Pollen in the surface sediments of wetlands in the Becher Point area, southwestern Australia: a baseline for use in interpreting Holocene sequences

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Abstract

Pollen was collected from the surface sediments of 16 wetland basins situated on a beachridge plain in the Becher Point area, southwestern Australia. Sampling was undertaken to determine the ratio of wetland/upland plant species contributing to the surface pollen in each wetland, to determine the contributions of local and regional pollen, and to develop indicator pollen assemblages as a baseline to interpret fossil Holocene sequences. The main wetland plant assemblages colonising the wetlands include sedges – *Baumea articulata* (R. Br.) S. T. Blake;. *Typha* L. spp.; mixed *Baumea articulata* and *Typha* spp.; *Isolepis nodosa* (Rottb.) R. Br.*; Baumea juncea* (R. Br.) Palla; *Lepidosperma gladiatum* Labill.; rushes – *Juncus krausii* Hochst.*;* grasses – *Sporobolus virginicus* (L.) Kunth.; shrubs – *Melaleuca viminea* Lindley; *Melaleuca teretifolia* Endl.; grass trees – *Xanthorrhoea preissii* Endl.; trees and shrubs – *Melaleuca rhaphiophylla* Schauer, *Melaleuca cuticularis* Labill. The pollen assemblages recovered from the surface sediments were separated into six categories as related to extant vegetation: that generated *in situ* from wetland basin vegetation; that derived from *in situ* wetland margin vegetation; that derived allochthonously from wetland vegetation; that from ridge vegetation (inhabiting the beachridges) and transported to the wetland basin; that from distal vegetation in the region; and uncategorised pollen. Of the plants extant in modern wetland centres and their margins, the following key species were commonly detected as pollen grains in the surface sediment: *Centella asiatica* (L.) Urban*, Baumea articulata, Baumea juncea, Isolepis nodosa, Lepidosperma gladiatum, Melaleuca cuticularis, Melaleuca viminea, Melaleuca rhaphiophylla, Melaleuca teretifolia, Sporobolus virginicus, Typha domingensis* Pers./*T. orientalis* C. Presl, and *Xanthorrhoea preissii*. In most wetlands, the majority of the surface pollen in the wetlands was derived from the local wetland and upland ridge vegetation (*i.e.*, that inhabiting the beachridges) of the cuspate foreland. Generally, *in situ* wetland pollen constituted a moderate proportion of the total pollen. Wetland margin pollen was abundant in only half the wetlands. Pollen from ridges was sub-dominant to pollen from allochthonous wetland species in about half the wetlands, and dominant in the remainder. The contribution of distal pollen varied from low in most wetlands to relatively high numbers and significant in others.

The potential dispersal mechanisms for pollen in this area are insects, avifauna, local processes of *in situ* generation, and easterly and westerly winds, and transport agents include wind, rain, sheet wash, and water transport. The differential effect of wind in transporting pollen was explored using local wetland species of *Melaleuca* as a signature, and the occurrence of upland species, such as Casuarinaceae spp., *Olearia axillaris* (DC.) F. Muell. ex Benth., and *Eucalyptus marginata* Donn ex Smith pollen. The patterns show that delivery of pollen to the wetland basins is heterogeneous.

Keywords: palynology, Holocene, wetlands, Becher Point, southwestern Australia

Introduction

The wetlands in the Becher Suite, in the Becher Point area, occur on a Holocene beachridge plain in southwestern Australia (Fig. 1), and comprise numerous small-scale inter-dune basins with a range of vegetation associations that vary from basin to basin (C A Semeniuk

2006). While there is topographic variation in the height of local beachridges, (+ 2–3 m), the basins of the Becher Suite essentially reside in an area with relatively homogeneous geomorphology, stratigraphy, hydrochemistry, and climate *i.e.*, the Becher cuspate foreland (Searle *et al*. 1988).

Palynological studies in Western Australia, using only one or two cores in large water-filled basins, such as Lake Gnangara, Lake Thompson, and North Lake, with
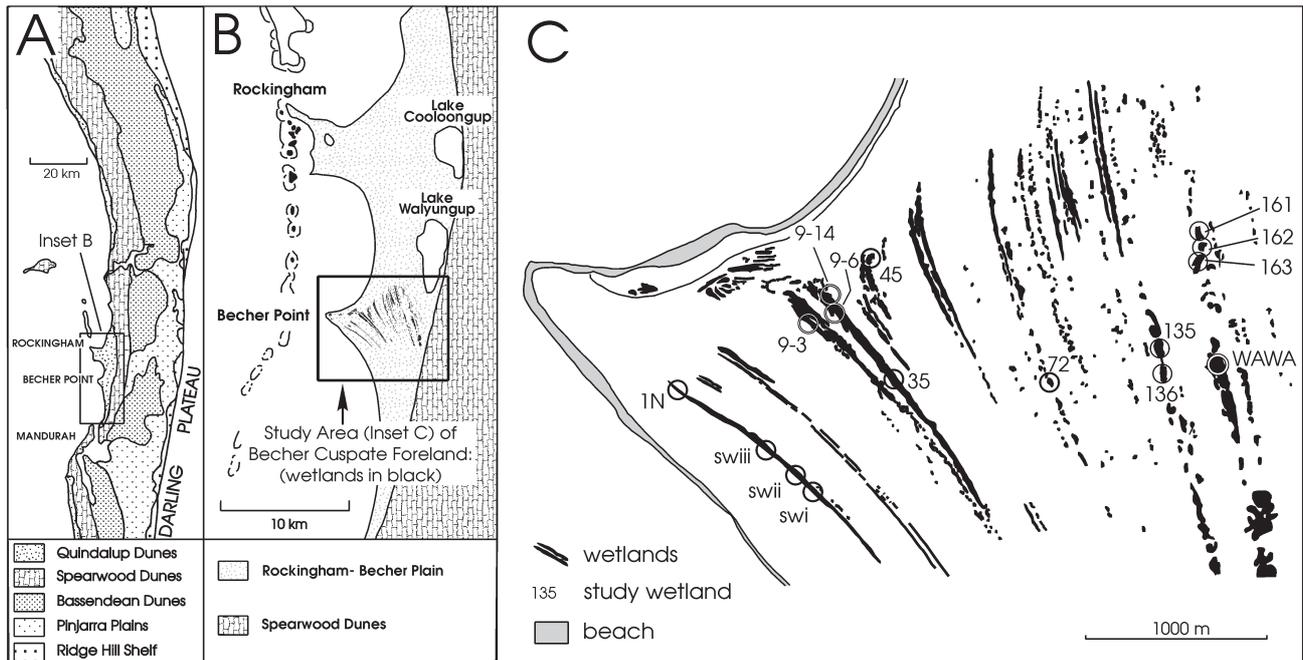
Figure 1. A. Location of Study Area in southwestern Australia. B. The Becher Point area and the Cuspate Foreland. C. Wetlands of the Becher Point area; basins selected for study are circled and annotated.

variable internal hydrodynamic processes, varied peripheral vegetation traps, and likely complex intrabasinal sediment transport, may provide a biased pollen record and impact on the interpretation of local vegetation and climate history. To date, in Western Australia, there have been no published studies directed towards determining the heterogeneity of the pollen record in the large isolated wetland basins, even though studies elsewhere have indicated the complexities inherent in the accumulation of pollen (Dodson 1983; D'Costa & Kershaw 1997; Luly 1997).

Although the area of wetland on the Becher cuspate foreland is equivalent to the large lakes of the Swan Coastal Plain (Fig. 1), the multiplicity of small basinal sinks within it provide, not one, but a series of replicate pollen capture zones, as well as a measure of how consistently pollen reflects the subregional and regional vegetation, and hence climate setting. Inter-basin variation in wetland plant assemblages provides a means to replicate the measure of how effectively *in situ* pollen production is reflected by the pollen record. Thus, the small-scale and numerous wetland basins of the Becher Suite, provide a rare opportunity to examine the relative contributions of autochthonous, and proximal and distal allochthonous pollen to contemporary pollen assemblages.

The specific objectives of this study were to investigate the relationship between present day pollen accumulation and present day vegetation in the wetlands and surrounds of the Becher cuspate foreland; firstly, to determine the ratio of wetland/upland species contributing to the surface pollen assemblages in each wetland; secondly, to determine the various contributions to the wetland basin of local and regional pollen; and, thirdly, to use the surface pollen assemblages as a baseline to interpret fossil sequences (the subject of a later

paper). For this study, the pollen of the surface sediments was investigated for 16 wetland basins (Fig. 1) for which there were data on the vegetation associations. A wide variety of wetland vegetation types were selected in order to encompass as many pollen assemblages as possible, and to determine whether the processes of pollen transport and preservation varied over the cuspate foreland.

Materials and methods

The wetlands selected for palynological study of their surface sediments were 161, 162, 163, WAWA, 135, 136, 72, 45, 35, 9-3, 9-6, 9-14, swi,swii, swiii, 1N (Fig. 1). The upper 1 cm of sediment from the surface, and in wetlands with a thick cover of leaf litter, samples from the surface litter were collected in the centre of each of these wetlands. Calcilutite in these wetlands has accumulated at a rate of 0.1–0.4 mm/yr (C A Semeniuk 2006), and therefore if sedimentation has continued into the present, the sampling interval represents at least 25–100 years of accumulation.

To provide an appreciation of the variability of vegetation assemblages in these wetlands, a programme of vegetation mapping, classification and quantitative analyses was undertaken during 1991–2001, with the quantitative studies occurring in three intervals for intra-decadal comparative purposes over the 10 years of study (C A Semeniuk 2006). The quantitative intra-decadal studies provided information on how stable the composition of the vegetation assemblages were against a background of declining water levels (C A Semeniuk 2006), and whether the pollen record in the surface sediments would reflect these short term compositional changes in vegetation. Wetland vegetation was classified into assemblages based on species composition and

structure. The distribution of these assemblages was mapped within each wetland basin. Transects were established across the basins to document gradients in vegetation composition. Assemblage composition was quantified in replicate quadrats, and classified using numerical classification techniques. The results of this programme are presented in more detail in C A Semeniuk (2006), but relevant aspects as they relate to describing vegetation associations for the composition of surface pollen in wetlands are presented briefly later in this paper.

Reference pollen was collected from living plant species colonising the wetlands and ridges in the region, as well as from herbarium sheets held by the W A Herbarium for species cited in the literature. Pollen samples were acetolysed following the standard technique of Erdtman (1960), as outlined by Phipps & Playford (1984).

Sediment samples were processed to extract the organic material following the general procedures of Phipps & Playford (1984). To assess the pollen content in each sample, a 0.2 ml suspension of pollen from an exotic (alien) species (from the Betulaceae) was added to each sample prior to processing (*circa* 2,700 ± 400 grains of Betulacid pollen per cm^3 of sediment).

In each sample, the Betulacid pollen was counted along with a total of two hundred pollen grains from the sediment. Total pollen in a given standard volume of sediment (*e.g.*, a cubic centimetre) was calculated from the counted pollen multiplied by the ratio of added Betulacid pollen to Betulacid pollen counted. Pollen identification was referred to prepared modern pollen standards, referenced to publications, or assigned to an "uncategorised" group.

A mathematical problem potentially occurs for pollen taxa with a count of zero in the volume of sample prepared. In multiplying the actual counted numbers of pollen of native plants by the ratio of Betulacid pollen added in a cubic centimetre of sediment to the number of Betulacid pollen recorded in order to transform the numbers of pollen of native species into abundances per cubic centimetre, zero still remains zero in contrast to all other taxa which increase proportionately. In fact, pollen recorded as zero in a low volume of sediment may have been detected in larger volumes of sediment, albeit in low numbers. Nonetheless, those pollen from native species which scored zero from a count of 200 pollen grains indicate either relative very low abundance in a cubic centimetre of sediment, or indeed absence.

Regional setting, local geomorphology, age structure and description of wetlands selected for study

The Rockingham-Becher Plain, as part of the Quindalup Dunes (McArthur & Bettenay 1960; Semeniuk *et al.* 1989), located in the larger physiographic unit of the Swan Coastal Plain, is a twin accretionary cuspate foreland system comprising a beachridge plain (Semeniuk & Searle 1986), extending from Cockburn Sound in the north to the Peel-Harvey Estuary exchange channel in the south (Fig. 1). The Spearwood Dune Ridge forms the eastern border of the beachridge plain. The basin wetlands of the Becher Suite are located in the inter-dune depressions or swales of the beachridge plain on the southern cusp of the twin

cuspate foreland whose apex is Becher Point. As described by Searle *et al.* (1988) and C A Semeniuk (2006), the coastal plain here consists of a series of parallel beachridges of height 2–3 m above AHD, with local ridges 3–8 m above AHD, *circa* 6000 years in age at its eastern part and 500 years in age to contemporary at its shore. The wetlands range in age from *circa* 4500 years in eastern parts of the beachridge plain to *circa* 680 years in the western parts. At the local scale, the individual wetland basins occur discontinuously along the axis of a beachridge swale and are generally flanked to east and west by beachridges and to north and south by sand structures that partition the longitudinal inter-dune depressions.

The wetland basins of the Becher Suite are filled with calcilutaceous muddy sand, calcilutite, quartz-calcareous sand, and peat (C A Semeniuk 2006). Sedimentary fill generally is < 1 m thick. The wetland vegetation has been described by C A Semeniuk (2006). This vegetation can be categorised, in general terms, into assemblages relative to the centre and to the margins of the wetlands: an inner, "core-of-wetland" assemblage, and an outer, peripheral assemblage. The plant assemblages identified by C A Semeniuk (2006) are:

1. *Centella asiatica (L.)* Urban herb assemblage
2. *Baumea articulata* (R. Br.) S. T. Blake sedge assemblage
3. *Typha* L. sp. sedge assemblage
4. mixed *B. articulata* and *Typha* sp. sedge assemblage
5. *Juncus kraussii* Hochst rush assemblage
6. *Melaleuca teretifolia* Endl. shrub assemblage
7. *Melaleuca rhaphiophylla* Schauer forest or shrub assemblage, with understorey of *C. asiatica* (L.) Urban
8. *Melaleuca cuticularis* Labill. forest assemblage
9. wetland margin *Melaleuca viminea* Lindley heath
10. wetland margin of *Xanthorrhoea preissii* Endl. with understorey of *Isolepis nodosa* (Rottb.) R. Br. sedge assemblage and *Sporobolus virginicus* (L.) Kunth. grass assemblage
11. wetland margin of *I. nodosa* sedge assemblage
12. wetland margin of *S. virginicus* grass assemblage
13. wetland margin of *Baumea juncea* (R. Br.) Palla sedge assemblage
14. wetland margin of *Lepidosperma gladiatum* Labill. sedge assemblage

The key plants within each of the selected wetlands are described in Table 1.

Species contributing to the pollen record

The species pool

A variety of plant species contribute pollen to the wetlands of the Becher Point area. These occur in the wetlands and on the ridges on the Becher Cuspate Foreland, and from terrain further east (Tables 2–4). For a more comprehensive description of the vegetation on the cuspate foreland refer to C A Semeniuk (2006).

Table 1

Description of wetlands in this study in terms of location relative to age structure, wetland type, sedimentary fill, and vegetation

Wetland	Geographic and implied age setting	Local geomorphic setting	Wetland type	Sediment fill	Structurally and numerically dominant species
161	older eastern part of suite	relatively high beachridges border east and west margins	sumpland	calcilutite, and basal calcilutaceous muddy sand	*Baumea articulata*
162	older eastern part of suite	relatively high beachridges border east and west margins	sumpland	calcilutite, and basal calcilutaceous muddy sand	*Melaleuca teretifolia*
163	older eastern part of suite	relatively high beachridges border east and west margins	sumpland	calcilutite, and basal calcilutaceous muddy sand	*Juncus kraussii*
WAWA	older eastern part of suite	relatively high beachridge borders east margin; low beachridge on west margin	sumpland	peat, calcilutite, and basal calcilutaceous muddy sand	*B. articulata, Typha orientalis*
135	middle age, central part of suite	relatively high beachridge borders east margin; low beachridge on west margin	sumpland	calcilutite, and basal calcilutaceous muddy sand	*M. rhaphiophylla, Centella asiatica*
136	middle age, central part of suite	relatively high beachridge borders east margin; low beachridge on west margin	sumpland	calcilutite, and basal calcilutaceous muddy sand	*M. rhaphiophylla, C. asiatica*
72	middle age, central part of suite	relatively high beachridges border east and west margins	dampland	calcilutite, and basal calcilutaceous muddy sand	*B. juncea, C. asiatica*
45	middle age, central part of suite	low beachridges border east and west margins	sumpland	calcilutite, and basal calcilutaceous muddy sand	*M. rhaphiophylla, C. asiatica*
35	middle age, central part of suite	low beachridges border east and west margins	sumpland	calcilutite, and basal calcilutaceous muddy sand	*M. rhaphiophylla, J. kraussii, C. asiatica*
9-3	younger western part of suite	relatively high beachridge borders west margin; low beachridge on east margin	sumpland	calcilutite, and basal calcilutaceous muddy sand	*B. juncea*
9-6	younger western part of suite	low beachridges border east and west margins	sumpland	calcilutite, and basal calcilutaceous muddy sand	*B. juncea, C. asiatica*
9-14	younger western part of suite	low beachridges border east and west margins	sumpland	calcilutite, and basal calcilutaceous muddy sand	*J. kraussii*
swi	younger western part of suite	low beachridges border east and west margins	dampland	calcilutite, and basal calcilutaceous muddy sand	*Lepidosperma gladiatum*
swii	younger western part of suite	low beachridges border east and west margins	dampland	calcilutite, and basal calcilutaceous muddy sand	*L. gladiatum*
swiii	younger western part of suite	low beachridges border east and west margins	sumpland	calcilutite, and basal calcilutaceous muddy sand	*Schoenoplectus validus* (M. Vahl) A. Love & D. Love
1-N	younger western part of suite	low beach ridges border east and west margins	dampland	calcilutite, and basal calcilutaceous muddy sand	*B. juncea*

Table 2

Main plant species within wetlands in the Becher Point area

Perennial species Family	Species	Annual species Family	Species
Apiaceae	*Centella asiatica* (L.)	Compositae	*Sonchus asper* Hill
Chenopodiaceae	*Halosarcia halocnemoides* (Nees) Paul G. Wilson	Papilionaceae	*Trifolium* L. spp.
Cyperaceae	*Baumea articulata*	Crassulaceae	*Crassula* L. sp.
	B. juncea	Brassicaceae	*Brassica tournefortii* Gouan
	Cyperus sp.	Iridaceae	*Romulea* sp.
	Isolepis nodosa		
	Isolepis cernua (M. Vahl) Roemer & Schultes		
	Lepidosperma gladiatum		
	Schoenoplectus validus		
	Typha domingensis		
	T. orientalis		
Geraniaceae	*Pelargonium capitatum* (L.) L'Her.		
Juncaceae	*Juncus kraussii*		
Juncaginaceae	*Triglochin striata* Ruiz Lopez & Pavon or		
	Triglochin mucronata R. Br.		
Lobeliaceae	*Lobelia alata* Labill.		
Myrtaceae	*Melaleuca cuticularis*		
	M. viminea		
	M. rhaphiophylla		
	M. teretifolia		
Poaceae	*Sporobolus virginicus*		
Primulaceae	*Samolus repens* (Forster & G. Forster) Pers.		
Verbenaceae	*Phyla nodiflora* (L.) E. Green		
Xanthorrhoeaceae	*Xanthorrhoea preissii*		

* denotes alien species

Table 3

Main plant species on beachridge/dunes of the Becher Cuspate Foreland

Family	Perennial species
Chenopodiaceae	*Rhagodia baccata* (Labill.) Moq.
Compositae	*Olearia axillaris* (DC) F. Muell. et Benth.
Cyperaceae	*Lepidosperma squamatum* Labill.
	Schoenus grandiflorus (Nees) F. Muell.
Dasypogonaceae	*Acanthocarpus preissii* Lehm.
	Lomandra maritima Choo
Epacridaceae	*Leucopogon parviflorus* (Andrews) Lindley
Euphorbiaceae	*Adriana quadripartita* (Labill.) Gaudich.
	Phyllanthus calycinus Labill.
Geraniaceae	*Pelargonium capitatum*
Haemodoraceae	*Conostylis aculeata* R. Br.
Mimoseae	*Acacia cyclops* Cunn. ex Don
	Acacia lasiocarpa Benth.
	Acacia pulchella R. Br.
	Acacia rostellifera Benth.
	Acacia saligna (Labill.) H. L. Wendl.
Myrtaceae	*Melaleuca systena* (formerly *M. acerosa* Schauer)
Poaceae	*Austrostipa flavescens* (Labill.) S W L Jacob, J Everett
Proteaceae	*Hakea prostrata* R. Br.
	Jacksonia furcellata (Bonpl.) DC.
Rhamnaceae	*Spyridium globulosum* (Labill.) Benth.
Santalaceae	*Exocarpos sparteus* R. Br.

* denotes alien species

Table 4

Key plant taxa as pollen sources from areas east of the wetlands on Becher Point

Family	Perennial species
Casuarinaceae	*Allocasuarina fraseriana* (Miq.) L. Johnson
	Casuarina humilis (Otto & Dietr.) L. Johnson
Myrtaceae	*Eucalyptus gomphocephala* DC.
	Eucalyptus marginata
	Hypocalymma robustum (Endl.) Lindley
Proteaceae	*Banksia attenuata* R. Br.
	Banksia menziesii R. Br.
	Banksia grandis Willd.

Preservation of pollen and its differential destruction in the sediment

The pollen derived from wetland plants and species on the adjacent ridges has variable natural preservation and variable resistance to the laboratory process of acetolysis. In the former context, pollen from the following families are well preserved and common: Casuarinaceae, Compositae and Poaceae. In the latter context, pollen grains which are often destroyed or badly damaged by acetolysis (Nilsson and Praglowski 1992), include those of Juncaceae. Therefore, the absence of this pollen from surface and core samples cannot be interpreted as indicating absence of species of Juncaceae in the wetland basin or surrounds. These remarks particularly pertain to wetland basins in which *Juncus kraussii* occurs or is dominant. Some Myrtaceae and Cyperaceae pollen grains also show susceptibility to

degradation, both as a result of the processing method and of oxidation.

Of the plants extant in modern wetland centres and their margins, the following key species were commonly detected as pollen grains in the sediments:

Centella asiatica

Baumea articulata

Baumea juncea

Isolepis nodosa

Lepidosperma gladiatum

Melaleuca cuticularis

Melaleuca rhaphiophylla

Melaleuca teretifolia

Melaleuca viminea

Sporobolus virginicus

Typha domingensis (or *T. orientalis*)

Xanthorrhoea preissii

Pollen transport and deposition

Potential dispersal processes and transporting agents for pollen include easterly and westerly winds, insects, avifauna, rain, local processes of *in situ* generation, sheet wash, and water transport. These processes are summarised in Figure 2.

In Western Australia there is scant information about pollen dispersal mechanisms for many plants, and this is particularly the case for Cyperaceae, species of which dominate the Becher wetlands. Pollen from Xanthorrhoeaceae and Myrtaceae, in particular *Melaleuca*, is dispersed by both insects and avifauna (Brown *et al.* 1997), and Casuarinaceae, a prolific pollen producer disperses its pollen by wind (Backhouse 1993). In lieu of data about specific dispersal mechanisms for pollen from wetland plants, some general observations about the effects on pollen dispersal within the setting of the Becher Suite wetlands are made. These relate to wind patterns, vegetation on the Spearwood Ridge and the Cooloongup and Walyungup wetlands to the east, local topography, and type of vegetation structure at the wetland margin, complemented by the actual occurrence of pollen species on the wetland surface and in cores.

In the Becher Point region, modern dispersal of pollen by wind would be related to the prevailing northeasterly and southwesterly winds typical of spring, and the west to south westerly seabreezes and the easterly quadrant landbreezes, both dominant in summer (Searle & Semeniuk 1985). The pattern of dispersal along these trajectories would result largely in a redistribution of pollen within the cuspate foreland, but pollen could also be transported from vegetation on the higher (Holocene) ridges in the Cooloongup Lake area and from the bordering Spearwood Dune Ridge (Fig. 1). Plant communities on the Holocene sand ridges at Lake Cooloongup comprise similar species to the ridges in the Becher Point region, with the important addition of tall woodland of *Eucalyptus gomphocephala*. The vegetation on the Spearwood Dune Ridge is *E. marginata/Banksia* spp. low woodland. On the Becher cuspate foreland,

pollen derived from local ridges and sub-regionally may be deposited in the wetlands directly by rain or by sheet wash from the ridges to the wetland margins. As the wetlands are located in swales, it is unlikely that pollen deposited onto the litter or sediment of the vegetated wetland basins would be remobilised.

The topography of the Becher cuspate foreland is composed of relatively low parallel ridges, but locally interspersed in this landscape are higher than average ridges which are approximately 3–8 m above the adjoining swale. These higher ridges are likely to have some impact on the amount and type of pollen deposited in any wetland on the lee side of the ridge. By forming a partial obstruction to easterly and northeasterly wind flows, the ridge can cause wind to rise from the relatively flatter and lower surface of the plain, initially increasing its velocity at the ridge crest and then decreasing velocity over the adjacent wetland. Pollen, carried by the wind from regional vegetation east of the Becher Point, as well as from vegetation colonising ridge crests, is likely to be deposited in the adjoining wetland bordered by a high ridge at a greater frequency than in wetlands between lower ridges.

In wetlands situated between the lower beachridges, deposition of allochthonous pollen into the centre of the basin, where the cores were obtained, may be hampered by the type of vegetation structure at the wetland margin. In wetlands 35 and 45, for example, this vegetation is composed of *Melaleuca* trees which effectively buffer the central part of the wetland. In other wetlands, *e.g.*, wetland 162, an effective buffer is created by a lower but tightly closed canopy of *X. preissii*. Pollen raining onto a closed canopy in central parts of the wetland basin can be expected to be later remobilised to the floor of the wetland basin by rain.

Pollen generated *in situ* from wetland plants situated in swales between the adjacent ridges is subject to reduced wind frequency and velocity. The locus for wind transport is between swale and ridge rather than along the swale, unless the swale is relatively shallow, and therefore the distance that pollen is transported from one wetland basin to another along any swale is likely to be very short. The wetlands may generally be regarded as pollen sinks for both *in situ* and imported pollen from local ridges.

Surface pollen within the wetland basin may be redistributed spatially in two ways: by wind generated water movement during inundation, and by bioturbation. Redistribution under the first process is likely to be minimal because of plant buffering. Redistribution under the second process is likely to be significant at the 10 cm scale.

Results: pollen in surface sediments

The pollen record in the surface sediments in the central basin of the 16 wetlands provided a baseline of surface pollen assemblages in relation to the various types of wetland plant assemblages, species inhabiting the adjoining beachridges, and species occurring distal to the Becher Suite. In each wetland, for the analysis of surface pollen, the pollen assemblages recovered from the surface sediments were separated into six categories as related to extant vegetation:
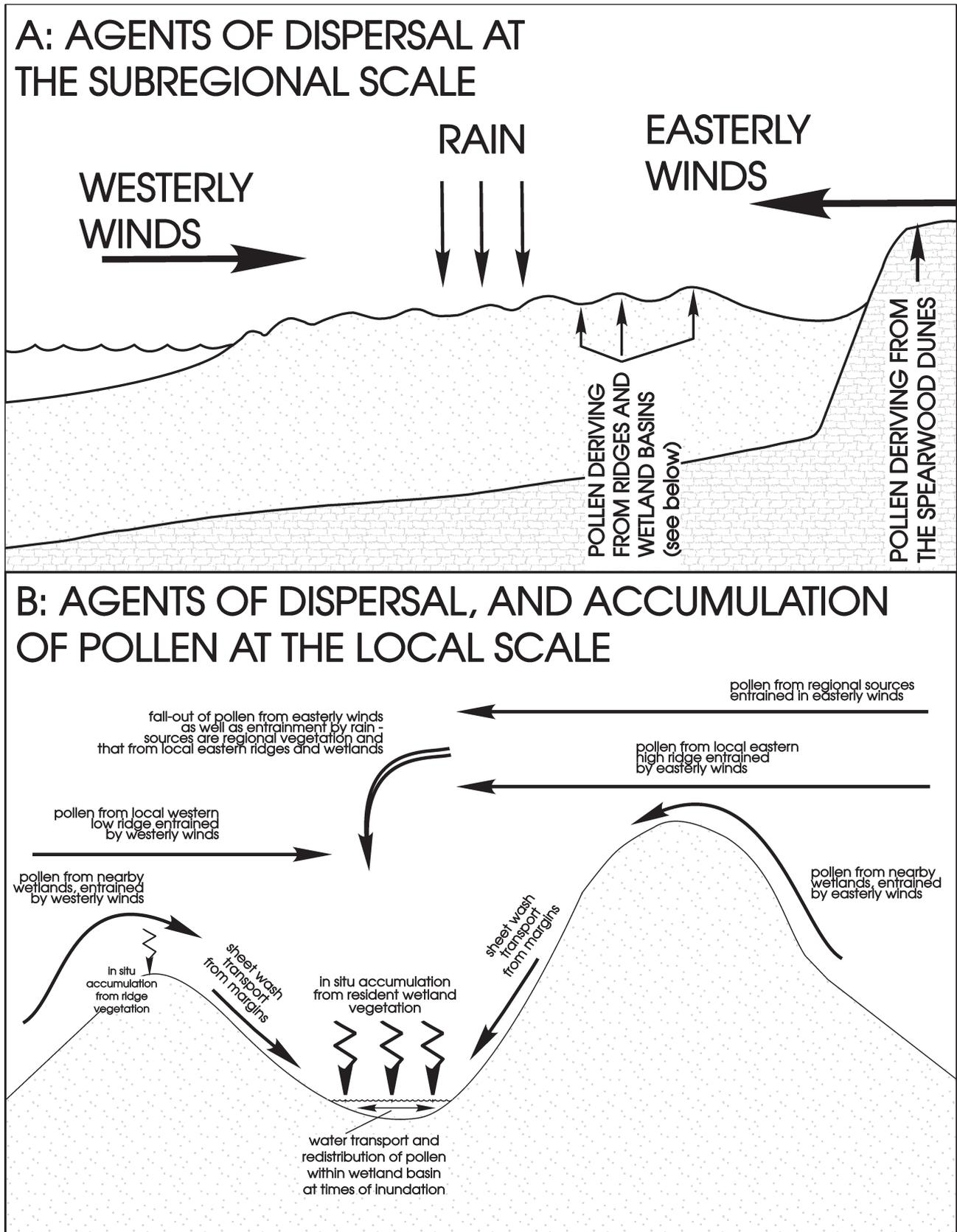
A: AGENTS OF DISPERSAL AT THE SUBREGIONAL SCALE

RAIN

WESTERLY WINDS

EASTERLY WINDS

POLLEN DERIVING FROM RIDGES AND WETLAND BASINS (see below)

POLLEN DERIVING FROM THE SPEARWOOD DUNES

B: AGENTS OF DISPERSAL, AND ACCUMULATION OF POLLEN AT THE LOCAL SCALE

pollen from regional sources entrained in easterly winds

fall-out of pollen from easterly winds as well as entrainment by rain - sources are regional vegetation and that from local eastern ridges and wetlands

pollen from local eastern high ridge entrained by easterly winds

pollen from local western low ridge entrained by westerly winds

pollen from nearby wetlands, entrained by westerly winds

pollen from nearby wetlands, entrained by easterly winds

in situ accumulation from ridge vegetation

sheet wash transport from margins

sheet wash transport from margins

in situ accumulation from resident wetland vegetation

water transport and redistribution of pollen within wetland basin at times of inundation

Figure 2. Potential patterns of dispersal and accumulation of pollen into wetland basins with *in situ,* local, and regional sources.

1. that generated *in situ* from wetland basin vegetation;

2. that derived from *in situ* wetland margin vegetation;

3. that derived allochthonously from wetland vegetation;

4. that from ridge vegetation and transported to the wetland basin;

5. that from vegetation distal to the region;

6. uncategorised pollen.

Pollen was categorised as deriving from *in situ* wetland vegetation or *in situ* wetland margin vegetation if the pollen species corresponded to either the wetland plant species or wetland marginal species currently colonising a particular wetland basin. Pollen derived allochthonously from wetland vegetation included that from species of wetland plants currently colonising the Becher Suite wetlands elsewhere in the sub-region of the Becher cuspate foreland, but not within the basin from which the surface pollen sample was obtained. "Ridge" pollen included pollen from species colonising the beach ridges comprising the upland on the Becher cuspate foreland, and "regional" pollen was categorised as deriving from beyond the Becher cuspate foreland. The patterns arising from the variable composition of surface pollen based on the different categories are described below and illustrated in Figure 3.

Overall, the majority of the surface pollen in the wetlands has been derived locally from the wetland and upland ridge vegetation of the Becher cuspate foreland. With the exception of wetland swi, *in situ* wetland pollen constituted a moderate proportion of the total pollen found at the surface, varying from 5–44% (Fig. 4). Wetland margin pollen was abundant in only half the wetlands. Pollen from allochthonous wetland species was present in most of the wetlands, specifically pollen from

species of *Melaleuca*. "Ridge" pollen was sub-dominant to pollen from wetland species in 7 wetlands; in the remaining wetlands it was the dominant type of pollen. Overall, there is an increase from east to west in "ridge" pollen contributing to the total pollen (compare the eastern wetlands 161, 162, 163, and WAWA with centrally located wetlands 135, 136, 72, 45, 35 and 9–14, and with westermost wetlands swi, swii and swiii), probably reflecting seabreezes from westerly quadrants delivering pollen from the ridges to the adjoining wetland basin having more effect in near coastal areas. The contribution and significance of "regional" pollen varied (0–48%), from low numbers in most wetlands to relatively high numbers and significant proportions in wetlands 161 (17%), WAWA (48%), and 1N (20%). Uncategorised pollen ranged from 0–28%.

To demonstrate the relationship between extant wetland vegetation and surface pollen abundance in a particular wetland basin, the estimated cover and percent of total surface pollen for each species are summarised in Table 5.

With the exception of *J. kraussii,* pollen for most species of plants colonising the wetland basin were present in the surface sediments (Fig. 4). Pollen derived from *in situ* wetland plants was dominated by several species, *M. rhaphiophylla, S. virginicus* and *C. asiatica.* For the majority of species, the pollen numbers did not reflect the current abundance of plants in the wetlands. Pollen abundance for both species of *Baumea,* for two species of *Melaleuca* (*M. viminea* and *M. teretifolia*), and for *L. gladiatum* were consistently lower than the present vegetation cover would suggest. Pollen of *P. nodiflora* was also absent or rare even when cover abundance in a particular wetland was high, probably because of the short period of wetland colonisation by this species. Wetland plant species, *M. rhaphiophylla, S. virginicus, T.*
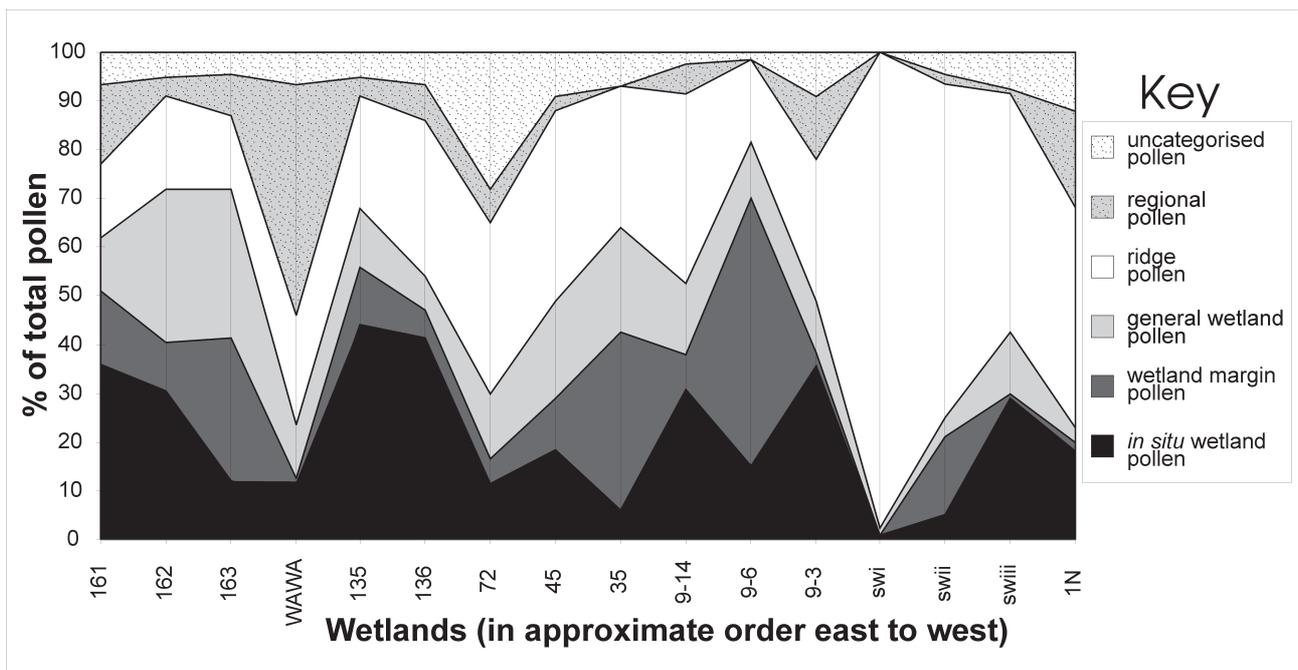

Figure 3. Composition of surface pollen for all sites.

Table 5

Comparison between extant vegetation and pollen abundance in surface. Categories used: a = abundant, *i.e.*, > 20%; p = present, *i.e.*, 5–20%; u = uncommon, *i.e.*, < 5%; ab = absent

Wetland basin	Species which are extant	Species abundance	Pollen abundance	Percentage of total pollen	Wetland basin	Species which are extant	Species abundance	Pollen abundance	Percentage of total pollen
161	*B. articulata*	a	p	5%	9-3	*B. juncea*	p	p	9%
	T. orientalis	p	p	12%		*I. nodosa*	p	a	21.5%
	C. asiatica	p	p	19%		*S. virginicus*	p	u	3%
	L. gladiatum	p	ab	0%		*M. rhaphiophylla*	u	u	4%
162	*M. teretifolia*	a	u	3%		*C. asiatica*	u	ab	0%
	C. asiatica	a	a	24%	9-6	*C. asiatica*	a	u	2.5%
	P. nodiflora	p	ab	0%		*B. juncea*	p	p	9%
	B. juncea	u	u	0.5%		*M. viminea*	p	u	1%
	S. virginicus	u	u	3%	9-14	*A. cyclops*	a	p	5.5%
163	*J. kraussii*	a	ab	0%		*J. kraussii*	p	ab	0%
	C. asiatica	p	p	10.5%		*B. juncea*	p	ab	0%
	B. juncea	p	u	1.5%		*S. virginicus*	p	p	6%
	S. virginicus	u	u	4%		*C. asiatica*	u	u	4%
WAWA	*B. articulata*	a	u	0.5%		*M. viminea*	p	p	15%
	T. orientalis	p	u	2%	swi	*L. gladiatum*	p	ab	0%
	M. viminea	p	u	0.5%		*J. kraussii*	p	ab	0%
	S. validus	u	ab	0%		*C. asiatica*	u	ab	0%
	C. asiatica	u	u	4.5%		*B. juncea*	u	u	1%
135	*M. rhaphiophylla*	a	p	15%	swii	*L. gladiatum*	p	ab	0%
	S. virginicus	a	a	29%		*J. kraussii*	p	ab	0%
	C. asiatica	p	ab	0%		*C. asiatica*	u	u	2.5%
136	*M. rhaphiophylla*	a	a	30%		*B. juncea*	u	u	2%
	C. asiatica	a	u	2%	swiii	*P. nodiflora*	a	u	0%
	S. virginicus	p	p	9.5%		*B. juncea*	p	u	0.5 %
72	*C. asiatica*	p	p	9%		*L. gladiatum*	p	p	5.5%
	B. juncea	p	u	0.5%		*C. asiatica*	p	ab	0%
	I. nodosa	u	u	2%		*J. kraussii*	p	ab	0%
45	*P. nodiflora*	a	u	1%		*S. validus*	p	p	14%
	C. asiatica	p	u	4.5%		*T. orientalis*	p	p	9%
	M. rhaphiophylla	p	p	13%	1N	*B. juncea*	a	ab	0%
	B. juncea	u	u	1%		*I. nodosa*	p	p	10%
	J. kraussii	u	ab	0%		*P. capitatum*	p	p	8%
35	*C. asiatica*	a	u	1%					
	M. rhaphiophylla	a	u	1.5%					
	M. cuticularis	p	u	2.5%					
	J. kraussii	p	ab	0%					
	P. nodiflora	u	u	1%					

orientalis, I. nodosa, and *C. asiatica*, were the most consistent contributors to the pollen assemblage (Fig. 4).

Pollen from species in the wetland margins was also differentially represented, with an abundance of *I. nodosa* pollen and a deficit of pollen from *X. preissii* and *A. saligna* (Fig. 4). For "ridge" pollen the most consistent contributors to the surface pollen were *O. axillaris* and species belonging to Chenopodiaceae (probably *Rhagodia baccata*), the latter being more abundant in wetlands nearest the coast where the plants are more numerous. Overall, the "regional" pollen was dominated

by species of Casuarinaceae (*Allocasuarina fraseriana, A. humilis*) and *Eucalyptus marginata,* important constituents of the *E. marginata/Banksia* spp. low woodland on the Spearwood Dune Ridge to the east.

Wetlands exhibited various amounts of pollen in the surface sediments. In order of abundance, the wetlands are listed in terms of total surface pollen per cm³ of sediment, percentage of pollen from *in situ* wetland plants, and percentage of wetland pollen which was not autochthonous (Tables 6 & 7).
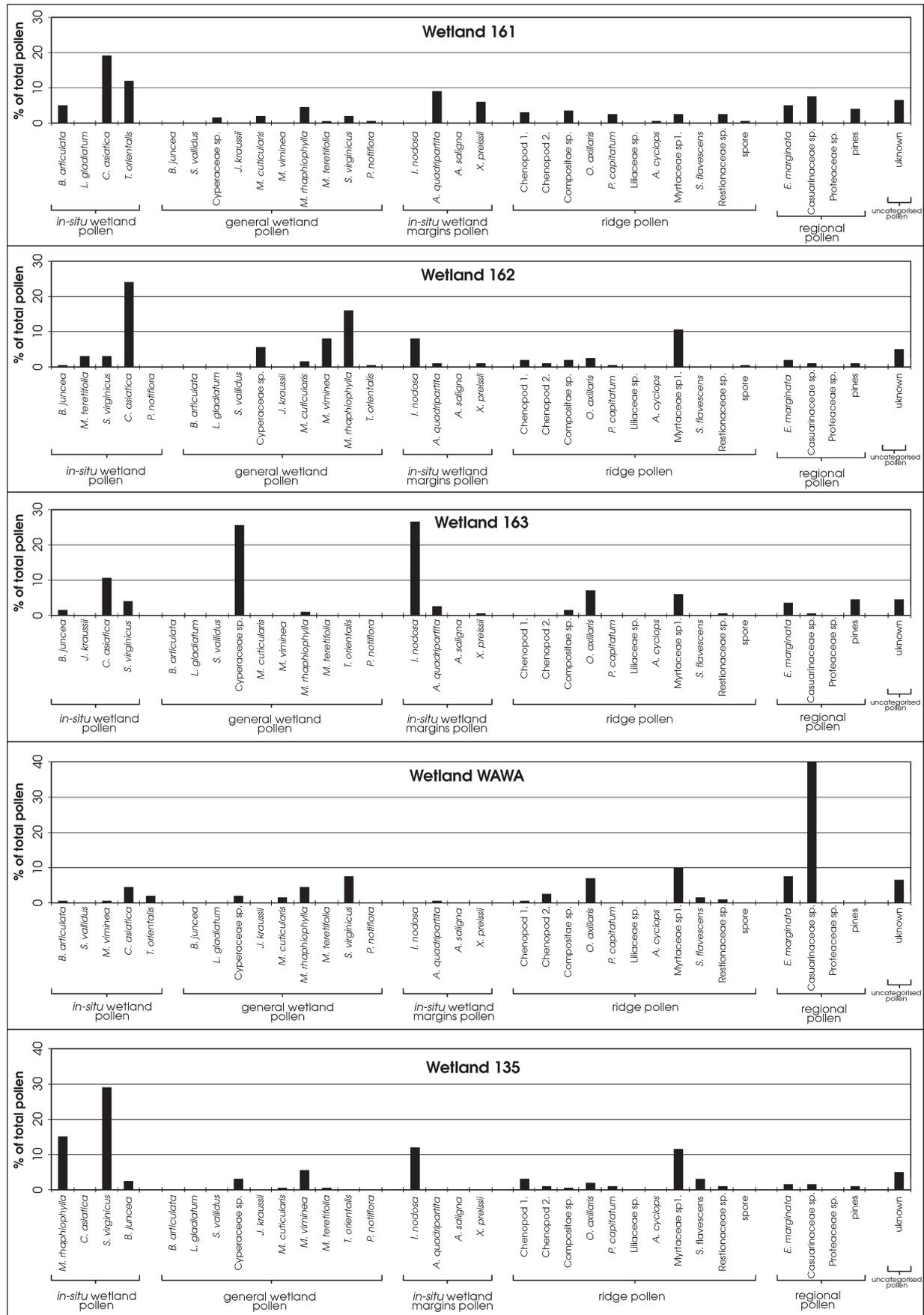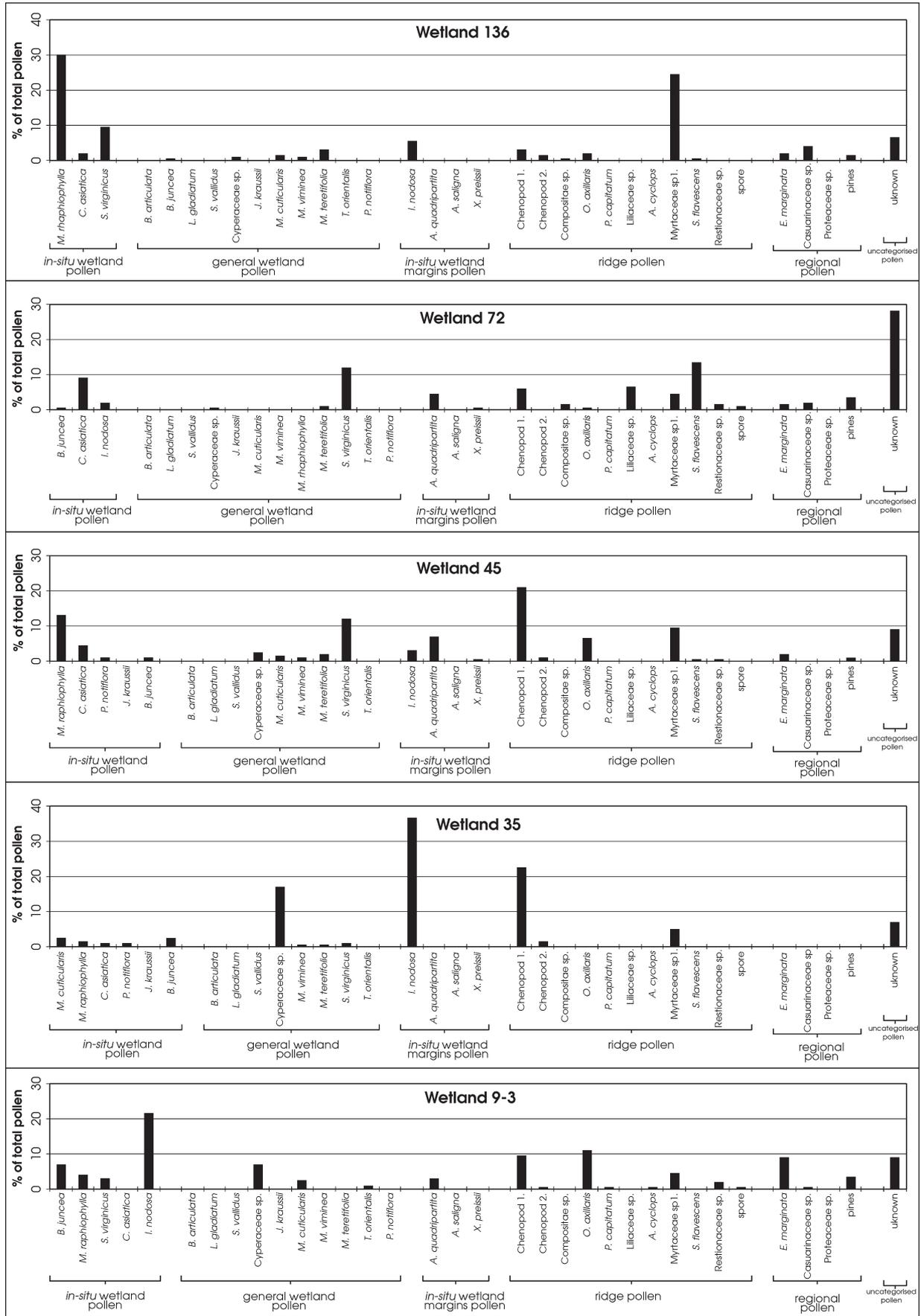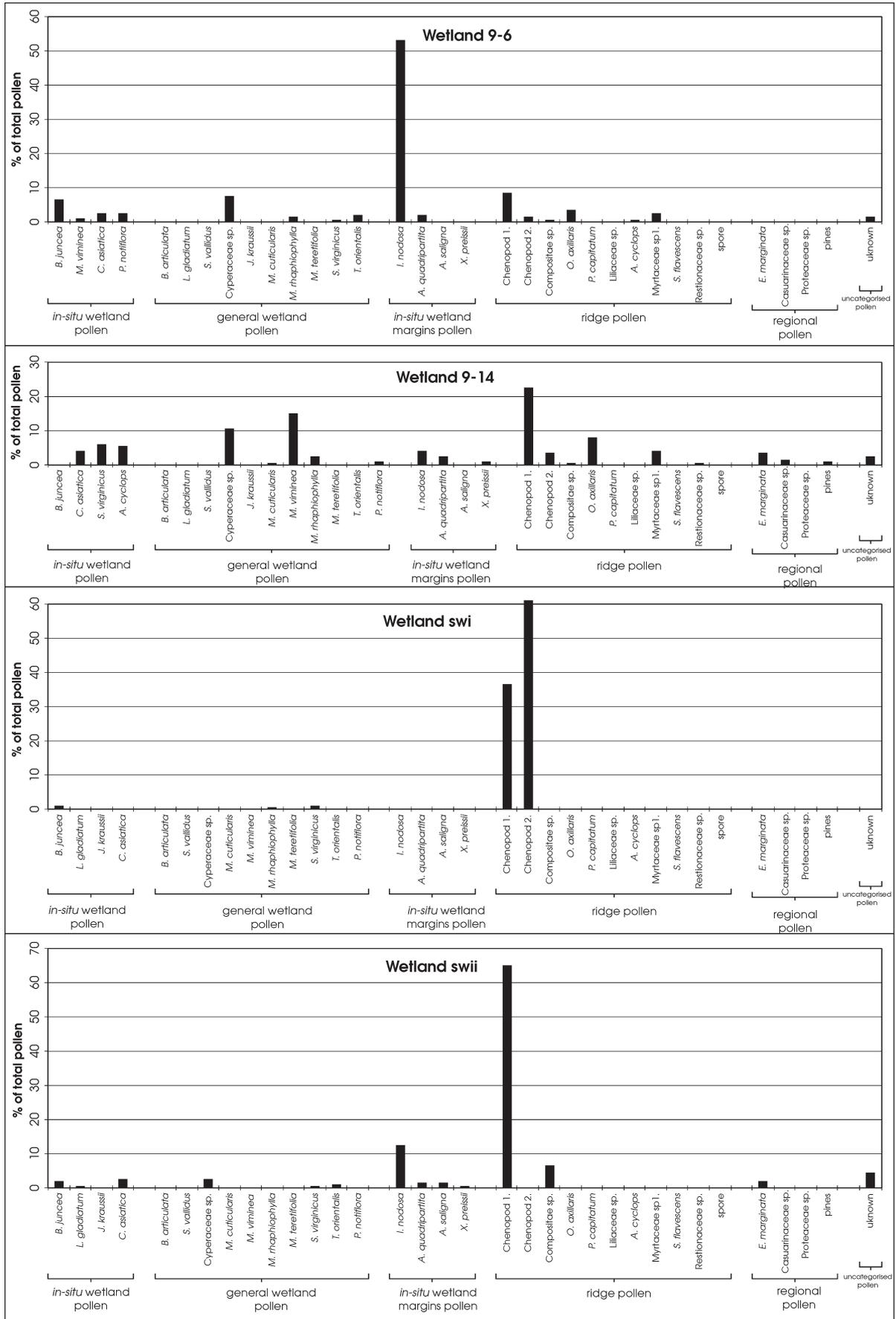
It can be seen that although wetland swi had the

Figure 4. a,b,c,d: Graphs showing the surface pollen taxa, grouped according to the six categories, plotted as a percentage of total pollen.
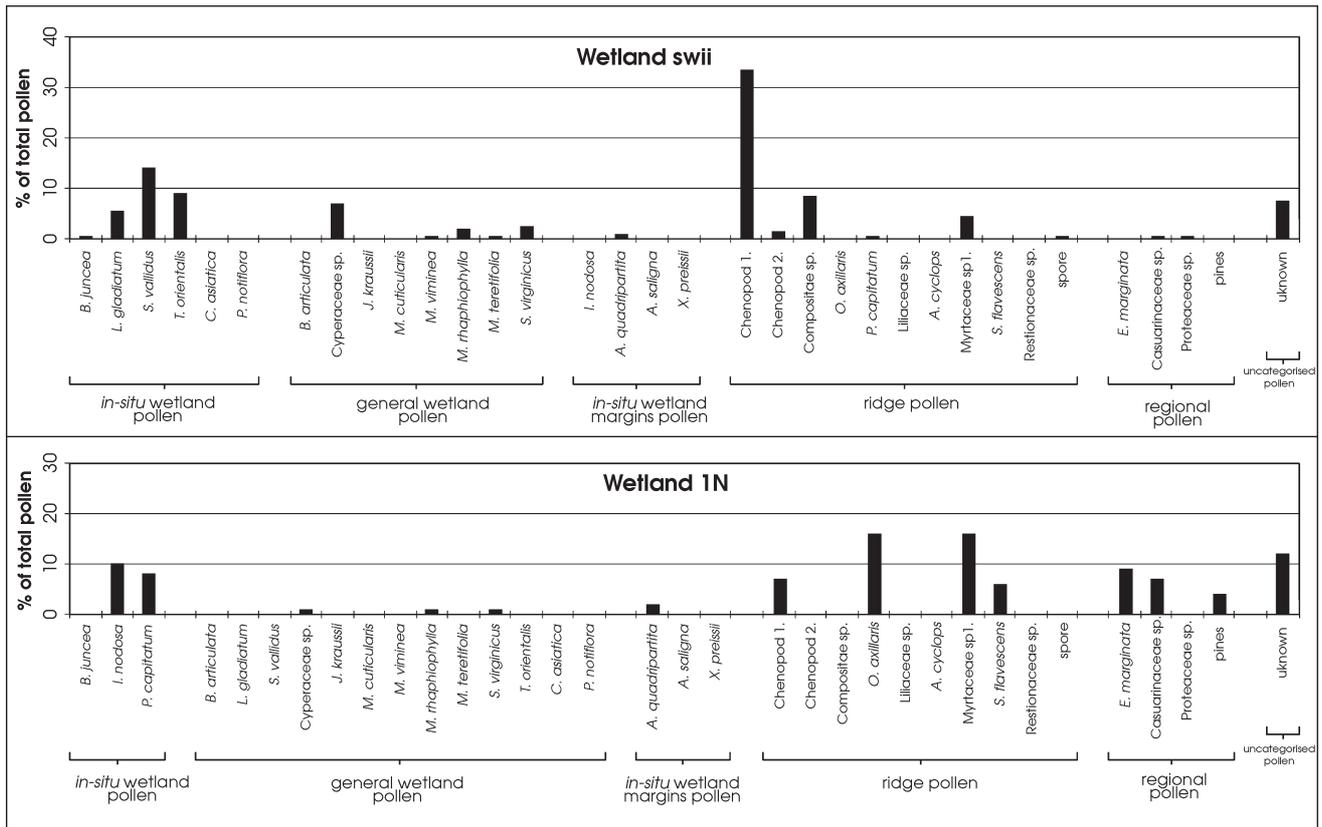
Table 6

Wetlands in order of decreasing pollen abundance in the surface sediments

Wetlands	Total pollen counts/cm³ (rounded to nearest 500)
swi	907,000
35-4	91,000
swii	88,000
9-6	81,000
45	47,000
135	40,000
136, swiii	35,000
9-3	34,500
161	34,000
9-14	31,000
163	29,000
72, 162	29,000
WAWA	26,000
1N	6,000

highest number of pollen per cm³ of sediment, the component of wetland pollen was minimal (Table 7). Wetland 162, in contrast, had much lower numbers of pollen grains per cm³ of sediment, but the proportion of wetland pollen was greater. Apart from wetland swi which was dominated by "ridge" pollen, many of the wetlands had very similar pollen densities in the surface sediments, *e.g.*, wetlands 135, 136, 9-3, 161, 9-14, swiii. The percentage of pollen derived from *in situ* wetland vegetation was more variable and is governed by a number of factors, some of which are: size of wetland;

ratio of cover of high pollen producing plants to low pollen producing plants; number of adjacent wetlands; proximity of adjacent wetlands; and height of basin floor relative to surrounding ridges. The low numbers of pollen grains from *in situ* wetland species in wetlands swi and swii can be explained in terms of the factors listed above. These wetlands are very small, with minimal elevation difference between basin floor and adjacent ridges, and a high proportion of low pollen producing plants.

Use of surface pollen assemblages in interpreting fossil wetland pollen sequences

Autochthonous *vs* allochthonous assemblages

Separating autochthonous pollen assemblages from proximal allochthonous assemblages and from distal allochthonous assemblages is an important consideration when pollen is to be used to interpret fossil wetland pollen sequences.

In most wetlands, the major component of surface pollen deriving from wetland vegetation was autochthonous. There were exceptions in three wetlands, *viz.*, 163, 35 and 72. In wetlands 163 and 35, where *J. kraussii* is present, the discrepancy probably was caused by the absence of *J. kraussii* pollen, and in wetland 72 by very low numbers of *B. juncea* pollen.

The major component of pollen derived from upland vegetation was from ridges adjacent to wetlands. This pollen was particularly numerous in wetland basins in the shallower swales which are also the youngest of the wetlands, *e.g.*, wetlands swi, swii, and 1N. In wetland

Table 7

Wetlands listed in order of decreasing pollen abundance in surface sediments from wetland species. (Key to species: Ac = *A. cyclops*, Ba = *B. articulata*, Bj = *B. juncea*, Ca = *C. asiatica*, In = *I. nodosa*, Lg = *L. gladiatum*, Mc = *M. cuticularis*, Mr = *M. rhaphiophylla*, Mt = *M. teretifolia*, Pc = *P. capitatum*, Scv = *S. validus*, Sv = *S. virginicus*, To = *T. orientalis*)

Wetlands	*In situ* wetland pollen as percentage of total pollen	Main species in pollen assemblage	Percentage of allochthonous wetland pollen	Total pollen counts/cm³ (rounded to nearest 500)
135	44	Sv, Mr	12	40,000
136	41.5	Mr, Sv	7	35,000
161	36	Ca, To, Ba	11	34,000
9-3	35.5	In, Bj, Mr	10.5	34,500
162	30.5	Ca, Mt, Sv	31.5	29,000
swiii	29	Scv, To, Lg	12.5	35,000
45	18.5	Mr, Ca	20	47,000
1N	18	In, Pc	3	6,000
9-14	15.5	Sv, Ac, Ca	14.5	31,000
9-6	15	Bj	11.5	81,000
163	12	Ca, Sv	30.5	29,000
72	11.5	Ca	13.5	29,000
WAWA	7.5	Ca	15.5	26,000
35	6	Mc	21.5	91,000
swii	5	Ca, Bj	4	88,000
swi	1	Bj	1.5	907,000

WAWA, which was the exception, the major component of the pollen derived from upland vegetation was regional pollen, probably because of the impedance effect of the higher than normal eastern ridge that borders the wetland. The high proportion of locally derived pollen on the Becher cuspate foreland is largely due to its geometry and configuration. The Rockingham Coastal Plain is a regionally prominent projecting feature along the coast. It lies between the Indian Ocean and mainland, where local wind and rain patterns differ slightly from the rest of the mainland (C A Semeniuk 2006). At the scale of the cuspate foreland, the topography is low and unlikely to interrupt the regional aeolian transport onshore and offshore. At the small scale, within the swales, wind is typically of low frequency and low velocity.

Interpreting fossil wetland pollen sequences

Whether pollen of wetland vegetation is *in situ*, derived from the wetland margins, or transported by wind to a particular basin from other proximal or distal basins, is a critical consideration in reconstructing vegetation history from the pollen record. While transported pollen preserved in the stratigraphic profile may reflect the long-term regional and sub-regional species pool, it cannot be used to reconstruct comparative vegetation history of individual wetlands. Difficulties in interpretation of the pollen record also will arise when the occurrence of a given species is the result of *in situ* production *and* wind transport.

Baumea articulata and *L. gladiatum* pollen appear to be reflecting *in situ* production and accumulation. The occurrences of pollen of *M. rhaphiophylla, M. viminea, M. teretifolia, M. cuticularis, Typha* sp., *S. virginicus,* and *C. asiatica* at first appearances would seem to be related in varying degrees to *in situ* production and contribution from wind. In an attempt to resolve this problem, the occurrences of the four species of *Melaleuca* in the study area, and the distribution of their pollen in surface

sediment were explored further (Fig. 5). The patterns for the four *Melaleuca* species show that abundant pollen for a given species occurs in the surface sediment where that species is currently growing. For instance, the highest numbers of pollen of *M. rhaphiophylla* are in wetlands 135, 136, and 45, where the species is common, and similarly, there are high numbers of pollen of *M. cuticularis* in wetland 35 where that species is present. In wetlands where *M. teretifolia* and *M. viminea* are present today, there are also relatively high numbers of their pollen, although in this case other wetlands exhibit a higher abundance.

There is also some indication of the effect of wind in transporting pollen using *Melaleuca* as a signature. For instance, there is a high proportion of pollen of *M. cuticularis* in the wetlands near wetland 35, signalling wind transport of this pollen from its source in wetland 35 to nearby basins by landbreezes and seabreezes, and none in wetlands further west, *viz.*, wetlands swi, swii, swiii, and 1N (Fig. 5). Further, there is a high proportion of pollen of *M. viminea* in the wetlands near wetland 9-6 and 9-14, signalling wind transport of this pollen from its source to nearby basins such as wetlands 45 and 35 by landbreezes and seabreezes. The occurrences of pollen of *M. rhaphiophylla*, *M. teretifolia* and *M. viminea* in wetland swiii, while absent in adjacent near-coastal wetlands along this same beachridge swale (*viz.*, swi, swii, and 1N) illustrate the localised nature of wind delivery of pollen by landbreezes.

While there appears to be a relationship between an extant species and high counts of their pollen in surface sediments, and the occurrence of high pollen counts of some species due to wind transport, there are variations. Wind transport does not explain several examples of high counts of pollen where the species do not occur today: *M. rhaphiophylla* in wetlands 161, 162, and 163, *M. teretifolia* in wetlands 136 and 45, and *M. viminea* in wetlands 162 and 135 (Fig. 5). This would suggest that these species have come and gone over the period of
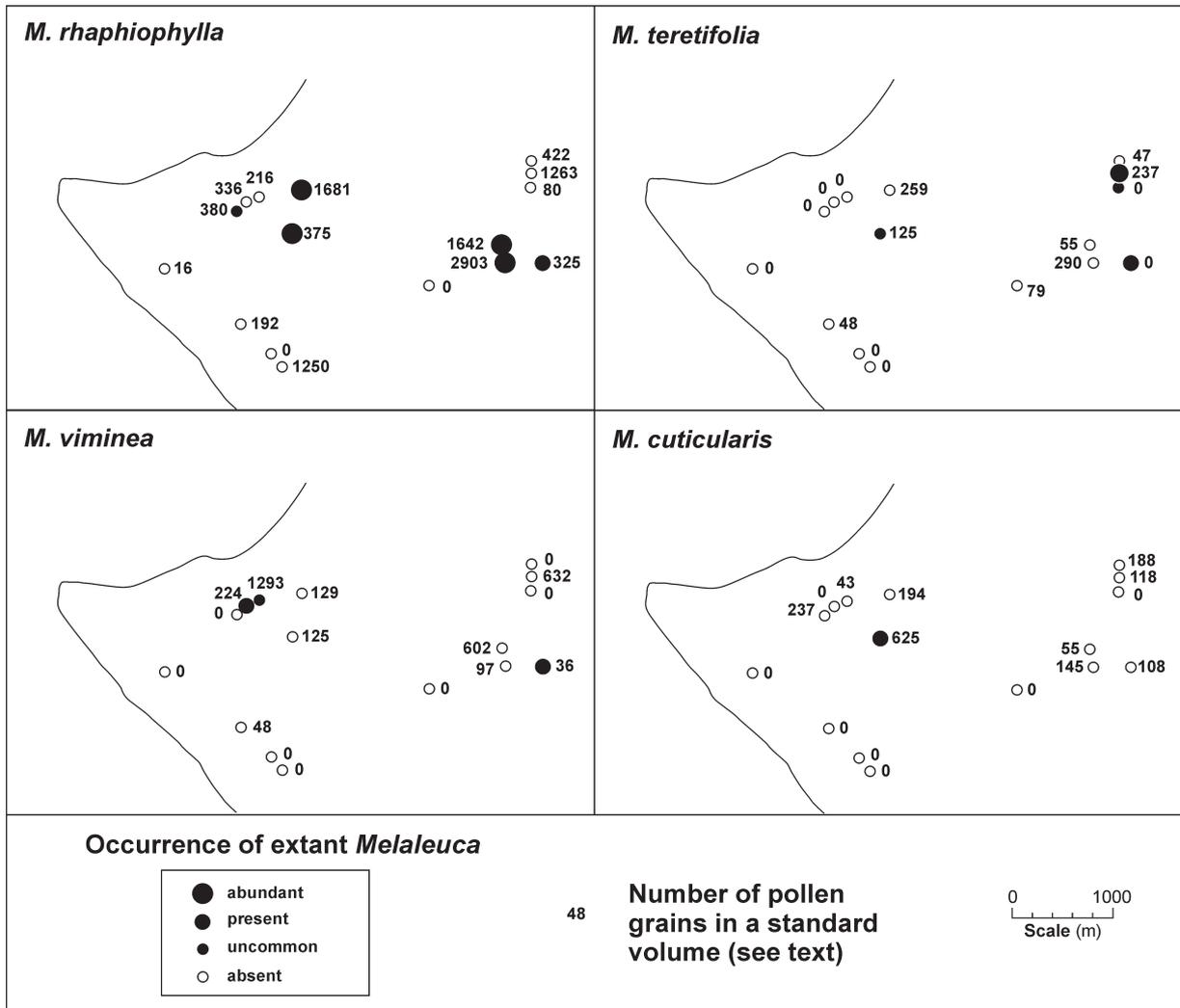
Figure 5. Occurrence of extant *Melaleuca* species in the wetland basins, noted in terms of relative abundance, and the abundance of their pollen in a standard volume of surface sediment (see text).

several decades or centuries, and that their pollen in the upper centimetre of sediment records these former populations.

Similarly, the distribution of *S. virginicus* pollen provides insight into the resolution of autochthonous *versus* wind derived pollen. The pollen is relatively widespread but does not occur throughout all wetland basins. *S. virginicus* tends to be an understorey component to shrubs such as *M. viminea*, the canopy of which largely precludes the dispersion of its pollen by wind.

A measure of the contribution of wind in supplying pollen from wetland species to a given basin was explored using the occurrence of the pollen of upland species, as these species definitively indicate an origin outside of the wetland basin (Fig. 6). The effect of wind in delivering upland pollen was explored using the distributions of three species of regional and sub-regional pollen with distinct distal sources to ascertain the contribution by easterly and westerly winds. *Olearia axillaris* is a primary dune species restricted to near

coastal locations. Its pollen would have to be delivered by westerly wind to the wetlands. Casuarinaceae spp. and *E. marginata* pollen derive from the Spearwood Dune Ridge and further eastward, and have to be delivered by easterly winds. The abundance of *O. axillaris,* Casuarinaceae spp., and *E. marginata* in the surface pollen varies from basin to basin, even for basins close to each other. There is no clear gradient in abundance from source to distal wetland. For example, for Casuarinaceae spp., adjacent wetlands 161, 162, 163, register 703, 79, and 40 pollen grains, respectively, and nearby wetland 9 shows spatial variation from 0 to 129. The patterns show different wind fields and different grain fallout for a single taxon, and between taxa in an essentially isochronous layer, *i.e.*, the surface sediment of the wetland in a coastal climatic setting of today, and illustrate a wide variation in abundance across the receiving depositional surface. The study of the three upland pollen types suggests that using upland pollen abundance in isolation as an indicator of wind intensity and possible climatic changes, without supplementary information on pollen aerodynamics, pollen production
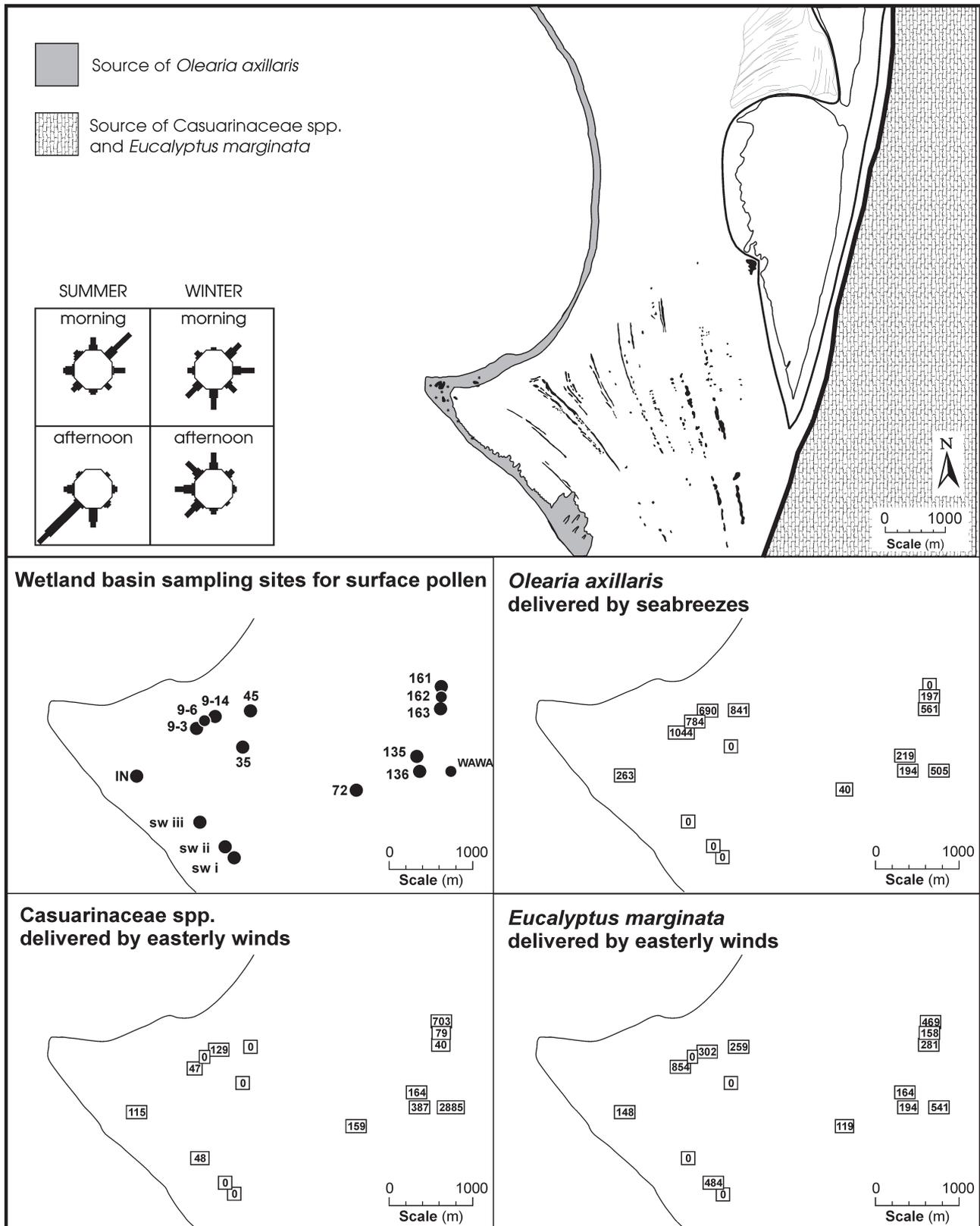
Figure 6. Sources of the three types of upland pollen (*viz.*, *O. axillaris*, *E. marginata*, and Casuarinaceae spp, with source being coastal, and inland regional, respectively), summary of wind delivery systems shown as wind roses for summer and winter, and abundance of these pollen in the surface sediments of the wetlands (boxed numbers refer to number of pollen within a standard volume; see text). The regional sources for *E. marginata* include that shown in the Figure (the Spearwood Dunes), as well as sources further east, such as the Bassendean Dunes and the Darling Plateau.

rates, abundance and location of source material, and wind currents, is problematic. The only conclusion that can be reached, if regional pollen occurs within a wetland basin within the Becher Suite, is that it is exogenic, and that for diagnostic taxa, it derives from easterly or westerly sources. The information in Figure 6 even suggests that the absence of diagnostic species of distal regional pollen within a given wetland basin cannot be used as an indicator of wind patterns.

It is concluded that the pollen of the main species of wetland plants forms *in situ* accumulations. With a baseline relationship established between extant wetland vegetation, subregional vegetation patterns, and regional vegetation patterns, the information in this paper can be used to construct the history of vegetation in wetlands of the Becher Point area, the subject of a later paper (C A Semeniuk, Milne, Ladd & Semeniuk, unpublished manuscript).

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