The Holocene History of the Vegetation and the Environment of Jibbon Swamp, Royal National Park, New South Wales

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Jibbon Swamp, in the north eastern part of Royal National Park, yielded a sedimentary history of 8,000 years. The present vegetation was mapped and the modern pollen deposition studied in order to assist interpretation. The palynology infers little change in the vegetation, other than a shifting mosaic of sclerophyllous communities similar to those seen in the area today.

The nature of the accumulating sediments and their algal and fungal spore content can be interpreted to reflect the hydrological history of the swamp. An initial establishment period of 8,000 to 5,500 year ago was followed by a permanent pool of water too deep for the sedgeland swamp vegetation, from 5,500 to 2,400 years ago and then a vegetated swamp that dried out periodically, from 2,400 years ago to present, as it does today.

Changes in the sediments and algae/fungi record suggest a wetter early Holocene and a drier mid-late Holocene climate, with an intensification of the dry periods about 2,500 years ago. This pattern of change seems to reflect regional climatic change. There is very little change in the less sensitive sclerophyllous vegetation. The likely impact of rising Holocene sea levels on this near-coastal environment is discussed.

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KEYWORDS: Holocene palynology, Holocene sea levels, Jibbon Swamp, Royal National Park, Vegetation history.

INTRODUCTION

Jibbon Swamp (Fig. 1) is located in the northeastern part of Royal National Park, behind Jibbon Beach and Port Hacking Point (Fig. 2). Its position is within a mosaic of sclerophyllous plant communities on nutrient poor sandstone soils. Currently, human interference in the area is minimal, considering its proximity to urban areas and disturbance is restricted to walking tracks and fire trails, but before European settlement, the Aborigines used the area. There are extensive rock engravings at Jibbon Head and small shell middens at Jibbon Beach (Attenbrow, 2002). The Aborigines were rapidly displaced after European settlement (Radford, 1999).

A large property was subdivided and the township of Bundeena was founded in 1898. During the 1930's Depression and World War II, there was an influx of people into the township and in shacks in the Park. The increased human influence probably caused greater disturbance and more fires (Radford, 1999).

The open areas around the swamp are grazed by native animals and introduced deer, the latter causing considerable damage. The fire frequency over most of the area is high, with the western border of the study area being burnt every year (in the early 1980's) for protection of the township of Bundeena (Chalson, 1983).

The fire history of Jibbon Lagoon has been studied in an attempt to determine if charcoal content could be correlated with known historic fire events (Radford, 1999; Mooney et al., 2001). The Holocene vegetation and environment has been reconstructed for sites on the nearby Kurnell Peninsula (Johnson, 1994; Martin, 1994).

This study examines the palynology of the swamp sediments and reconstructs the history of the vegetation, which in turn may indicate some change in climate. The close proximity of the swamp to the coastline means that changes in sea levels could have had an impact on the environment (Smith et al., 2011; Fleming et al., 1998).

Fig. 1. Jibbon Swamp in 1983

THE ENVIRONMENT

The area is situated on Hawkesbury Sandstone that has been covered, in part, by sheets of dune sand. Jibbon Swamp lies in a swale of the dunes. The bedrock of Hawkesbury Sandstone produces soils that are mainly lithosols and yellow podsols in the study area. All the soils are sandy throughout their profile and are acidic and poor in nutrients (Beadle, 1981).

The Hawkesbury Sandstone is impermeable but a system of vertical joints throughout facilitate the percolation of surface water and the result is very water stressed conditions for plants over large areas, especially on exposed sites such as ridge tops. Clay derived from the weathering of the sandstone collects in the dune swales forming a relatively impermeable layer that locally raises the watertable and may form a swamp, such as Jibbon Swamp (Branagan, 1979).

The climate is influenced by the proximity of Jibbon Lagoon to the coast and its low altitude of about 10 m above sea level. The temperature and humidity contrasts are reduced when compared with more inland sites (Bureau of Meteorology, 1991). The mean annual rainfall is about 1,220 mm (for the Cronulla South Bowling Club, elevation 31 m: BoM, 2011), some 2 km to the northwest. Rainfall is fairly evenly distributed throughout the year, with the wettest months February to June, recording an average of over 120 mm per month, and the driest months September to December with a mean of 62 to 87 mm per month. The mean maximum temperatures range from 26.4 °C in January to 17 °C in July while the mean minimum temperatures range from 18.8 °C in January to 7.1 °C in July (for Sydney Airport AMO: BoM, 2011).

METHODS

Fieldwork was carried out in 1983 when the vegetation was surveyed, using a combination of aerial photos and random transects. As many species as possible were collected and identified. The plant communities were defined on structure of the vegetation and the dominant species, following the classification of Specht (1970). Surface pollen samples for the definition of the pollen signature of the communities were collected from the surface of the soil. A number of samples from each plant community were mixed and sub sampled to prevent over-representation by the close proximity of one particular species.

The stratigraphy of Jibbon Swamp was explored using a Russian or D-section core sampler (Birks and Birks, 1980) for the clay sediments in the swamp and for samples used in pollen analysis. It was necessary to use a soil auger in the sandy soils around the swamp. The swamp was surveyed with one N-S transect the length of the swamp and four E-W transects across the swamp.

Samples for palynology were collected from a core in the deepest part of the swamp. The samples

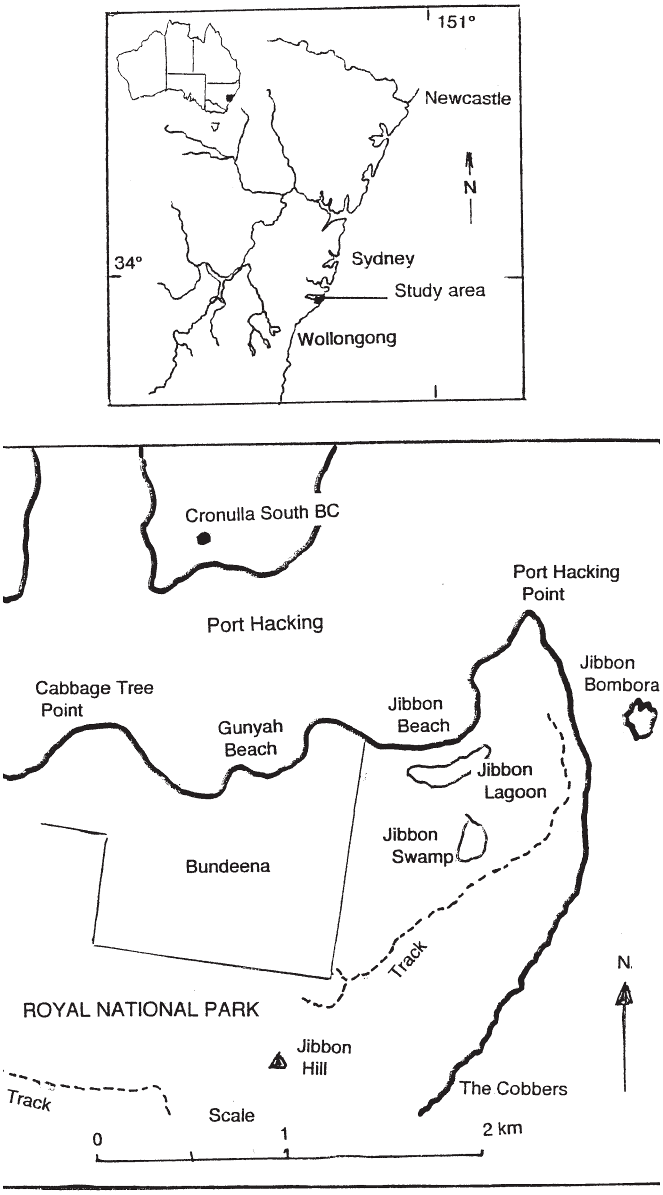


Fig. 2. Location of Jibbon Swamp in Royal National Park.

were taken at 10 cm intervals, or closer if the stratigraphy was complex. Samples chosen for radiocarbon dating were taken from the base of the major stratigraphic units and were dated by Mr. V. Djohadze of the then School of Nuclear and Radiation Chemistry at the University of New South Wales. These samples were dated just before the laboratory was closed, and laboratory numbers for the samples have not been located.

Samples for pollen analysis were spiked with an exotic pollen (*Alnus*) suspension of known concentration and processed with a procedure adapted from Brown (1960). Reference pollen collected from species growing in the area was treated by the standard acetolysis method (Birks and Birks, 1980). Sediment and reference pollen residues were mounted in glycerine jelly.

Identification of the pollen from the swamp sediments was done by comparison with the reference pollen. The similarity of the myrtaceous pollen required a careful analysis of the finer morphological features (Chalson and Martin, 1995) to achieve identification. Algal spores were identified by consulting the literature as a reference collection was not available. Total concentration of fungal spores was estimated and further identification was not attempted. For a quantitative analysis, pollen on transects across the slide were counted. Tests showed that a minimum of 140 grains was sufficient to give a representative sample.

Both percentages and pollen concentrations for individual pollen types were calculated from the counts. As these two different methods gave very similar results (Chalson, 1983), percentages have been used to construct the pollen spectra diagrams presented here.

STRATIGRAPHY OF THE SWAMP SEDIMENTS

Fig. 3 shows the location of two cross-sections of the swamp and Fig. 4 presents the profiles of the swamp sediments. The core for palynology was taken close to test hole A7, in the deepest part of the swamp and Fig. 5 shows the stratigraphy for this hole. Table 1 presents the radiocarbon dates: the base of the swamp is 7,250±120 radiocarbon years, or 8,224-7,786 calibrated years before the present (8.2-7.7 cal ka BP).

At the base of the swamp, there is a continuous, irregular layer, 5 to 10 cm thick of a fine-grained black material with a thin, reddish brown clay layer, and a mottled grey clay layer above it. Above the mottled layer, a thick layer of olive clay merges horizontally with grey and brown clays to the north. A black clay layer caps the olive clay and humic clay and peat form the uppermost layer. In the north, there are some intrusive sand wedges.

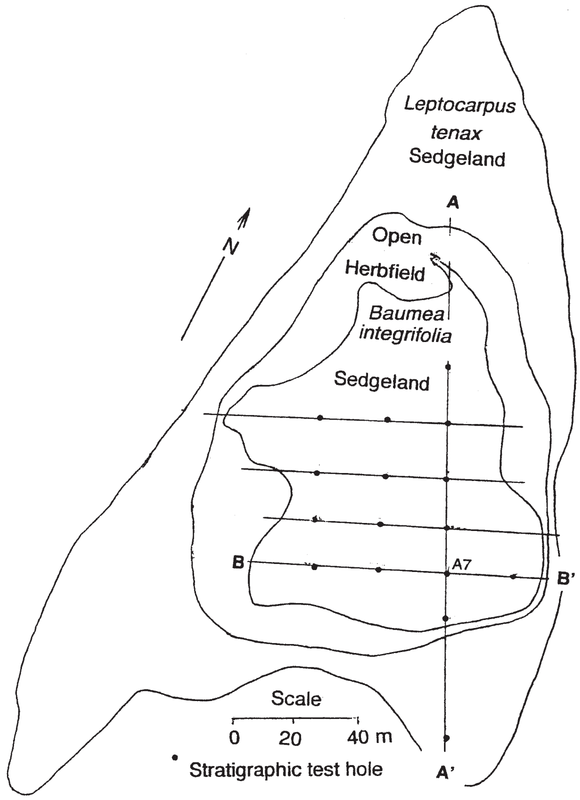


Fig. 3 (left). Location of transects and stratigraphic test holes across swamp.

THE VEGETATION

The *Eucalyptus/Corymbia/Angophora* woodlands and forests on soils of low fertility have a richly diverse sclerophyllous understorey (Beadle, 1981). In this near coastal location, wind and salt spray has a considerable effect, especially on moisture relationships. The areas fully exposed to the wind usually only support heaths or shrublands where the tree species remain stunted to about 2 m high. The soils are well drained and water stress is probably common. In recent historic times, frequent fires are also a feature of the environment of these communities (Mooney et al., 2001). Appendix 1 presents the species found in each of the plant communities described below and the distribution of these communities is shown in Fig. 6.

Cupaniopsis/Eucalyptus botryoides Open Forest occupies the barrier dune along the rear of Jibbon beach in areas with least exposure to winds, salt spray and fire. Compared with the rest of the

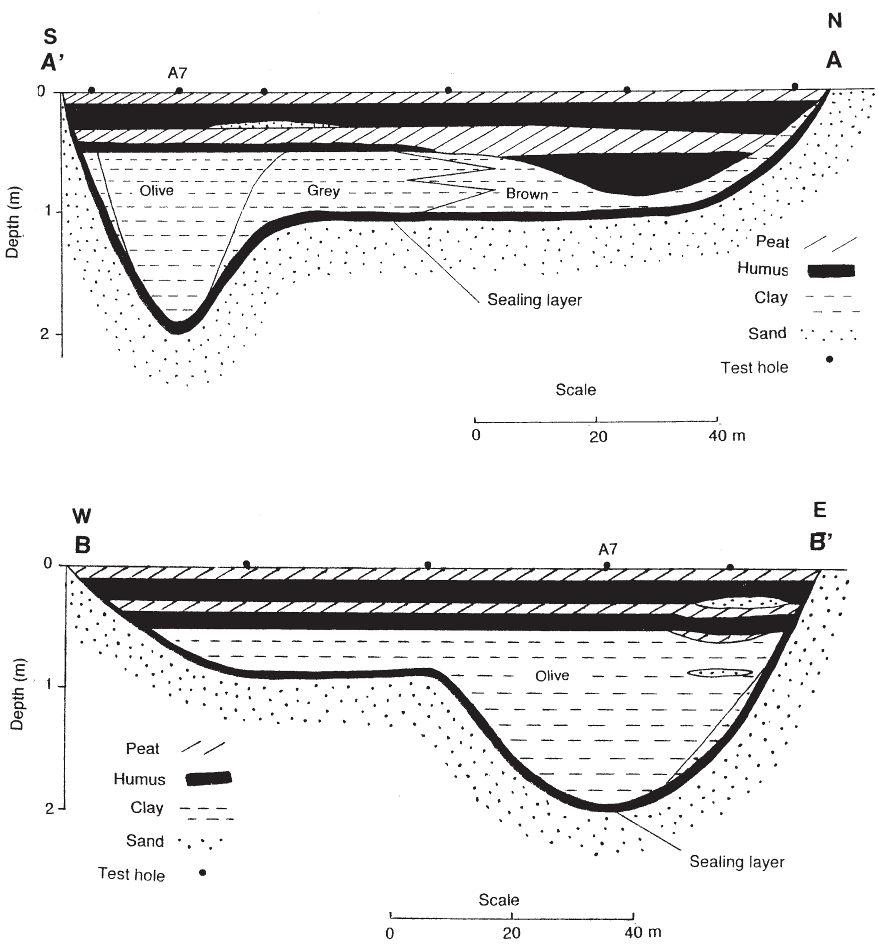


Figure 4 (left). North-south and east-west stratigraphic profiles of the swamp sediments. The location of the transects on the swamp is shown in Fig. 3.

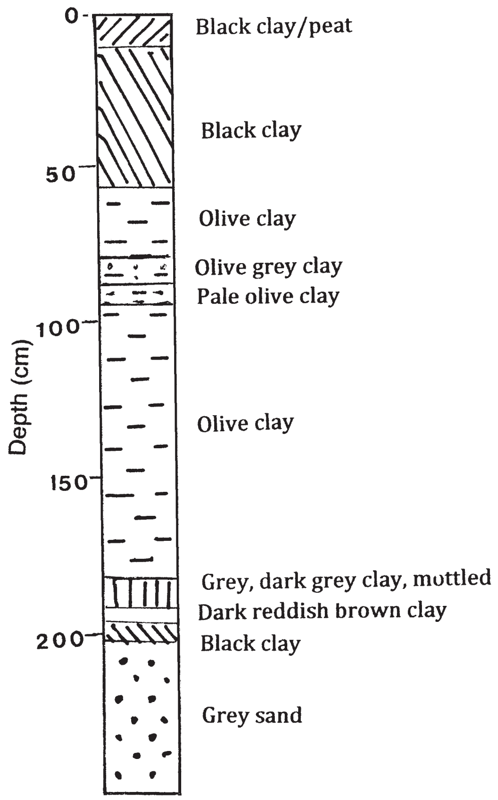


Fig. 5. Stratigraphy of hole A7 from the deepest part of the swamp. For location, see Fig. 2.

area, the soil is relatively well developed. The canopy is 10 to 12 m high with *Cupaniopsis anacardioides* dominant at the eastern end and both this species and *Eucalyptus botryoides* dominant at the western end of the community. The dense understorey is 1 to 3 m high and dominated by *Acmena smithii* and the introduced *Cestrum parqui*. *Asparagus plumosus* and *A. aethiopicus* dominate the ground layer to a height of half a metre. This community has largely escaped burning.

Angophora costata/Eucalyptus botryoides Low Open Forest is found in a narrow strip at the northeastern end of Jibbon Beach and in a small area to the southeast. It grows on shallow but well developed soil over the Hawkesbury Sandstone that is more retentive of moisture than most soils in the region. It is well protected from winds, salt spray and fire by the sand dunes to the north and east. The open canopy, 3 to 6 m high, is dominated by *A. costata*, *E. botryoides* and *Corymbia gummifera*. The understorey ranges from 0 to 2 m in height and is dominated by *Leptospermum laevigatum* and *Banksia serrata*.

Angophora costata/ Corymbia gummifera Low Open Forest occupies a large area to the west of Jibbon Swamp and grows exclusively on dune sand with a moderate soil development and poor water retaining capacity. Dune crests form the eastern boundary of this community and it appears that they protect it from salt damage (P. Stricker, pers. comm.). The open canopy is 3 to 6 m high and is dominated by *A. costata* and *C. gummifera*. An understorey up to 1 m high is dominated by *Lomandra longifolia* and *Pteridium esculentum*. The latter two species are often indicative of disturbance to the native vegetation. This community has been frequently burnt as a firebreak for the township of Bundeena.

Banksia ericifolia/Persoonia lanceolata Closed Scrub is found in a small area adjacent to the *A. costata/E. botryoides* Forest to the northeast. Here,

Table 1. Radiocarbon dates of the sediments

Sample depth (cm)	Nature of material	Radiocarbon years	Calibrated Age[a] (relative area under probability distribution)	Years Before Present (BP[b])
20-30	Black clay	NSW 1400±80	cal AD 560- 881 (100%)	1390-1069 BP
40-50	Black clay	NSW 2600±100	cal BC 846- 402 (98.9%)	2796-2352 BP
60-70	Olive clay	NSW 3100±100	cal BC 1510- 1004 (100%)	3460-2954 BP
180-190	Olive clay	NSW 4980±100	cal BC 3961- 3518 (99.7%)	5911-5468 BP
190-200	Black clay	NSW 6740±120	cal BC 5838- 5463 (96.2%)	7788-7413 BP
210-220	Sand	NSW 7250±120	cal BC 6274- 5836 (94.9%)	8224-7786 BP

[a] The radiocarbon dates were calibrated using the Southern Hemisphere atmosphere data set (SHCal04.14C SH terrestrial dataset) in CALIB version 6.0html, available at http://calib.qub.ac.uk/calib/ accessed October 2011. The calibrated ages represent the 2-sigma (95.4 %) calendar age ranges with the highest relative area under the probability distribution (with the relative area indicated in brackets) (Reimer et al., 2004)

[b] BP=before 1950

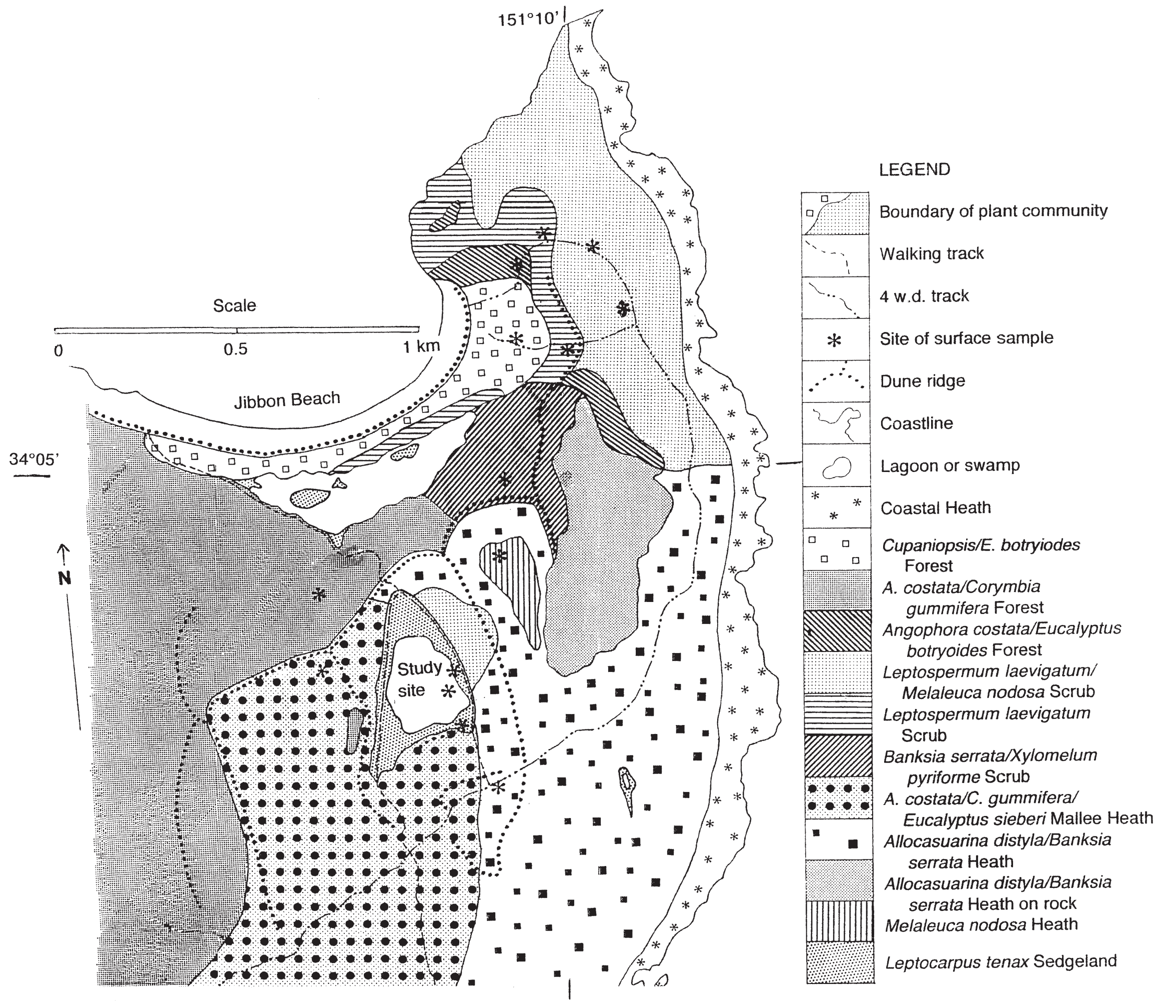


Fig. 6. Vegetation communities in the area around Jibbon Swamp, in the early 1980's

the soils are shallow and moderately developed on Hawkesbury Sandstone. The scrub is drier than the forest and more exposed to wind and fire. The over storey is extremely dense extending from 0.5 to 2 m high. Floristically, it is very diverse and the following species are the most common: *B. ericifolia*, *P. lanceolata*, *Callistemon rigidus*, *Kunzea ambigua* and *Melaleuca nodosa*. The understorey is up to 0.3 m high and dominated by Cyperaceae, mosses and *Drosera* species.

Leptospermum laevigatum/Melaleuca nodosa Closed Scrub occupies a large area to the northeast of the region and this community is bounded to the east by a narrow band of highly pruned, salt tolerant plants of the Coastal Heath, and to the west by *L. laevigatum* Scrub. The underlying soils are moderately developed on dune sand. The drainage varies considerably and the community often contains small shallow swamps 3 to 4 m across, adjacent to very dry, well drained areas. This community is highly exposed to wind, salt spray and fire although it has not been burnt since a wildfire in 1955 (up to the early 1980's P. Stricker, pers. comm.). The over storey is extremely dense, extending from 0.5 to 2 m high. The dominant species are *L. laevigatum* and *M. nodosa,* but it is floristically very diverse. The understorey is 0 to 0.3 m high and is dominated by Cyperaceae and Poaceae. Clearing for picnic and camping areas have altered parts of this community considerably.

Banksia serrata/ Xylomelum pyriforme Open Scrub is found east of Jibbon Lagoon, on poorly developed but well-drained soils on deep dune sands. It is highly exposed to fire, although less so to wind and salt spray. Since the wildfire in 1955 and up to the early 1980's, it has undergone regular hazard reduct-ion burning (P. Stricker, pers. comm.). The over storey is irregular, occurring in thickets and extending from about 0.5 to 2 m in height. The dominants are *Banksia serrata, Xylomelum pyriforme, Allocasuarina distyla, Leptospermum laevigatum* and *Melaleuca nodosa.* Cyperaceae and Poaceae dominate the understorey.

Leptospermum laevigatum Closed Scrub forms a narrow band around the southern, eastern and northeastern boundaries of the *Cupaniopsis*/*Eucalyptus botryoides* Forest. To the north, it is found on shallow sandy soils of the Hawkesbury Sandstone, but to the east and south, it grows more luxuriantly on poor soils of the sand dunes. The scrub is protected from wind and salt spray by dune crests along its boundary and has not been burnt since 1955 and up to 1983, forming a buffer zone for the *Cupaniosis*/*E. botryoides* Forest. The dense canopy, 5 to 7 m high, is exclusively *Leptospermum laevigatum.* There are a few scattered *Banksia serrata* shrubs, 2 m high and a more extensive ground cover, to 0.3 m high, dominated by *Phebalium squamulosum* and *Lepidosperma concavum*.

Melaleuca nodosa Closed Heath is found in the dune swale immediately to the east of the swamp and receives runoff from a Hawkesbury Sandstone ledge to the east, but the moderately developed soils are well drained. The community is sheltered from wind and salt spray by a sand dune ridge that runs over the ledge. The community has been subjected to hazard reduction burning prior to 1983. *M. nodosa* is the dominant species with a few scattered *Banksia serrata* shrubs about 30 m apart. The only understorey species is the fungus *Cantharellus cibarius* var. *australiensis* (A.E. Wood, pers. comm.).

Angophora costata/Corymbia gummifera/ Eucalyptus sieberi Mallee Heath (Low Shrubland) occupies a large area to the south west of the region. In the north, the mallee heath grows on dune sand with poor soil development and in the far south, beyond Bundeena, it is found on shallow soils of the Hawkesbury Sandstone. This community is very exposed to wind, salt spray and fire, being regularly burnt for hazard reduction purposes in the early 1980's. The over storey, 0.5 to 2 m high, is a diverse heathland with patches of short, multistemmed mallees of *A. costata*, *C. gummifera* and *E. sieberi*. The dominants are *Banksia serrata, Hakea dactyloides, Allocasuarina distyla, Styphelia viridus* and *Melaleuca nodosa*. The understorey, up to 0.5 m is a sparse mix of Cyperaceae and Poaceae.

Allocasuarina distyla/Banksia serrata Closed Heath occupies a large area to the south east of the study site and is found on the poor soils of the dune sand and occasional patches of very thin soils of the Hawkesbury Sandstone. The community is floristically very diverse and the dominants, *B. serrata* and *A. distyla* are only slightly more frequent than many other species. There is no layering, the tallest plants being 1 m high. The community has the richest diversity in the dune sands and is floristically poorer, more open and lower in height on the sandstone soils. The heathland is highly exposed to wind, salt spray and fire, being regularly burnt for hazard reduction purposes in the early 1980's.

Leptocarpus tenax Closed Sedgeland is found on the extensive flat area around Jibbon Swamp. The area has poor soil but good moisture relationships as runoff from the dune ridges on three sides collect here, and at times of high rainfall, may be waterlogged. The community is well protected from wind and salt spray but it has been regularly burnt in the 1980's for fire hazard reduction. The dominant sedges are *L. tenax* and *Schoenus brevifolius*, forming a layer about 0.8 m high. There is a low, 2 cm understorey of *Goodenia paniculata* and *Gonocarpus micranthus*.

Open Herbfield is found in a 1 to 5 m wide zone between the *Leptocarpus tenax* Sedgeland and the *Baumea teretifolia* Sedgeland of the swamp proper. There is no visible soil development although there are faint broad colour bands down the profile. Protection, drainage and water relations are approximately the same as for the *L. tenax* Sedgeland. There is only about a 10% plant cover and a few pioneer heathland species become established in drier conditions. There are several species of Asteraceae (not native) and several large patches of *Viola sieberana*.

Baumea teretifolia Sedgeland is found in the swamp that usually contains standing water, except in extended dry periods when most of it dries out. The soils are usually waterlogged. *B. teretifolia* is the dominant sedge, with *Baumea juncacea* and *Chorizandra sphaerocephala* found along the fringes of the swamp. *Triglochin procera* grows in disturbed sites.

MODERN POLLEN DEPOSITION

The most abundant pollen types in the pollen spectra produced by the communities are shown in Fig. 7A, 7B, and the low frequency and rare types found in each community are recorded in Table 2. Knowledge of the pollen spectra produced by the plant communities should assist in the interpretation of the spectra found in the swamp sediments.

The pollen spectra show that only a few pollen types contribute substantial percentages, e.g. *Allocasuarina/Casuarina*. Other types contribute less pollen that may still vary between communities e.g.

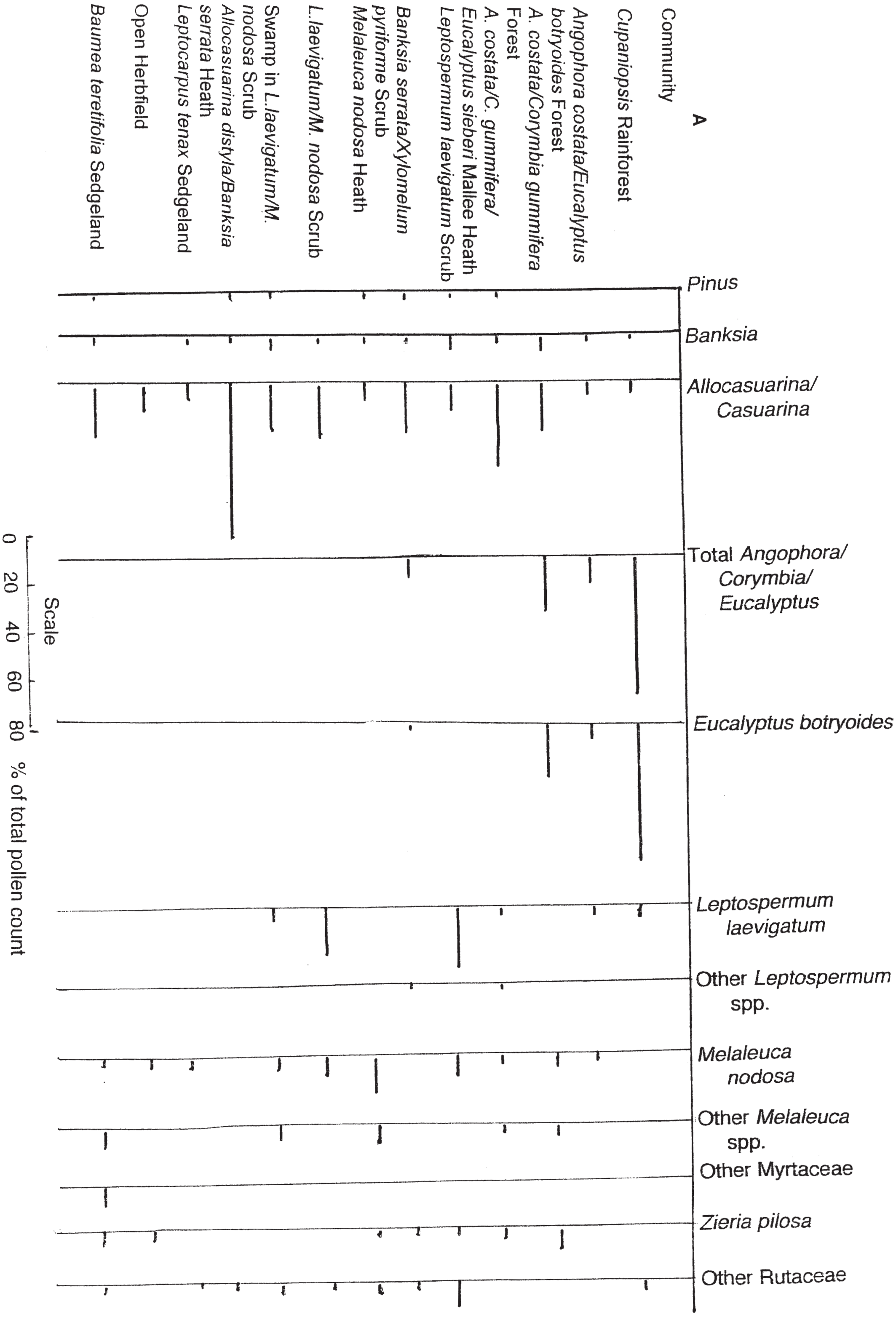


Fig. 7. Modern pollen deposition by the communities.

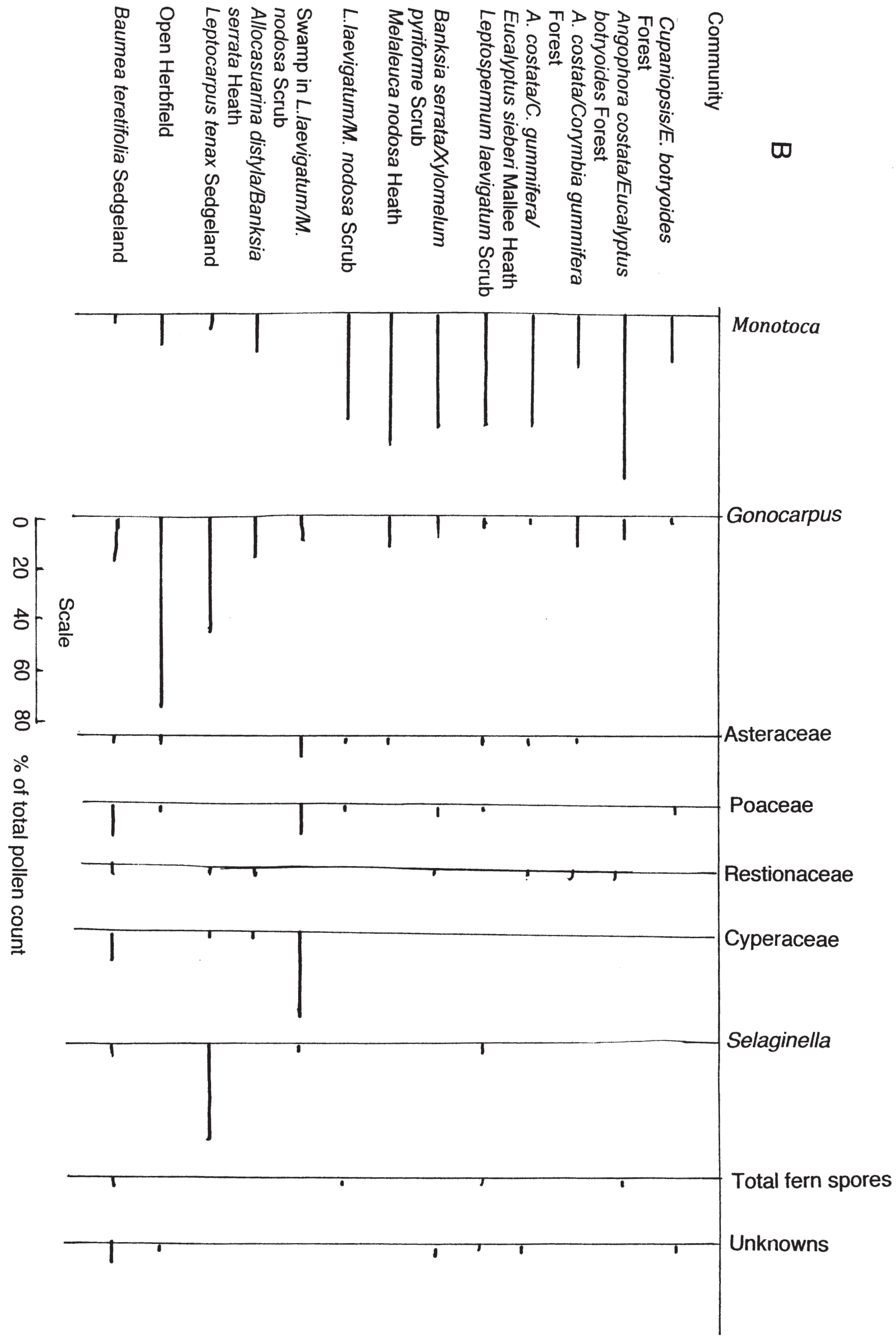

B
Community
Cupaniopsis/E. botryoides Forest
Angophora costata/Eucalyptus botryoides Forest
A. costata/Corymbia gummifera Forest
A. costata/C. gummifera/ Eucalyptus sieberi Mallee Heath
Leptospermum laevigatum Scrub
Banksia serrata/Xylomelum pyriforme Scrub
Melaleuca nodosa Heath
L.laevigatum/M. nodosa Scrub
Swamp in L.laevigatum/M. nodosa Scrub
Allocasuarina distyla/Banksia serrata Heath
Leptocarpus tenax Sedgeland
Open Herbfield
Baumea teretifolia Sedgeland
Monotoca
Gonocarpus
Asteraceae
Poaceae
Restionaceae
Cyperaceae
Selaginella
Total fern spores
Unknowns
Scale
0 20 40 60 80
% of total pollen count

Table 2. Modern pollen deposition: low frequency and rare species

Key to species numbers

1. *Angophora cordifolia*	7. *Persoonia* sp
2. *Eucalyptus haemastoma*	8. *Achronychia* sp
3. *E. sieberi*	9. *Geijera salicifolia*
4. *Leptospermum trinervum*	10. *Zieria* sp.
5. *Melaleuca armillaris*	11. *Correa reflexa*
6. *M. quinquinerva*	12. *C. alba*

Pollen percentages of total count given.

	Species											
Community	1	2	3	4	5	6	7	8	9	10	11	12
Cupaniopsis/E. botryoides Forest									2		3	
Angophora costata/ Eucalyptus botryoides Forest	2	1									1	
A. costata/Corymbia gummifera Forest	1					2					2	
A. costata/C. gummifera/ E. sieberi Mallee Heath				2		2						
Leptospermum laevigatum Scrub								1				
Banksia serrata/Xylomelum pyriforme Scrub	1		1				2					
Melaleuca nodosa Heath					3							
L. laevigatum/M. nodosa Scrub									1	2		2
Swamp in *L.laevigatum/M. nodosa* Scrub				1		1						5
Allocasuarina distyla/Banksia serrata Heath								1				1
Leptocarpus tenax Sedgeland											1	
Open Herbfield						3						1

Leptospermum laevigatum, but some are only ever found in low frequencies e.g. *Banksia, Zieria pilosa* (Fig. 7, Table 2). Many factors influence the pollen representation and whether a taxon is wind or animal pollinated is perhaps the most important. Wind pollinated species usually produce copious quantities of relatively small grains that may be widely distributed, e.g. *Allocasuarina/Casuarina*, whereas animal pollinated plants usually produce fewer, larger and stickier grains that are less likely to be distributed widely, e.g. *Banksia*.

An examination of the pollen spectra shows that some distinctive features may be used to deduce the nature of the community. Pollen of *Allocasuarina/Casuarina* may be found almost everywhere, but Table 3 shows that where it is dominant, there is over 40%: where present but not dominant, from 20 to 40%, and where it is not present, less than about 20% of the pollen spectrum. *Eucalyptus botryoides* contributes a substantial percentage to the *Cupaniopsis*/*E. botryoides* Forest, where it is a co-dominant, but the other co-dominant, *Cupaniopsis* does not contribute any pollen to the spectrum. It seems puzzling that *E. botryoides* contributes relatively little pollen to the spectrum of the *Angophora costata*/*E. botryoides* Forest, but this latter spectrum has relatively high percentages of *Monotoca* pollen. *Monotoca* is common in this community, but not in the *Cupaniopsis*/*E. botryoides* Forest. *Angophora* and *Corymbia* have larger grains than *Eucalyptus* and are usually not well distributed.

Variable preservation of the grains may sometimes be a factor influencing representation in the spectrum.. There are both dryland and swamp

Table 3. Distinctive Pollen Features of the Communities

Key to pollen type numbers.

1. *Angophora*
2. *Eucalyptus/Corymbia*
3. *Melaleuca*
4. *Leptospermum*
5. *Allocasuarina/Casuarina*
6. *Gonocarpus*
7. Restionaceae
8. Cyperaceae
9. *Selaginella*
10. Total fern spores

Pollen percentages of total count given

	Pollen type									
Community	1	2	3	4	5	6	7	8	9	10
Cupaniopsis/E. botryoides Forest	2	67	5	3	<20	-	-	-	-	-
Angophora costata/Eucalyptus botryoides Forest	-	7	-	5	<20	8	-	-	-	-
A. costata/Corymbia gummifera Forest	3	13	-	-	<20	11	-	-	-	-
A. costata/C. gummifera/ Eucalyptus sieberi Mallee Heath	-	-	7	-	20-40	-	-	-	-	-
Leptospermum laevigatum Scrub	-	-	6	22	<20	-	-	-	-	-
Banksia serrata/Xylomelum pyriforme Scrub	-	-	-	-	20-40	-	-	-	-	-
Melaleuca nodosa Heath	-	-	21	_	<20	9	-	-	-	-
L. laevigatum/M. nodosa Scrub	-	-	-	22	20-40	-	-	-	-	-
Allocasuarina distyla/Banksia serrata Heath	-	-	-	-	>40	12	-	-	-	-
Leptocarpus tenax Sedgeland	-	-	-	-	<22	40	5	-	35	-
Open Herbfield	-	-	-	-	<20	70	-	-	-	-
Baumea teretifolia Sedgeland	-	-	7	-	-	13	-	12	5	5

species of Cyperaceae. The pollen of Cyperaceae is particularly thin-walled and subject to crumpling that makes identification difficult. The *Leptospermum laevigatum/Melaleuca nodosa* Scrub was sampled twice, one in the same manner as all the other surface samples and the other from a small swamp in the community. The swamp sample has appreciable pollen of Cyperaceae whereas the dryland sample has none. Nearly all of the surface samples were taken from dryland situations, a necessity in this environment, hence they are not exactly equivalent to the core samples taken from the swamp. Still, the surface pollen spectra should give some guidance for the interpretation of the core samples.

Algal and fungal spores found in the surface samples are presented in Fig 8. The Unknown algal type 1 (see Fig. 9) is common in all the communities, but relatively less is found in the *Baumea teretifolia* Sedgeland swamp community. *Zygnema*-type is found occasionally in low frequencies. Zygnemataceae are found in fresh-water ponds, ditches and streams, and are characteristic of oxygen-rich, shallow, stagnant water (Head, 1992). Its presence in these dryland communities may be ephemeral following particularly wet weather.

Botyococcus braunii is common in the *Baumea teretifolia* Sedgeland, but it is absent from, or there is very little in most of the other dryland communities. *B. braunii* is a widespread planktonic species that is found in fresh/brackish waters (Pentacost, 1984). Algal type 2 (See Fig. 9) is rarely seen.

The fungal spore concentration in most communities is high, but one of the lowest is found in the *B. teritifolia* Sedgeland. A high concentration of fungal spores is usually regarded as a sign of a relatively dry environment, at least seasonally (Van Geel and Van der Hammen, 1978).

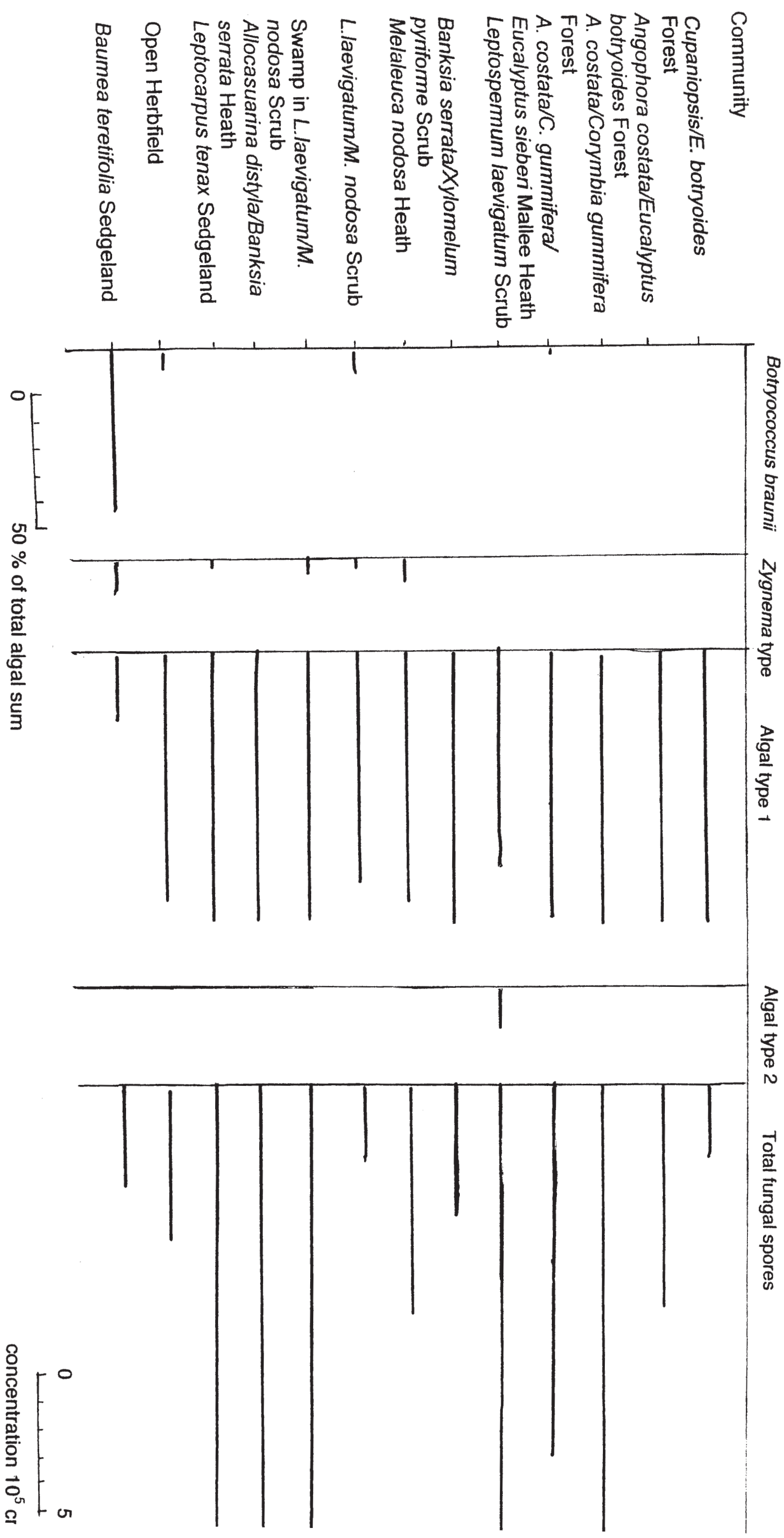


Fig. 8. Modern algal and fungal spore found in the communities.

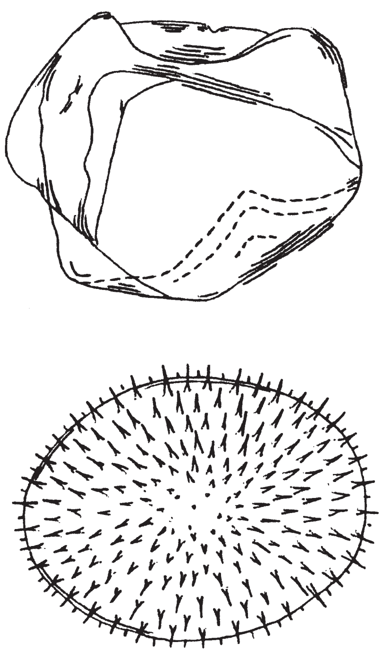


Fig. 9. Unknown algal spores. Top, Algal type 1, possibly a Zygnematacaceae (see Head, 1992). Bottom, Algal type 2. For named algal spore types, see Pentecost (1984).

PALYNOLOGY OF THE SWAMP SEDIMENTS

The most abundant pollen types in the swamp sediment pollen spectra are shown on Figs 10A and 10B and the low frequency and rare pollen types are presented in Table 4. A comparison with the distinctive pollen features of the communities (Table 3) shows that the spectra are a combination of some dryland community and the on-site swamp community.

In general, the whole of the dryland part of the spectra best fits the modern *Angophora costata/ Corymbia gummifera/Eucalyptus sieberi* mallee heath community, with the exception that the *Monotoca* content is far lower than in the modern community. The surface pollen samples (Figs 7A, 7B) show that *Monotoca* pollen is more abundant in the dryland communities and less so in the sedgelands and herbfield around the swamp and the lesser quantities in the swamp sediments many simply reflect this.

Some spectra, however, suggest other communities. The 195 cm level (peak C of Chalson, 1983) is comparable with the *Angophora costata/Corymbia gummifera* Forest community and has the highest peak for *Angophora/ Corymbia/Eucalyptus* and an unusually low *Allocasuarina/Casuarina* content of <20%. This level is within the black humus layer sealing the swamp. The representation of Cyperaceae, Restionaceae and *Sellaginella* are comparable to the *Baumea teretifolia* Sedgeland, the community on the swamp itself.

The 140-150 cm and 70-80 cm levels have percentages for *Allocasuarina/Casuarin*a exceeding 40%, suggesting that it was dominant, at times. *Angophora/Corymbia/Eucalyptus* is not represented at these levels. Again, the representation of Cyperaceae and Restionaceae are comparable to the *Baumea teretifolia* Sedgeland.

The vegetation in the whole of the profile, representing about 8 cal ka BP, is thus very similar to that of today, with a suggestion that there may have been a forest in the oldest part of the profile. The variations in the pollen spectra probably represent shifting patterns, perhaps with a slightly different assortment of species within the sclerophyllous vegetation that was essentially similar to today.

The algal and fungal components (Fig. 11) show some patterns of change and they indicate hydrological conditions in the swamp. The algae and fungi, with their short life cycles, can respond quickly to environmental changes. The swamp sediments are zoned on the hydrological changes thus:

Zone 3: 220-180 cm, ~ 8.0-5.5 cal ka BP. *Botryococcus braunii* is mostly low, the *Zygnema* type is well represented, *Spirogyra* is usually present, Algal type 1 (see Fig. 9) is usually abundant and the fungal spores are well represented. *B. braunii* is a planktonic species and indicates standing fresh to brackish water (Pentacost, 1984). The Zygnemataceae (*Zygnema* and *Spirogyra*) are found in freshwater lakes and pools. Many forms prefer temporary standing water and the increased temperatures experienced as the pool dries out would encourage spore formation, a necessity for preservation in the swamp sediments. The surface pollen spectra show that Algal type 1 is associated with dryland conditions and fungal spores indicate dry conditions (van Geel and van der Hammen, 1978). Thus Zone 3 suggests a swamp that had standing water at times, but it dried out regularly. After periods of wet weather, there were temporary pools of water that soon dried out.

Zone 2: 170-40 cm, ~ 5.5-2.4 cal ka BP. The *B. braunii* content is greater and the *Zygnema* type and Algal type 1 are lower than in the zone below. Standing water, too deep for sedgelands that would have been confined to the edge of the swamp, was consistently present in this zone. Fungal spores are generally low, indicating moist conditions, except for the 100-70 cm level, where they are higher. There is no change in the algal abundance in this level, suggesting that any seasonal dry periods were insufficient to influence the maintenance of the permanent pool of water.

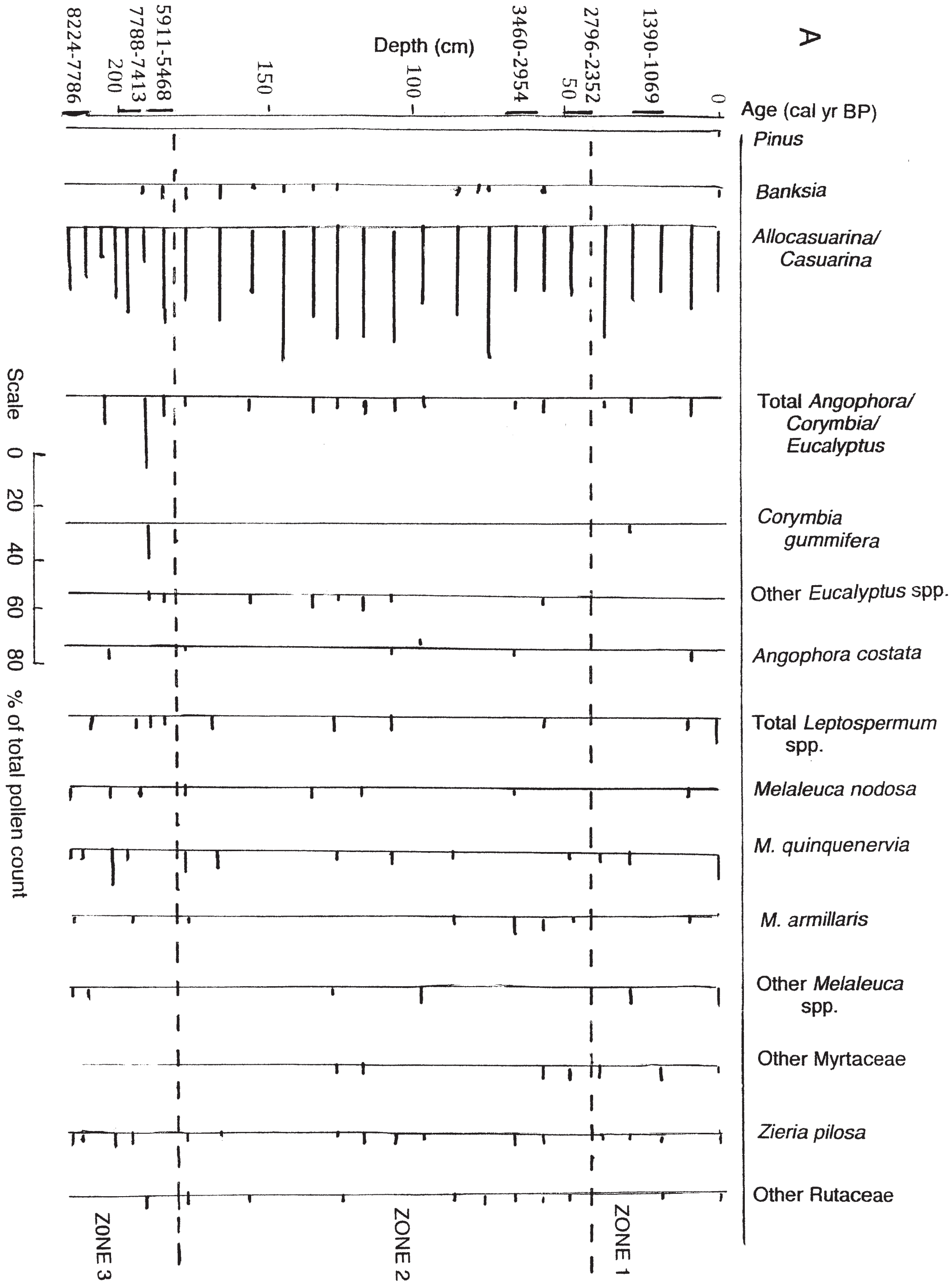


Fig. 10. Pollen spectra from the swamp sediments.

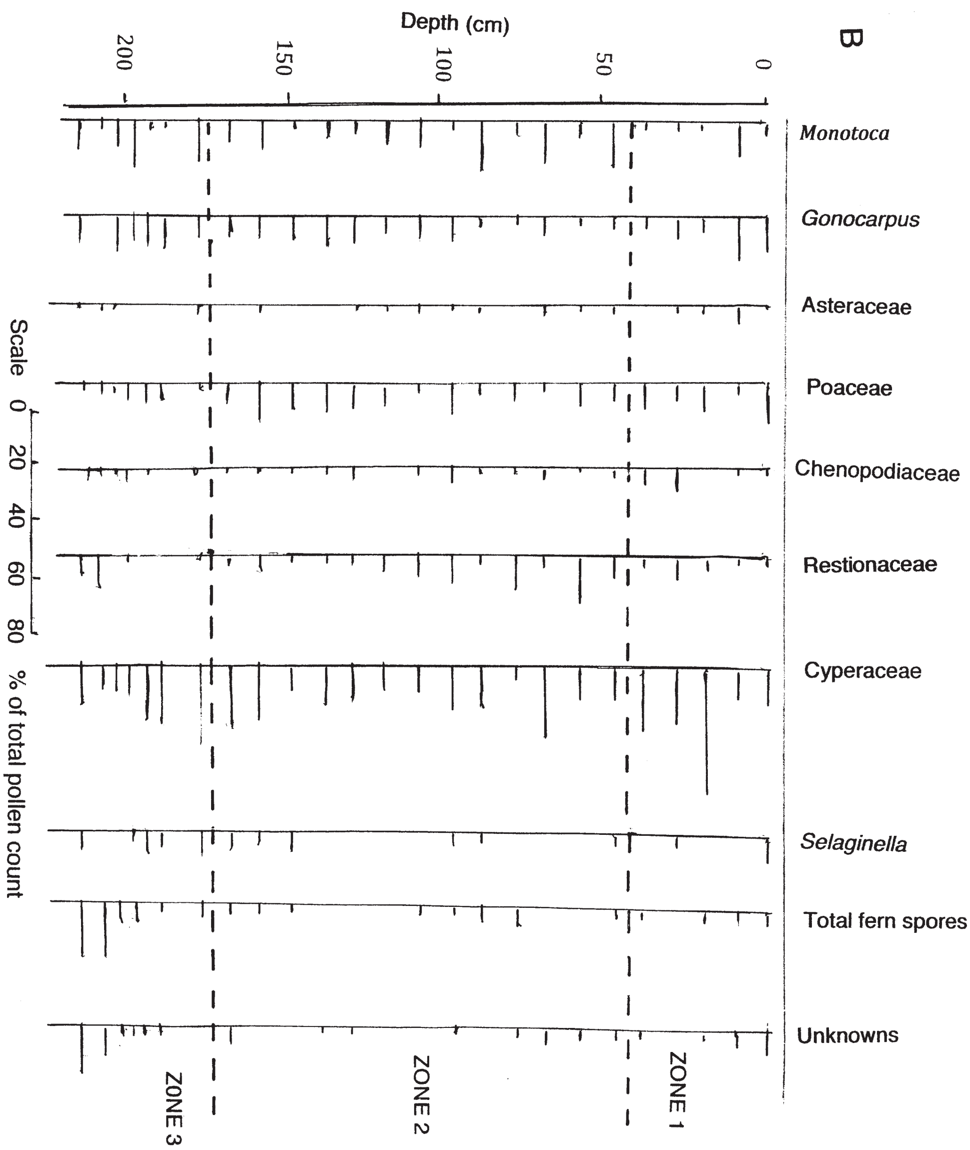

B
Depth (cm)
0
50
100
150
200
Monotoca
Gonocarpus
Asteraceae
Poaceae
Chenopodiaceae
Restionaceae
Cyperaceae
Selaginella
Total fern spores
Unknowns
Scale 0 20 40 60 80 % of total pollen count
ZONE 1
ZONE 2
ZONE 3

Table 4. Low frequency and rare species in the pollen profile

Key to species numbers

1. *Eucalyptus sieberi*	8. *Persoonia*
2. *E. leuhmaniana*	9. *Tasmannia*
3. *E. haemastoma*	10. *Acronychia*
4. *Angophora cordifolia*	11. *Euodia*
5. *Leptospermum trinervium*	12. *Geijera salicifolia*
6. *L. polygalifolium*	13. *Correa* spp.
7. *L. laevigatum*	14. Ericaceae

Pollen recorded as % of total pollen count.

	Species													
Depth (cm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0					1								1	
10						3				1				
20													2	1
30														
40	1									3				
50	1										3		1	
60			3										1	
70														
80														
90														
100								1		1	1		1	
110			2											
120	2		4				2					2		
130									1					1
140	2					2						3		
150										2				
160				1							3		2	
170														
180				2	2									
190		3		3						1	2		2	1
200								1						1
210				2	2								1	
220					2			1			1		2	

Zone 1: 30-0 cm, ~ 2.4-0 cal ka BP. Here, the *B. braunii* content is reduced and the *Zygnema*, Algal type 1 and fungal spores are increased, thus conditions would have been drier, with the swamp drying out more often, at least for short periods. Sedgelands were able to colonise the whole of the swamp surface under these conditions.

A summary of the age, stratigraphy and zones is shown on Fig. 12.

DISCUSSION

Jibbon Swamp was initiated ~8 cal ka years ago when the dune swale was stabilised by vegetation that acted as a trap for the fine-grained particles derived from the Hawkesbury Sandstone. Decomposition of organic material occurred in a waterlogged environment where sulphur bacteria were active, judging from the odour of the sediment. The reddish brown layer indicates exposure to air and oxidising conditions and the mottled layer was formed under a fluctuating water table. This complex of layers acted as a sealant over the basal sand substrate and enabled water to accumulate in the swamp (Fig. 4).

The thick olive green clay layer suggests reducing conditions of an anaerobic environment (Reeves, 1968) with a water depth of more than a few centimetres. The water was too deep for sedgelands that would have been restricted to the edges of the

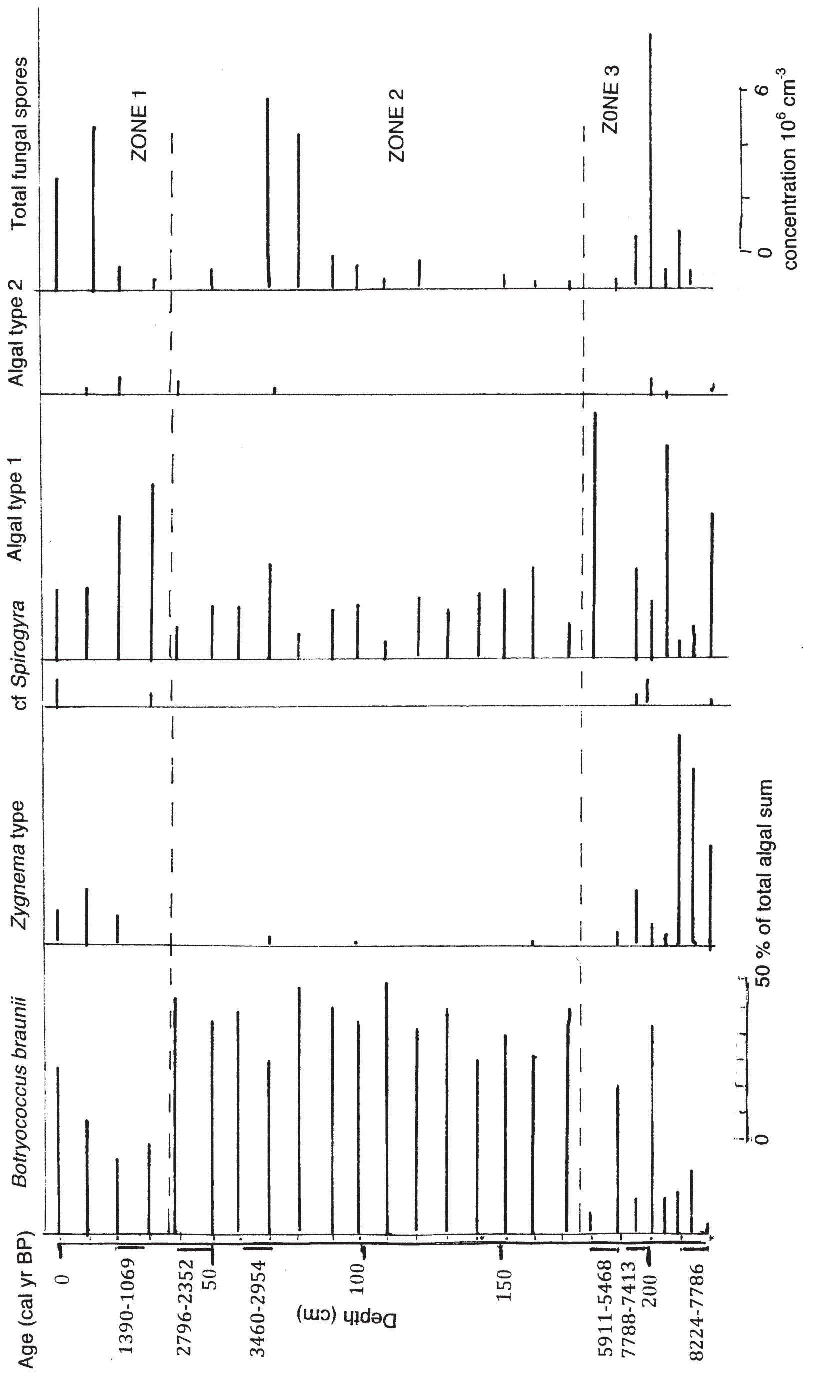


Fig. 11. Algal and fungal spores from swamp sediments

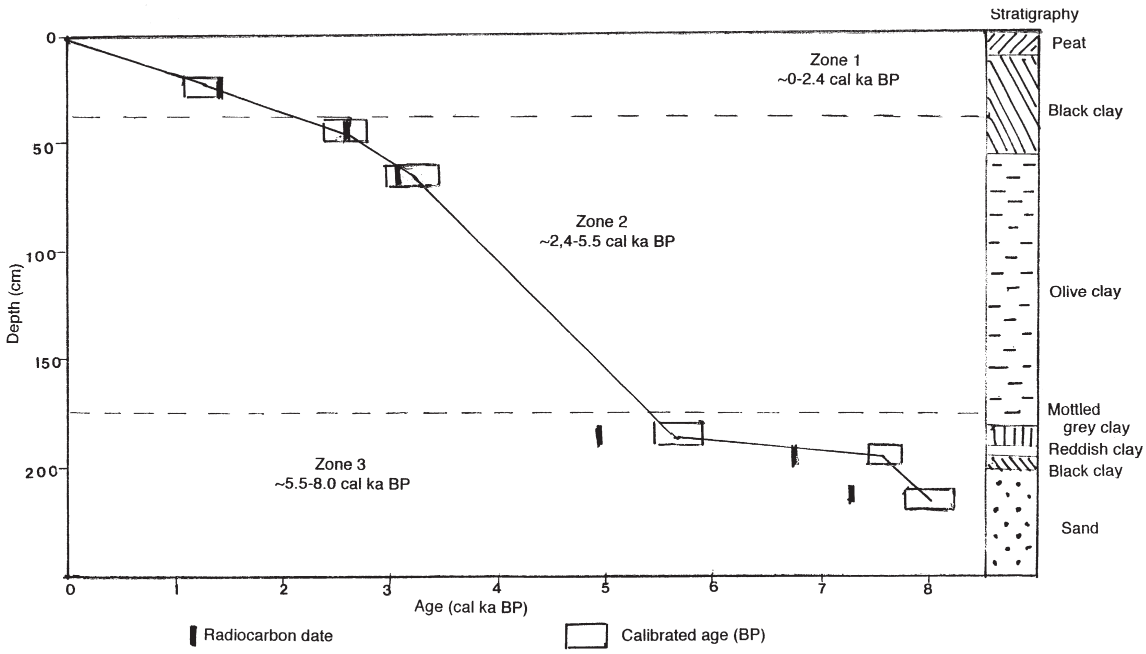


Fig. 12. Summary diagram of stratigraphy, zones and age of the sediments in Jibbon Swamp.

swamp. The grey clays were probably anaerobic but not reducing, and the brown clays were at times exposed to oxidising conditions. The north-south section (A - A', Fig. 4) suggests that the deepest southern part of the swamp was permanently wet with an appreciable depth of water and the extent of standing water fluctuated to the north.

Peat accumulated in layers above the clay when the water depth was shallow enough to allow sedgelands to colonise the swamp surface. When decomposition was more active, probably due to microbial activity in intermittent anaerobic conditions, the structure of the plant material was destroyed, producing humus. The alternating peat/humus layers near the surface reflect wetter/drier conditions when the swamp may have dried out for relatively short periods, as it does today.

Two wedges of sand in the northern part of the swamp probably were the result of dune instability

Throughout the ~8 cal ka that the swamp sediments represent, the vegetation would have been essentially similar to that of today. The same species as today were present the whole time, with the exception of *Melaleuca quinquenervia* that occurs throughout the sedimentary profile but it is not recorded from the vegetation of the area. Today, *M. quinquenervia* is found north of Botany Bay (N.S.W. Flora Online 2011), some 6-8 km to the north. The pollen types recorded at any one level suggest that at any one time, the community may have been somewhat different from those described in the area today. This is not surprising: these nutrient-poor soils are only suitable for sclerophyllous formations, and even with climate change, some form of sclerophyllous vegetation would persist.

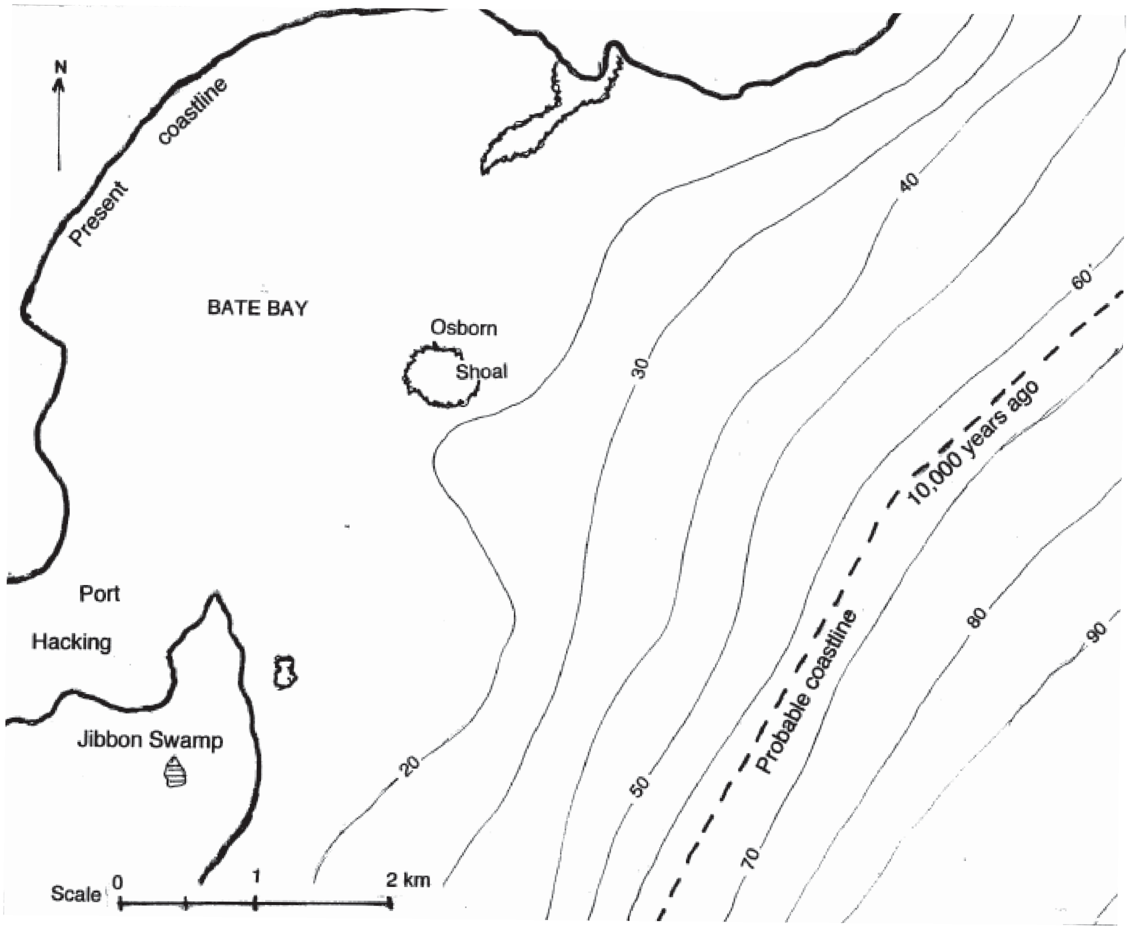
The algal and fungal spore content, however, does show changes. Their short life cycles allow them to respond quickly to environmental changes, unlike the higher plants that have long life cycles that may allow the plants to persist for some time after favourable environmental conditions for regeneration have deteriorated. The algae chart the establishment of the swamp, a period when the swamp had a permanent pool of water, then a drier period when the swamp dried out, at least for short periods, similar to today.

In such a coastal location as this, rising sea levels have most likely had an influence on the history of the swamp. Global sea levels rose slowly after the last glacial maximum (~20-18 ka BP) as temperatures rose and ice melted (Fleming et al., 1998). The late Pleistocene experienced colder temperatures: the "Antarctic cold reversal" (starting ~14.5 cal ka BP) in the southern hemisphere (Blunier et al., 1997) and the "Younger Dryas" (~12.8-11.5 cal ka BP) in the northern hemisphere (Alley, 2000). These cold periods slowed ice melt and the rise in global sea levels. In the early Holocene, temperatures were warmer and deglaciation proceeded, resulting in a rapid rise of sea levels during the period 11.6-7.0 cal ka BP. It is estimated that there was a rise of ~60 m over most of the globe during this period (Smith et al. 2011). After 7 cal ka BP, only about 3-5 m has been added to sea levels, bringing them to about their present position ~6 cal ka BP (Fleming et al., 1998).

Evidence from the east coast of Australia indicates that sea levels followed these general global trends, but after 7 ka, they were about 1-1.5 m higher than those of today. Sea levels gradually lowered to their present position after 2-2.5 ka. There were fluctuations within the high stand (Sloss et al, 2007; Lewis et al, 2008; Woodroffe, 2009; Switzeret al., 2010).

The probable coastline offshore of Jibbon Swamp may be inferred from these studies of sea level changes. About 10 ka BP, before the formation of Jibbon Swamp, the sea level was some 60-65 m lower than its present level (Smith et al., 2011), and the coastline would have been over 5 km away from the site (Fig. 13). Port Hacking and Bate Bay were dry land, and the Jibbon Swamp site would have been at an elevation of over 70 m. The early Holocene rapid rise in sea level brought the coastline close to its present position about 8-7 cal ka BP, flooded Port Hacking and Bate Bay, and brought the elevation of the site down to about 10 m. The shallow seas in Bate Bay and Port Hacking are likely to have been a significant source of evaporation and local rainfall. At this lower elevation, drainage would have been sluggish. Concurrently, Jibbon Swamp was established. The sea level gradually lowered 1-1.5 m after 2.5 cal ka BP (Sloss et al., 2007), probably improving drainage. About this time, the water level in the swamp became lower, allowing the sedgelands to colonise the whole surface of the swamp. The swamp would have dried out on occasions, as it does today.

Sites on the Kurnell Peninsula, some 8 km to the NNE also have an 8 ka vegetation history (Martin, 1994), but unlike Jibbon Swamp, they are in an estuarine environment. The oldest sediments indicate woodland and a slowly accumulating swamp. About 5 ka, a protobarrier was destabilised, the tree pollen types declined and the swamp became a rapidly



13. Location showing probable coastline before the formation of Jibbon swamp about 8 cal ka BP. From Smith et al (2011) and the Port Hacking Topographic Map, 1:25 000, second edition (1985)

accumulating fen peat. After 2.5 ka, the shrubby element became more prominent in the dryland vegetation and the swamp became more acid, with species typically found in wet heaths and bogs. *Sphagnum* was sometime present: it is not found in the region today (Martin, 1994). Thus the Kurnell site experienced substantial changes in the vegetation about the same time as those at Jibbon swamp.

The late Holocene history of a coastal plain site near Kiama (Jones, 1990), ~70 km to the SSW of Jibbon Swamp, indicates wet sclerophyll/rainforest vegetation, similar to that in the region today. There was a change in the swamp environment, about 2.5 ka: most likely from intertidal to fresh water, probably associated with a lower sea level or the development of a more effective barrier. Casuarinaceae decreases about this time (Jones, 1990). This change at Kiama occurred about the same time as a change in the hydrology at Jibbon Swamp.

Palynological studies in more inland sites in the Sydney Basin indicate the early Holocene was warmer and wetter and the late Holocene was drier, Otherwise, suggestions of climatic change after the mid Holocene are relatively slight, and do not show consistent patterns. Small changes in the late Holocene vegetation seem to be site specific and may have more to do with the dynamics of the swamp development (Chalson and Martin, 2009; Robbie and Martin, 2007; Rose and Martin, 2007; Black et al., 2006; Black and Mooney, 2006; 2007). The resilient nature of the sclerophyllous vegetation on these poor sandstone soils may mean that it is relatively insensitive to minor climatic changes (Black and Mooney, 2007). The three coastal sites, however, suggest that changes in sea level had some influence on changes in the hydrology and vegetation.

A review of Holocene pollen evidence in eastern Australia (Donders et al., 2007) indicates an early Holocene moisture optimum ~8 cal ka BP, an initial drying period ~5.5 cal ka BP followed by a further intensification of the dry periods after ~3 cal ka BP, although there is considerable variation in the dates and the intensity of the event due to local conditions. These trends are seen further afield in the Southern Hemisphere, and it is thought that they reflect the intensification of the El Nino-Southern Oscillation cycles (ENSO) towards frequencies and intensities similar to modern times (Donders et al., 2008).

CONCLUSIONS

Jibbon Swamp has a sedimentary record of about 8,000 years and exhibits three zones: an initial establishment zone of a fine-grained sealant layer and several other thin layers that indicate the swamp occasionally dried out, then a middle zone when the swamp was permanently wet with a pool of water too deep for vegetation to grow there, followed by a shallower top zone that was vegetated and occasionally dried out.

A survey of the vegetation in the study area shows a complex mosaic of sclerophyllous forest, mallee, scrub and heath communities on nutrient poor soils. The modern pollen deposition under these communities provides guidelines for the interpretation of the palynology of the swamp sediments.

A study of the palynology shows that the vegetation would have been similar to the sclerophyll communities occupying the area today. It is difficult to match the pollen spectra from the swamp precisely with a surface pollen sample from a particular community, suggesting that there was a shifting mosaic of communities. The swamp pollen profile shows almost no zonation, with only a suggestion that the vegetation was probably a sclerophyllous forest in the oldest part of the profile and mallee heath in younger parts.

The algal and fungal spore content indicates three hydrological zones: a lower drier zone (~8.0 to 5.5 cal ka BP), a middle wetter zone (~ 5.5 to 2.4 cal ka BP) and a drier top zone (2.4 cal ka BP to present). These algal/fungal zones correspond to the sedimentary zones.

An examination of global sea levels shows that there was a rapid rise of about 60 m in the early Holocene. Before this sea level rise, Jibbon Swamp would have been at an elevation of over 70 m and the coastline about 5 km away. After this rise, the elevation was about 10 m, the coastline was near to its present position and drainage would have been more sluggish. The altered hydrologic environment probably initiated the establishment of Jibbon Swamp.

The hydrologic regime suggests that the early Holocene climate was wetter and the mid-late Holocene drier, but this trend is slight and hardly registers in the less sensitive sclerophyllous vegetation.

These results are in general accord with other sites in the Sydney Basin: a wetter early Holocene and a drier late Holocene, but with no consistent trends in the latter. However, Jibbon and two other coastal sites suggest that changing sea levels may have had some influence on hydrology and hence the observed palynology, particularly of the swamp environment.

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Appendix

Jibbon Lagoon check list of species found in1983. For location of plant communities, see Fig. 5. D, dominant, +, present in the community, * introduced species. For authority of species, see NSW Flora Online (2011).

Plant communities:

1. *Cupaniopsis* Forest
2. *Angophora costata*/*Corymbia gummifera* Forest
3. *Angophora costata*/*Eucalyptus botryoides* Forest
4. *Banksia ericifolia*/*Persoonia lanceolata* Scrub
5. *Leptospermum laevigatum*/*Melaleuca nodosa* Scrub
6. *Banksia serrata*/*Xylomelum pyriforme* Scrub
7. *Leptospermum laevigatum* Heath
8. *Melaleuca nodosa* Heath
9. *Angophora costata/Corymbia gummifera/Eucalyptus sieberi* Mallee Heath
10. *Allocasuarina distyla/Banksia serrata* Heath
11. *Leptocarpus tenax* Sedgeland
12. Open Herbfield
13. *Baumea teretifolia* Sedgeland.

Plant formation		Forest			Scrub			Heath				Sedge/herb	
Plant community	1	2	3	4	5	6	7	8	9	10	11	12	13
Species													
Pteridophytes													
Adiantaceae													
Pellaea fastigata var. *fastigata*	+												
Dicksoniaceae													
Calochlaena dubia			+										
Gleicheniaceae													
Gleichenia microphylla												+	
Sellaginaceae													
Sellaginella uliginosa											+		
Angiosperms: Dicotyledons													
Asclepiadaceae													
Marsdenia flavescens	+												
Asteraceae													
Arrhenechthites mixta	+												
Erigeron karvinskianus	+												
Senecio bipinnatisectus	+												
Caryophyllaceae													
Stellaria media													
Casuarinaceae													
Allocasuarina distyla					+	D			D	D			
Casuarina glauca													+
Chenopodiaceae													
Rhagodia candolleana subsp. *candolleana*	+												

Plant formation	Forest			Scrub			Heath				Sedge/herb		
Plant community	1	2	3	4	5	6	7	8	9	10	11	12	13
Dilleniaceae													
Hibbertia monogyna					+								
H. scandens	+		+										
H. serpyllifolia										+			
Droseraceae													
Drosera peltata					+								
D. spathulata											+	+	
Elaeocarpaceae													
Elaeocarpus reticulatus	+												
Ericaceae													
Astroloma pinifolium										+			
Brachyloma daphnoides										+			
Epacris longiflora				+									
E. microphylla				+									
Leucopogon ericoides		+				+				+			
Lissanthes strigosa										+			
Monotoca elliptica			+	+	+								
Styphelia viridis													
Euphorbiaceae													
Amperea xiphoclada		+											
Breynia oblongifolia	+		+										
Ricinocarpos pinifolius						+				+			
Poranthers corymbosa										+			
Fabaceae: Faboideae													
Aotus ericoides						+				+			
Bossiaea heterophylla		+											
B. scolopendria		+								+			
Dilwynia retorta var. *retorta*					+								
Gompholobium glabratum									+	+			
Hardenbergia violaceae		+											
Oxylobium cordifolia										+			
Sphaerolobium vimineum													+
Fabaceae: Mimosoideae													
Acacia decurrens		+								+			
A. longifolia		+							+				
A. suaeveolens		+											
A. terminalis										+			
A. ulicifolia		+											
Goodeniaceae													
Goodenia paniculata											+		

Plant formation	Forest			Scrub			Heath				Sedge/herb		
Plant community	1	2	3	4	5	6	7	8	9	10	11	12	13
Haloragaceae													
Gonocarpus micranthus ssp. micranthus											+		
G. teucriodies										+			
Menispermaceae													
Stephania japonica var. discolor	+												
Moraceae													
Ficus oblique	+												
F. rubiginosa	+												
Myrtaceae													
Acmena smithii	D												
Angophora costata		D	D						D				
Callistemon rigidus				D									
Corymbia gummifera		D	D						D				
Darwinia fascicularis ssp. fascicularis				+	+								
Eucalyptus botryoides	D		D										
E. sieberi									D				
Kunzea ambigua				D									
Leptospermum laevigatum			D		D	+	D		+	+			
L. juniperinum										+			
L. polygalifolium ssp. *polygalifolium*		+											
L. trinervium									+				
Melaleuca armillaris		+											
M. nodosa				D	D	+		D	D	+			
M. thymelifolia													+
Oleaceae													
Notelaea longifolia	+		+										
Proteaceae													
Banksia ericifolia				D	+								
B. integrifolia	+	+	+							+			
B. marginata						+			+	+			
B. serrata		+	D			D	+	D	D	D			
Conospermum ellipticum						+							
Grevillea sphacelata		+			+					+			
Hakea dactyloides						+			D	+			
H. sericea						+							
Isopogon anemonifolius					+	+			+	+			
Lambertia Formosa									D	+			
Persoonia lanceolata		+		D		+			+	+			
Petrophile pulchella					+	+			+	+			
Xylomelum pyriforme		+				D			+	+			

Plant formation	Forest			Scrub				Heath			Sedge/herb		
Plant community	1	2	3	4	5	6	7	8	9	10	11	12	13
Rhamnaceae													
Cryptandra amara									+	+			
Rutaceae													
Acronychia oblongifolia	+												
Boronia ledifolia					+	+			+	+			
B. parviflora					+				+	+		+	
Phebalium squamosum ssp. *argentum*													
Philotheca buxifolia										+			
Santalaceae													
Leptomeria acida			+										
Sapindaceae													
Cupaniopsis anacardiodes	D												
Solanaceae													
**Cestrum parqui*	D												
**Solanum linnaeanum*	+												
S. stelligerum	+												
Sterculiaceae													
Lasiopetalum ferrugineum						+				+			
Thymeliaceae													
Pimelea linifolia										+			
Apiaceae										+			
Actinotus helianthi										+			
Xanthosia pilosa													
Hydrocotyle acutiloba	+												
Violaceae													
Viola sieberiana												+	
Angiosperm: Monocotyledons													
Anthericaceae													
Thysanotus tuberosus											+		
Asparagaceae													
Asparagus aethiopicus	D												
A. plumosus	D												
Cyperaceae													
Baumea juncea													+
B. teretifolia													D
Chorizandra sphaerocephala													D
Caustis pentandra						+				+			+
Eleocharis sphacelata													+
Lepidosperma concavum		+					D			+			
Leptocarpus tenax											D		
Schoenus brevifolius											+		
Scirpus nodosus											+		

Plant formation		Forest			Scrub				Heath			Sedge/herb	
Plant community	1	2	3	4	5	6	7	8	9	10	11	12	13
Haemodorum sp										+			
Iridaceae													
Patersonia glabrata									+				
P. sericea									+				
Juncaginaceae													
Triglochin procera													+
Luzuriagaceae													
Eustrphus latifolius	+												
Geitonoplesium cymosum	+												
Phormiacaeae													
Dianella caerulea		+	+										
Poaceae													
Anisopogon avenaceus											+		
Cynodon dactylon												+	
Eragrostis brownii												+	
Imperata cylindrica	+												
Poa sp.	+												
Tetrarrhena juncea											+		
Themeda australis												+	
Restionaceae													
Hypolaena fastigata									+	+			
Leptocarpus tenax											D		
Lepyrodia scariosa				+									
Smilacaceae													
Smilax glyciphylla		+	+										
Xanthorrhoeaceae													
Lomandra glauca								+					
L. longifolia	+	D							+				
Xanthorrhoea resinosa ssp. *resinosa*		+								+			