen distribution

The results of the analyses of a wide range of surface contemporary samples showed that while *Avicennia marina* pollen occurred in the samples collected from environments under mangrove canopy and in immediately adjacent environments (*e.g.* nearby non-mangrove inhabited tidal flat saltmarsh environments), it was not recorded from most estuarine surfaces (see Table 3). Significantly, *Avicennia marina* pollen was not recorded from the sub-recent samples.

Discussion

A major objective of this study was to determine if pollen assemblages could be related to depositional environment, and therefore of use in interpreting earlier Holocene sequences in the area. The results to date suggest that this is possible. The baseline studies of the contemporary sediments show that it is possible to separate the saltmarsh, western platform, central basin, and eastern platform pollen assemblages at a gross scale using family groupings, and in some instances at the generic or species level. The saltmarsh environment, dominated by Chenopodiaceae pollen, is relatively simple to differentiate. Similarly, species that are proximal

to their source generate pollen abundance gradients which serve to distinguish specific environments and indicate the nature of the immediate upland source vegetation. For some sites, potential transport systems assist in explaining the distribution of palynomorphs.

Although a clearer picture of the characteristics of pollen assemblages from each environment will emerge during future studies, it is possible from the preliminary baselines to suggest the environments of deposition for some of the sub-recent samples in the northern estuary (*i.e.* BR/N series of samples). For example, the pollen assemblage from the LI-6 (40-50 cm) sample is similar to those in the contemporary saltmarsh samples (*e.g.* Br-Sa, LI-5B). In BR/N-5 (40-50 cm) and BR/N-1 (90-100 cm) the most indicative characteristic of the pollen assemblages is the relative prominence of *Lepidosperma gladiatum* and the presence of *Olearia axillaris*, together with a moderate abundance of Chenopodiaceae pollen. The most similar contemporary assemblages are in C17 from the northern central basin, and C13 on the western platform. In C17, it is thought the relative abundance of pollen of these species is due to water current or aerial transport, whereas in C13, *L. gladiatum* and *O. axillaris* are common in the adjacent vegetation. Considering the stratigraphic and prograding setting of the two BR/N samples, they may both have been deposited in a northerly section of the northern subtidal flat.

It is stressed that the results and conclusions of this study are preliminary in nature. To obtain a fuller understanding of the distribution and internal variability in the environment-related pollen assemblages, more samples across the estuary are needed, and more replication within sites and replication between sites within the same depositional unit are required.

Interpretations of the Holocene pollen record in terms of depositional environments, proximal vegetation associations, and climate change need to be based firmly on an holistic understanding of the dynamics of pollen in the modern environment. Holistic studies integrating aspects such as vegetation sources, wind patterns, depositional processes, and pollen taphonomy amongst others, are difficult and seldom attempted. To date, the emphasis in Australia has been on interpreting the pollen record in a single borehole (*e.g.* Churchill 1959, 1968; Newsome & Pickett 1993; Jenkins & Kershaw 1997; Lloyd & Kershaw 1997). While these studies are useful generally in illustrating changes in the pollen record, and are used to infer climatic and environmental changes, they are not placed in a comparative contemporary setting, nor do they offer the details of processes that may provide an explanation of the natural variability in the record to separate serial vegetation changes from that induced by local environmental changes (*e.g.* water table changes), or those actually related to climate changes. Luly (1997), however, provides a more holistic study of pollen in a playa in semi-arid Victoria, recognising that the pollen assemblages in sites of sedimentary accumulations are the result of what the author terms a "myriad of influences". From a grid of surface sampling sites, the concentration of different pollen taxa was mapped, and from pollen traps, the pollen transport pathways were characterised. The results were used in the analysis of the pollen record of two cores. Studies such as Luly's (1997), and that of the contem-

porary deposits of Leschenault Inlet, provide insights into the significance of pollen assemblages in a given environment, and highlight inherent problems of interpreting the pollen record from single cores without addressing the complexities of pollen dynamics.

The second objective of the Leschenault Inlet study was to determine if the mangrove *Avicennia marina* was present in the area in the recent past. *Avicennia marina* was not recorded from the sub-recent samples, either indicating that mangrove stands were too distant from the site of accumulating sediment where our samples are located, or that mangroves were in fact absent from the estuary at that time. While mangroves are present in sufficient numbers in Leschenault Inlet today to develop closed low forests and scrub, their pollen only occurs in small numbers in adjacent saltmarsh environments (e.g. T5-Hb, 98 PRD surface) and the northern part of the central basin (C17). The sub-recent stratigraphic samples were drawn from former tidal flat settings, targeting the zone of most likely occurrence of mangrove pollen. The previously noted similarity of the sub-recent pollen assemblages to those of the saltmarsh environment and the northern central basin (C17), both of which contain *A. marina* pollen, and the presence of *A. marina* pollen in contemporary samples from saltmarsh and proximal environments (see Table 3), confirms that the correct zone was targeted. The absence of *A. marina* pollen in the stratigraphic samples therefore suggests that mangroves were not present in the vegetation of sub-recent tidal environments of Leschenault Inlet.

Our results suggest the Leschenault Inlet mangroves are not relicts. Semeniuk *et al.* (2000) argue that *Avicennia marina* is probably a very recent arrival to the region following a change in climate linked to the effects of Earth-axis precession. The hypothesis is forwarded that during the past 7 000 years, as the Tropic of Capricorn migrated northwards, the zone of maximum aridity in Western Australia moved northwards from Shark Bay to Exmouth (Semeniuk 1995b), and the shallow waters of the Northwest Shelf, subject to a progressively more tropical arid climate, became warmer. This contributed to the Leeuwin Current, which then delivered propagules of *A. marina* southwards to the Bunbury region from the Gascoyne-Shark Bay region, a process which appears counter-intuitive to the northwards migration of the tropical zones. The mangrove populations were sustained in the Bunbury region (specifically at Leschenault Inlet) by the quasi-tropical marine conditions that exist in the Geographe Bay to Bunbury area, where the Leeuwin Current impinges onto, and eddies northward along, the coast. To fully test this hypothesis, more intensive sampling of Holocene estuarine tidal flat sediments in the Leschenault Inlet system needs to be undertaken.

From a geoheritage perspective, the Leschenault Inlet estuary probably ranks as significant at a national level. Because of its uncomplicated north-south oriented sedimentary environments and parallel landform and vegetation units, it also provides a classic environment in which to study the dynamics of pollen deposition. In a broad sense it is a relatively simple estuarine system, yet within it is a complex of vegetation units related to landforms, and sedimentary environments influenced by fluvial input, tidal induced currents, and variable wind di-

rections, all of which have the potential to effect pollen transport within the system. An understanding of the variability of the pollen assemblages in contemporary samples, and the processes that contribute to their composition in a given environment, will lead to a better understanding of the significance of pollen assemblages in the Quaternary record. In essence, this study has set the framework for future work and provided preliminary results to illustrate the research potential of the study area.

References

- Churchill D M 1959 Late Quaternary eustatic changes in the Swan River district *Journal of the Royal Society of Western Australia* 42:53-55.
- Churchill D M 1968 The distribution and prehistory of *Eucalyptus diversicolour* F Muell *E marginata* Donn ex Sm and *E calophylla* R Br in relation to rainfall. *Australian Journal of Botany* 16:125-151.
- Cresswell I D & Bridgewater P 1985 Dune vegetation of the Swan Coastal Plain Western Australia. *Journal of the Royal Society of Western Australia* 67:137-148.
- Heddl E M, Loneragan O W & Havel J J 1980 Vegetation complexes of the Darling System, Western Australia. In: Atlas of Natural Resources, Darling System Western Australia. Department Conservation & Environment, Perth, 37-72.
- Jenkins M A & Kershaw A P 1997 A mid-late Holocene vegetation record from an interdunal swamp Mornington Peninsula, Victoria. *Proceedings of the Royal Society of Victoria* 109(2):133-148.
- Lloyd P J & Kershaw A P 1997 Late Quaternary vegetation and early Holocene quantitative climate estimates from Morwell Swamp, Latrobe Valley, south-eastern Australia. *Australian Journal of Botany* 45:549-563.
- Luly J G 1997 Modern pollen dynamics and surficial sedimentary processes at Lake Tyrrell, semi-arid north-western Victoria, Australia. *Review of Palaeobotany and Palynology* 97:301-308.
- Marchant N G, Wheeler J R, Rye B L, Bennett E M, Lander N S & Macfarlane T D 1987 Flora of the Perth Region. Western Australian Herbarium, Department of Agriculture, Perth.
- Newsome J C & Pickett E J 1993 Palynology and palaeoclimatic implications of two Holocene sequences from south-western Australia. *Palaeogeography Palaeoclimatology Palaeoecology* 101:245-261
- Pen L, Semeniuk V & Semeniuk C A 2000 Peripheral wetland habitats and vegetation of Leschenault Inlet estuary. *Journal of the Royal Society of Western Australia* 83:293-316.
- Phipps D & Playford G 1984 Laboratory techniques for extraction of palynomorphs from sediments. *Papers of the Department of Geology, University of Queensland* 11:1-23.
- Semeniuk V 1983 The Quaternary stratigraphy and geological history of the Australind-Leschenault Inlet area Western Australia. *Journal of the Royal Society of Western Australia* 66:71-83.
- Semeniuk V 1985 The age structure of a Holocene barrier dune system and its implication for sealevel history reconstructions in south-western Australia. *Marine Geology* 67:197-212.
- Semeniuk V 1995a An early Holocene record of rising sea level along a bathymetrically complex coast in south-western Australia. *Marine Geology* 131:177-193.

- Semeniuk V 1995b The Holocene record of climatic, eustatic and tectonic events along a coastal zone of Western Australia - a review. *Journal of Coastal Research Special Issue* 17:247-259.
- Semeniuk V 1997 New Pleistocene and Holocene stratigraphic units in the Yalgorup Plain area (amended from Yoongarillup Plain) Southern Swan Coastal Plain. *Journal of the Royal Society of Western Australia* 78:67-79.
- Semeniuk V 2000 Sedimentology and Holocene stratigraphy of Leschenault Inlet. *Journal of the Royal Society of Western Australia* 83:255-274.
- Semeniuk V & Meagher T D 1981a The geomorphology and surface processes of the Australind - Leschenault Inlet coastal area. *Journal of the Royal Society of Western Australia* 64:33-51.
- Semeniuk V & Meagher T D 1981b Calcrete in Quaternary coastal dunes in SW Australia. a capillary-rise phenomenon associated with plants. *Journal of Sedimentary Petrology* 51:47-68
- Semeniuk V, Cresswell I D & Wurm P A S 1989 Quindalup Dunes. The regional system physical framework and vegetation habitats. *Journal of the Royal Society of Western Australia* 71:23-47.
- Semeniuk V, Kenneally K F & Wilson P G 1978 Mangroves of Western Australia. Handbook 12. Western Australian Naturalists Club, Perth.
- Semeniuk V, Tauss C & Unno J 2000 The white mangrove *Avicennia marina* in the Leschenault Inlet area. *Journal of the Royal Society of Western Australia* 83:317-334.
- Smith G G 1985 A guide to the coastal flora of Western Australia. Handbook 10. Western Australian Naturalists Club, Perth.
- Specht R L 1970 Vegetation. In: *The Australian Environment* (ed G W Leeper). CSIRO, Australia, 44-67.
- Trudgeon M E 1984 The Leschenault Peninsula - flora and vegetation survey with an analysis of its conservation value and appropriate uses. Bulletin 157. Department of Conservation and Environment, Perth.
- Wurm P A S & Semeniuk V 2000 Leschenault Inlet estuary - its physical features and habitats for benthic fauna. *Journal of the Royal Society of Western Australia* 83:229-250.