

An Expanded Recent Pollen Database from South-eastern Australia and its Potential for Refinement of Palaeoclimatic Estimates

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Abstract

Seventy-one pollen spectra from prior to the period of European impact were extracted from fossil pollen diagrams on mainland south-eastern Australia in 1991 to use as a modern reference for refinement of vegetation and climatic histories constructed from the region. This paper presents results of an extension of this recent database to 135 spectra, derived from additional fossil pollen sites on the mainland and also from sites in Tasmania. The sites include those of almost all late Quaternary pollen studies ever undertaken. Estimates of climate for each site, derived by BIOCLIM, have allowed an examination of patterns of representation of individual recorded taxa in relation to regional variation in major climatic parameters. Pollen taxa show variable representation in relation to their inferred presence and abundance in parent vegetation due to differential pollen production and dispersal characteristics. However, patterns of pollen representation do appear to relate, in broad terms, to climatic variation. It is considered that this modern pollen and climate database should lead to more certain interpretation of future pollen records including some quantification of palaeoclimatic conditions.

Introduction

Pollen analysis is a major technique used in the reconstruction of past climates within south-eastern Australia. The accuracy of the reconstructions depends on relating fossil assemblages to the vegetation and climate from which they were derived. The vegetation can be inferred from the nature and distribution of present-day communities but, because of the variables involved in the production of pollen assemblages from parent vegetation, these reconstructions tend to be very generalised and sometimes misleading. Refinement of interpretation can be achieved by the collection of modern pollen assemblages from different communities and comparing these directly with the fossil assemblages. If the climatic conditions of the modern assemblages are known, then direct comparisons between the modern and fossil assemblages can allow the development of transfer functions which provide estimates of past climatic conditions.

More than 130 pollen diagrams have been constructed for south-eastern Australia, but there have been few systematic studies on modern pollen deposition to provide a firm basis for detailed interpretation of them. Recently, a pollen database was constructed for part of the region from recent samples taken from the topmost sections of existing pollen diagrams in an attempt to redress this imbalance (Kershaw *et al.* 1994). These samples have the limitation of not being from defined communities, which restricts their usefulness for detailed vegetation reconstruction, but have the advantage of relating most closely to the environments of deposition of fossil samples. The use of the climatic prediction system BIOCLIM (Busby 1991) to estimate the climate at each sample site, provides a basis for detailed and quantitative determinations of past climates from fossil assemblages.

The recent samples were taken from the very tops of the fossil records and from just beneath the first evidence for European settlement, indicated by the presence of exotic pollen. A comparison of these indicated that the pre-European samples reflect the general natural

vegetation and climate of the area better than the modern samples, because of the degree of disturbance to the vegetation within the last 100 years or so (Kershaw *et al.* 1994; Kershaw and Bulman 1996). The pre-European samples have been used in a preliminary application to the refinement of interpretation of one pollen diagram from the region (Kershaw and Bulman 1996).

This paper presents results from an extended recent database for the region, incorporating information from virtually all pollen diagrams from south-eastern mainland Australia and Tasmania, and examines the spatial patterns of pollen taxa in relation to major climatic variables. Following the preferred sample set of the restricted data set, it looks at only the pre-European settlement pollen spectra. It is hoped that the data presented here will provide a starting point for interpretation of new records from the region and also the re-interpretation of existing records. The database as a whole is available in EXCEL format on the World Wide Web (<http://www.geography.monash.edu.au>) under the Centre for Palynology and Palaeoecology section of the entry for the Department of Geography and Environmental Science, Monash University, or directly from the Centre. This will allow greater interrogation of the data in relation to additional bioclimatic parameters, which will hopefully lead to more refined reconstruction of palaeoclimates from pollen data.

Materials and Methods

Pollen Sites

The original database included pre-European spectra from 71 sites in Victoria and adjacent parts of South Australia and New South Wales. The diagrams of a further 10 sites in Victoria and 2 sites in New South Wales have become available since this time and have been included in this analysis. Pre-European pollen spectra have also been extracted from all available late Quaternary pollen records that extend to the present day from Tasmania and the Bass Strait Islands. This has added a further 52 sites to the database, although 5 sites have been excluded from analysis. This has been done on the grounds that: (i) sample resolution was too coarse to allow determination of a clear phase prior to European impact; (ii) available data were incomplete or (iii) that samples were from archaeological cave sites where processes of pollen transport, deposition and preservation may have differed from more open, waterlogged sites. The location of the 135 sites is shown in Fig. 1 in relation to the distribution of major structural vegetation types, and selected isohyets whilst some features of the sites, including climatic estimates generated by BIOCLIM, are listed in the Appendix. The sites are ordered on a west-east longitudinal basis.

The Regional Setting

The south-eastern Australian mainland is influenced by eastward progression of high pressure systems which result in a winter wet temperate climate with generally warm to hot summers and mild winters over most of the region, whilst Tasmania experiences a similar, but more maritime climate. Higher rainfalls are experienced in the upland, eastern part of the mainland due to the failure of low pressure systems that bring rain to the eastern part of the mainland to extend their influence westward. Consequently, the west is drier with rainfall steadily diminishing inland from the coast with outliers of orographically induced rainfall centred on the Otway and Grampian Ranges (Australian Surveying and Land Information Group 1986).

The Western Highlands and Central Plateau of Tasmania intercept moisture-bearing, eastward-moving low pressure systems resulting in a strong precipitation gradient across individual mountains and across Tasmania as a whole (Bureau of Meteorology 1988).

A large range of structural vegetation types (Specht 1970) are present in the region (Australian Surveying and Land Information Group 1990). Areas with more than 800 mm rainfall per annum, located predominantly in western Tasmania and eastern parts of the South-eastern Highlands, are dominated by sclerophyll evergreen forests with *Eucalyptus* species, in the main, forming the canopy. These forests are divided into wetter tall open forest (= wet sclerophyll forest) that characteristically have tree heights in excess of 30 m, with an understorey of mesomorphic trees or shrubs, and drier, open forests (= dry sclerophyll forests) of lower stature with an understorey of xeromorphic shrubs and herbs. Closed forest, most commonly dominated by the cool temperate forest species, *Nothofagus cunninghamii*, exists in the wettest areas, usually as patches confined to sheltered, moist and

Elsewhere, drier, open forests merge into woodlands with a predominantly grassy understorey where rainfall decreases to below 1000–700 mm. Eucalypts again dominate, although *Casuarina*, *Acacia* and *Callitris* may be important canopy components in drier areas inland.

Natural tussock grasslands occur under annual rainfalls in the range of 400 to 600 mm and are associated with the basaltic plains of western Victoria and with drier, upland areas of New South Wales. Extensive areas of sedgeland dominated by *Gymnoschoenus sphaerocephalus*, occur in western Tasmania under higher rainfalls, and are largely associated with peaty, podzolic soils.

In drier parts of South Australia and north-western Victoria, Pleistocene dunes retain a predominantly tall shrubland cover, which is composed mainly of mallee eucalypts, while chenopodiaceous low shrublands dominate more saline areas.

Open scrubs and heaths, which are dominated by a range of taxa including non-eucalypt Myrtaceae and Proteaceae, are generally associated with coastal areas of Tasmania and Bass Strait Islands, whilst in Victoria and South Australia, they occur on very poor nutrient soils.

Distribution of Pollen Sites

The distribution of pollen sites is patchy, reflecting, to a large extent, the suitability of different environments for accumulation and survival of pollen-bearing sediments. The vast majority of sites receive more than 600 mm of rainfall annually. Site concentrations occur on the Western Plains of Victoria with its myriad volcanic craters, which often contain lakes and swamps and where basalt flows have disrupted pre-existing drainage patterns; in the highlands where high precipitation and low temperatures have combined to facilitate the development of bogs in topographically suitable areas; and along the coast, where dunes and estuaries have provided sedimentation sites, particularly since the attainment of the present sea level approximately 6000 years ago. Other sites have formed as meander cut-offs, spring seepages within river valleys, as a result of landslips and, in Tasmania and the Mount Kosciusko area, as a result of glaciation, in cirques or drainage dammed by moraines. High rainfall and low temperatures in Tasmania have given rise to blanket peats which are increasingly becoming the focus for palynological investigation. There are many wind-deflated hollows in north-western Victoria but, in these semi-arid environments, the ephemeral nature of the contained lakes is not conducive to long-term pollen preservation, except where there is a protective salt cover, as at Lake Tyrell. Overall, the sites cover a substantial climatic range with mean annual temperatures varying from 4.0 to 17.2°C and mean annual precipitation from 276 to 3225 mm.

The Pollen Samples

Pre-European pollen samples are an average of two or three adjacent samples from each core prior to the appearance of an identifiable exotic pollen type, usually *Plantago* (which is separated from native members of the genus on the presence of thickened pores), *Echium* or *Pinus*, and cover about 50–100 years in most cases. The time period depends on the sampling interval and rate of sediment accumulation.

Percentage pollen values from the original studies, which used a variety of different taxa as the basis of the pollen sum, were recalculated to a percentage of a common pollen sum for all sites. Since reconstruction of regional vegetation and climate is the primary purpose of the database, taxa that reflect mainly or frequently local site conditions were excluded from the sum. These included the predominantly aquatic taxa, fern spores, Chenopodiaceae which can be grossly over-represented in salt marsh environments, and taxa such as Epacridaceae, *Tasmannia* and the myrtaceous shrubs *Melaleuca* and *Leptospermum* which, although essentially dryland plants, have very poor pollen dispersal and are only recorded in substantial numbers where they are marginal to, or encroach upon, mire surfaces. Minor taxa, whose representation would vary according to the size of the pollen count counts and the expertise of the analyst, were also excluded. This resulted in an eventual pollen sum for the original database of the following taxa: *Nothofagus*, *Podocarpus*, *Elaeocarpus*, *Eucalyptus*, Casuarinaceae, *Pomaderris*, *Acacia*, *Dodonaea*, *Banksia*, Poaceae, *Plantago* (native), Apiaceae (excluding *Hydrocotyle*), *Astelia* and Asteraceae (Tubuliflorae). *Phyllocladus*, and *Lagarostobos*, which have regional pollen dispersal and are restricted in their distribution to Tasmania, have been added to the pollen sum for this study, and percentages for all sites were recalculated on the basis of this new sum. Information on the production and dispersal characteristics of most of the taxa recorded is listed by Dodson (1983) and some information for Tasmanian taxa is provided by Macphail (1979).

Results and Discussion

Relationships between Pollen, Vegetation and Climate

Values for all taxa within the pollen sum are graphed along temperature and precipitation gradients in Figs 2a and 3a respectively, whilst values for taxa outside the pollen sum are presented in Figs 2b and 3b along the same gradients. These representations of site data allow an examination of pollen variation in relation to climate that can provide some assessment of the potential value of pollen for palaeoclimatic reconstruction within the region.

Most taxa display a preference for parts of the annual temperature and precipitation gradients that could be predicted from a knowledge of the ecology and distribution of source plants. The most useful taxa are those which are identifiable to a refined taxonomic level. Many of these are restricted to cool temperate rainforests and adjacent tall open forests and subalpine communities. They include: *Nothofagus cunninghamii*, *N. gunnii*, *Microstrobos*, *Microcachrys*, *Phyllocladus*, *Lagarostrobos*, *Agastachys*, *Eucryphia–Anodopetalum*, *Lycopodium* and *Astelia*. They are largely confined to the cooler, wetter end of the gradients, although they show interesting variation in their representation. Some of these taxa, particularly *N. cunninghamii* and to a lesser extent *Phyllocladus*, have broad representation outside their areas of occurrence. This is probably due to a combination of their relative abundance in the vegetation and their broad pollen dispersal ability. A number of sites existing under drier and warmer conditions have significant representation of rainforest taxa due to stream transport of pollen from higher altitude source areas. For most taxa this does not pose a problem, as highest values are clearly related to the distribution of source plants, but may be significant in the case of the tree ferns, *Cyathea* and *Dicksonia*, which are concentrated along streams and whose spores are noted for their transport by water (Crowder and Cuddy 1972). Obvious care must be exercised in interpreting fossil pollen spectra from sites which have a connection with rivers or streams.

There are few identified taxa that are mainly restricted to warmer and drier environments. Major reasons for this are that many plants in these environments do not rely on wind as a pollen dispersal mechanism, and major components of the vegetation contain a number of species whose pollen is not easily separated. The Chenopodiaceae, when present in abundance, most clearly characterise the warmer and drier ends of the ranges but, like *N. cunninghamii*, have broad pollen dispersal. Unlike the rainforest species, there is little problem with water transport from the drier part of the continent where most of the Chenopodiaceae pollen is obviously derived. However, the plant can have local representation in wetter environments, particularly where there is a marine influence. The aquatic taxa, *Ruppia* and *Myriophyllum muelleri*, are more clearly confined to the driest environments, but their value as climatic indicators is limited by their sporadic occurrences. *Typha* and Gyrostemonaceae have a similar though less restricted distribution. *Casuarina* shows a marked preference for the drier and warmer environments despite the inclusion of a variety of species covering a range of environments. Again, part of the reason for its pollen representation is the absence of many other wind-pollinated taxa in drier areas, although there are woodlands dominated by this genus in drier areas. It is also clear from the comparison of modern and pre-European spectra (Kershaw *et al.* 1994) that the abundance of parent plants used to be higher in these areas and the taxon has suffered much more than other identified taxa, particularly *Eucalyptus* and Poaceae, as a result of European activities. *Acacia* is found in drier and warmer sites, although considering the abundance of source plants the genus is grossly under-represented along the whole transect. Other taxa showing a preference include *Plantago* and the bracken fern, *Pteridium*.

One taxon with a rather surprising representation is *Sphagnum*. Despite the fact that source plants are most evident within cool, high altitude, raised bogs, sites which are well-represented in the data set, high spore percentages for this taxon are largely restricted to the middle of both temperature and rainfall gradients. A suspected reason for this is that

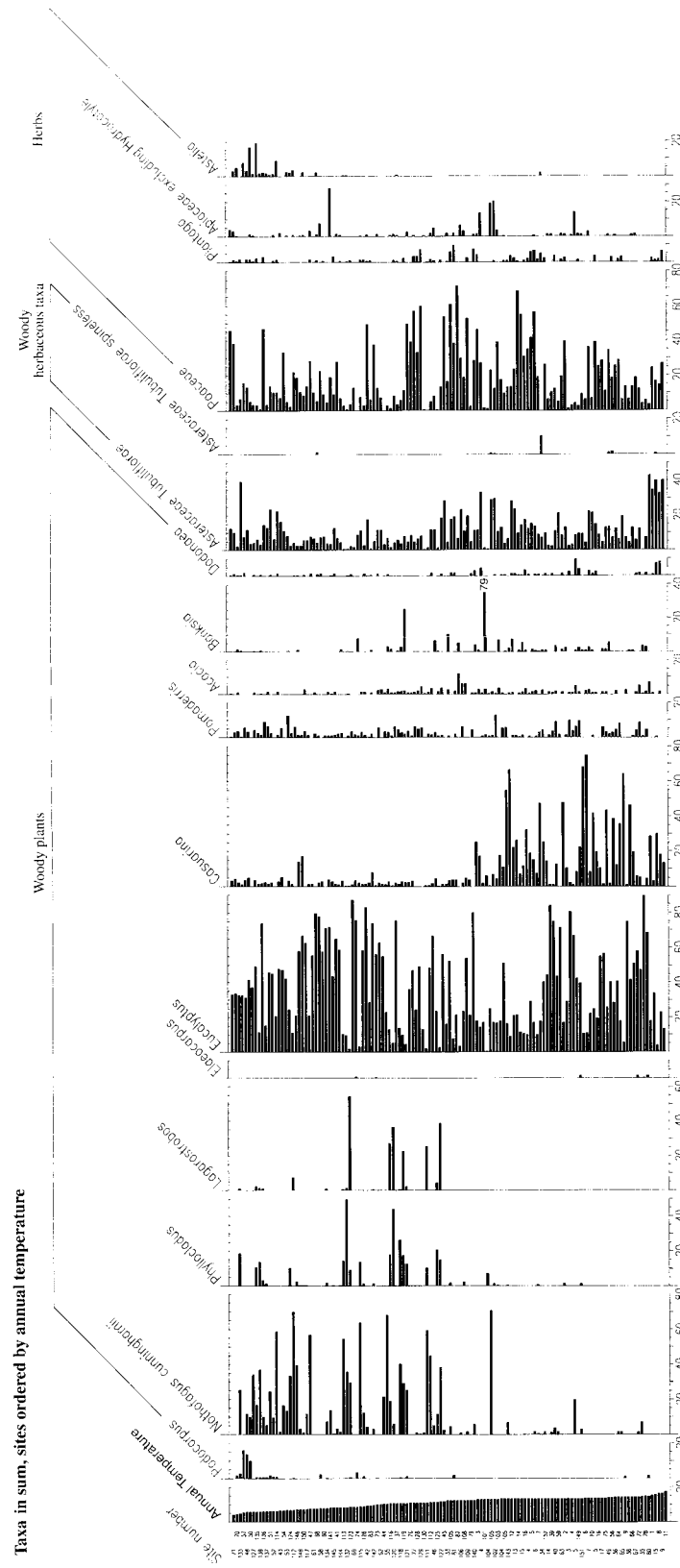


Fig. 2. (a) Percentages of those taxa composing the pollen sum from pre-European spectra of south-eastern Australian pollen diagrams, ordered along the gradient of mean annual temperature.

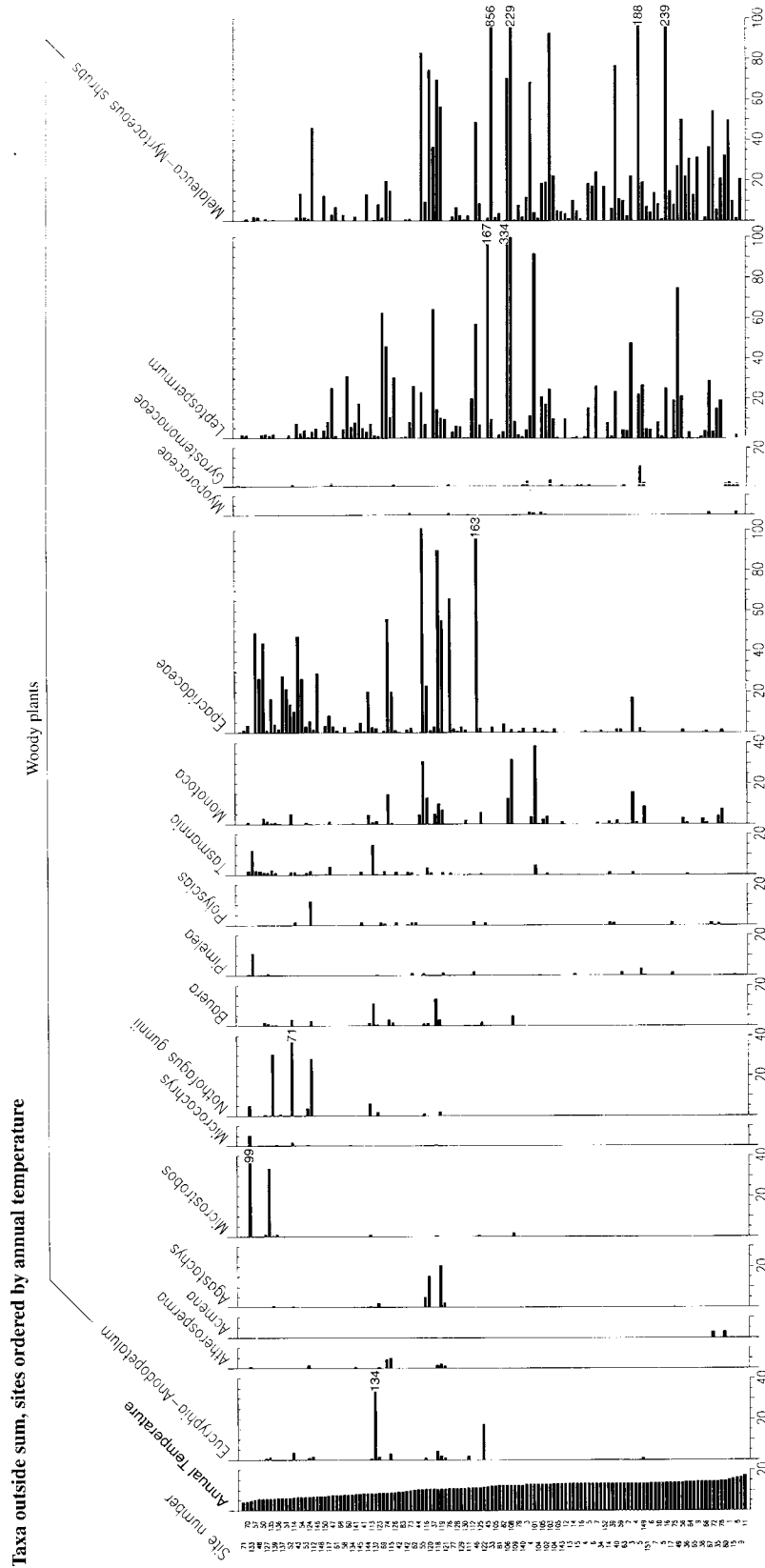


Fig. 2. (b) Percentages of those taxa excluded from the pollen sum for pre-European spectra of south-eastern Australian pollen diagrams, ordered along the gradient of mean annual temperature.

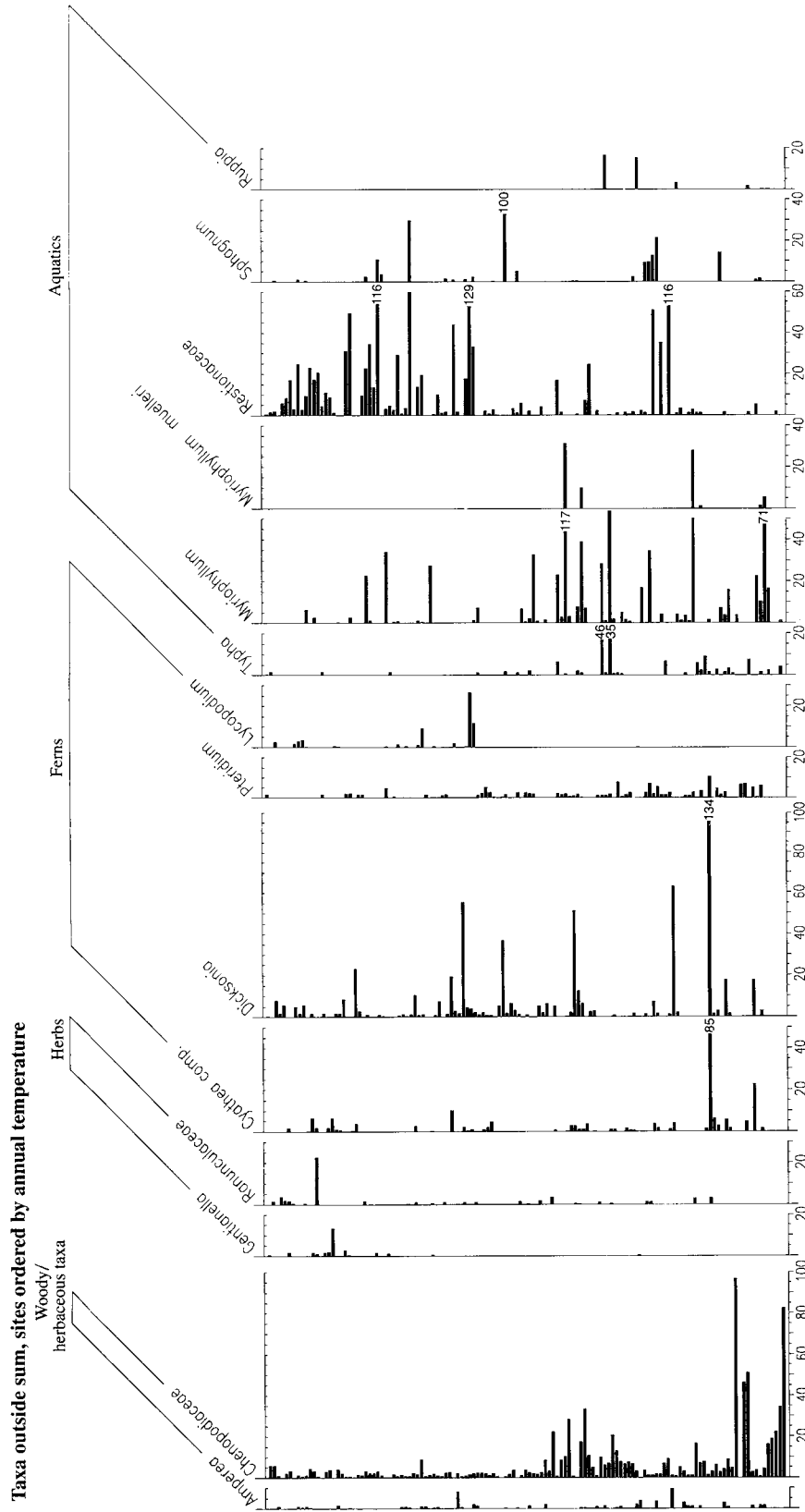


Fig. 2. (b) (continued)

reproduction is mainly by vegetative means under 'optimal' conditions, and that substantial sporing is caused by increased temperatures and perhaps drought stress in areas where survival is possible outside of these environments (Gell *et al.* 1993). There are few other taxa which characterise these mid-ranges. *Banksia* and *Monotoca* show a tendency to peak in the mid-range for temperature, but their precipitation ranges are more bimodal. This suggests domination of the taxa by two major species or groups of species. By contrast, the distribution of Apiaceae, generally peaking around the middle of the precipitation gradient, breaks up along the temperature gradient.

As expected, three of the most universal regional taxa, *Eucalyptus*, Poaceae and Asteraceae, have high values at many of the sites and clear patterns are difficult to discern. Percentages for *Eucalyptus* are most consistently high, for rainfall, in the mid- to high-range where eucalypt open and tall open forest predominate. Values decrease in drier environments where there is a much more open canopy, even if composed of eucalypts, and in the highest rainfall areas where rainforest patches are most continuous. With temperature, percentages are generally highest towards, but not at the temperature extremes, and lowest in the centre where there are very high Poaceae values. Many of these sites relate to open communities like the Western Plains of Victoria and the western slopes of the South-eastern Highlands, where edaphic factors contribute a sparsity of trees and a continuous understorey of grasses. Although the Poaceae curve tends to mirror that for *Eucalyptus* along the temperature gradient, this is not the case for precipitation. Poaceae values are consistently low at sites receiving high rainfall, but very variable elsewhere. Asteraceae has a complex pattern of distribution, reflecting its ecological and structural diversity. Values are most consistently high in the driest and warmest sites, where climatic variability combined with a more open landscape produces environments most favourable for opportunistic herbs and small shrubs. There is a second peak in the mid-temperature range which partially corresponds to that of Poaceae and many sites are from the grass-dominated, edaphically influenced woodlands. Other sites within this peak are from tall open forests where small-treed Asteraceae contribute to a distinctive understorey. This type of vegetation is clearly identified in the Asteraceae peak towards the wetter end of the precipitation gradient. The relatively high values of Asteraceae at the cool end of the temperature gradient derive largely from the open subalpine to alpine vegetation. Although grasses are also well-represented in these environments, their pollen response is not marked.

By contrast to Asteraceae and *Eucalyptus*, which provide some guide to the occurrence of tall open forests, the more obvious indicator of this vegetation type, *Pomaderris* (identified as *P. aspera-apterala*), and one which has been widely used to indicate tall open forest expansion in the early to mid Holocene (Macphail 1983) shows poor correspondence with its source vegetation. The spread of the taxon along both gradients is indicative of broad pollen dispersal and probably the poor representation of lower altitude tall open forest environments around the pollen sites.

The four major taxa outside the pollen sum which have substantial representation in both swamp and dryland environments are the myrtaceous shrubs *Leptospermum* and *Melaleuca*, and Epacridaceae and Restionaceae. Their extreme variability in representation indicates that their value as indicators is limited to local aquatic environments. All of these taxa, except *Melaleuca*, virtually die out towards the warmer ends of the ranges despite the good representation of these taxa in the extensive heath and shrublands of north-western Victoria. Both *Melaleuca* and *Leptospermum* have very low values within the low temperature records where sites are often dominated by Restionaceae and Epacridaceae.

Potential for Quantification of Palaeoclimates

Despite the variability of taxon representation along the climate transects, it is possible to identify temperature or precipitation threshold levels for many taxa that could impose

maximum or minimum climatic values on fossil spectra. A number of identified thresholds, from the representation of those taxa where sufficient data are considered available, are listed in Table 1. Furthermore, the superimposition of a number of such thresholds could provide climatic envelopes within which the true values for climatic parameters would lie. The thresholds identified in this study are in accordance with the bioclimatic profiles that have been generated for some Tasmanian taxa (Busby 1986; J. Read, pers. comm.), and provide validation of the methodology applied here. The use of additional climatic parameters calculated by BIOCLIM would allow assessment of seasonal variation in addition to simply annual means as illustrated here.

More refined palaeoclimatic estimates might be generated by spectrum rather than individual taxon comparisons. The modern analogue approach (Overpeck *et al.* 1985), of deriving palaeoclimatic estimates from the statistically most similar modern spectra to each fossil spectrum, achieved a degree of success from an application of the restricted recent pollen data set to the Northwest Crater pollen record (Kershaw and Bulman 1996). Some interesting insights into the nature of climatic change through the Holocene was achieved, although significant differences between some fossil spectra and the range of variation within the recent spectra prohibited quantitative estimates to be made with any confidence. This extended data set may provide the necessary increase in range in variation if, in fact, there are modern analogues for past vegetation associations and palaeoclimates. If this analogue approach is successful, then further refinements of palaeoclimatic estimates might be attempted by the application of more rigorous quantitative methods of comparison which have had success in some other parts of the world, notably Europe and North America (e.g. Webb 1980; Bartlein *et al.* 1986; Guiot 1990).

Conclusions

This extended recent pollen database provides a firmer framework for interpretation of fossil pollen records within the south-eastern Australian region. It illustrates that there is substantial variability in representation of pollen taxa along major climatic gradients, but that

Table 1. Threshold pollen percentages for precipitation and temperature values from selected taxa

Taxa	% Recorded	Average annual rainfall (mm)	% Recorded	Average annual temperature (°C)
<i>Podocarpus</i>	> 5	> 1500	> 3	> 5.7
<i>Nothofagus cunninghamii</i>	Trace–10	> 1200		
	>10 to < 20	> 1600	> 20	< 11.7
	>20	> 2000		
<i>Phyllocladus</i>	Trace–10	> 1500		
	> 10	> 1800		
<i>Lagarostrobos</i>	> 5	> 2400	> 10	8.6–11.7
<i>Eucalyptus</i>	> 60	< 900		
<i>Casuarina</i>	< 5	< 1000	< 5	< 13.0
Asteraceae	Greater than	> 650	Greater than	
Tubuliflorae	Poaceae values		Poaceae values	> 14.3
<i>Astelia</i>	> 3	> 1300	> 3	< 7.5
<i>Agastachys</i>	> 3	> 2400	> 3	> 10.7
<i>Gentianella</i>	> 1	> 1450	Any	< 9.5
<i>Lycopodium</i>	> 1	> 1450	Any	< 10.7
Epacridaceae	> 25	> 1500	> 25	< 12
<i>Myriophyllum</i>	> 5	< 1250		

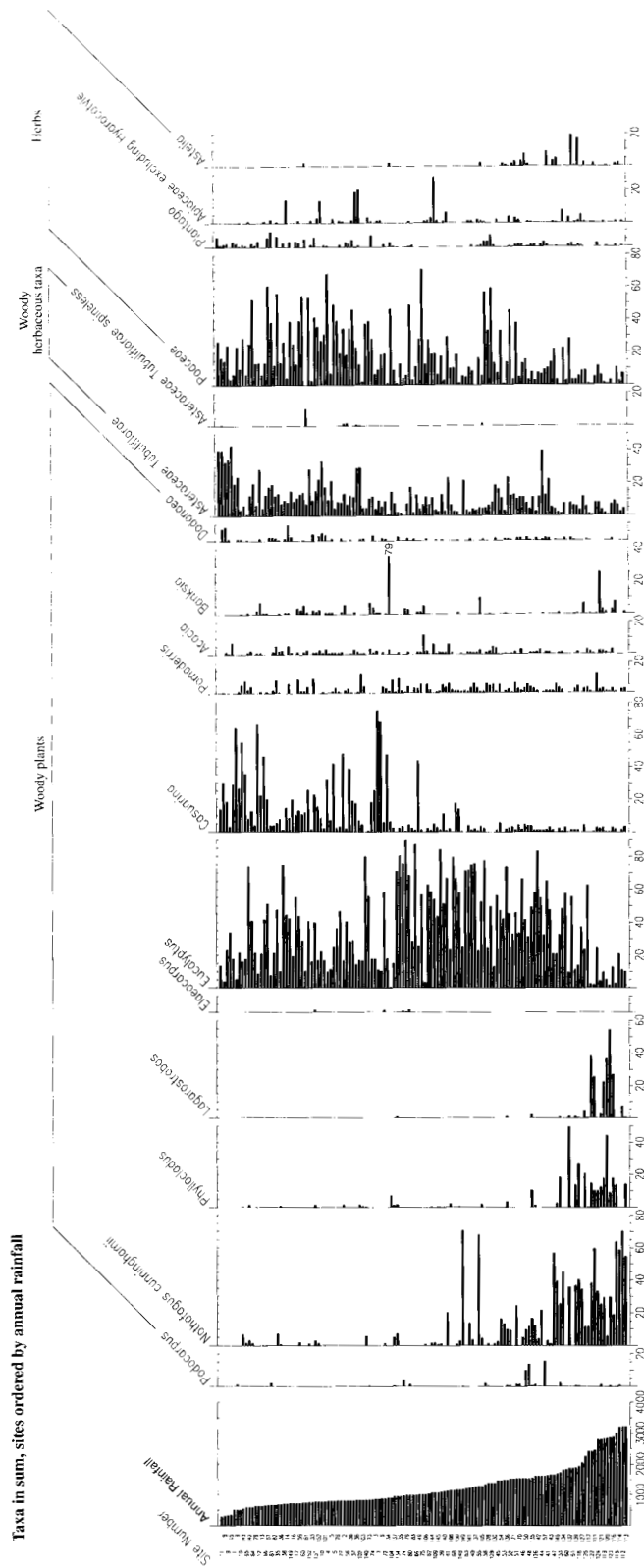


Fig. 3. (a) Percentages of those taxa composing the pollen sum from pre-European spectra of south-eastern Australian pollen diagrams, ordered along the gradient of mean annual precipitation.

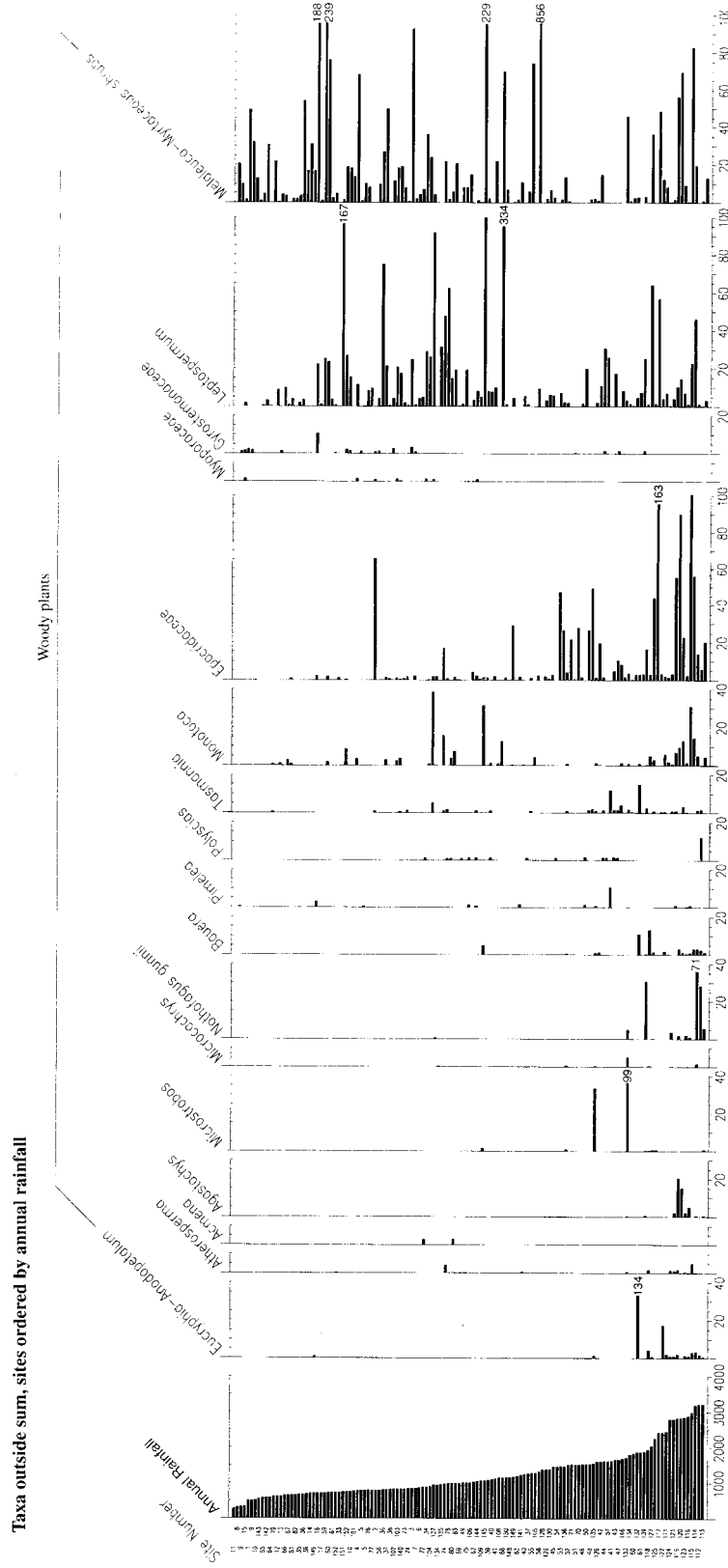


Fig. 3. (b) Percentages of those taxa excluded from the pollen sum for pre-European spectra of south-eastern Australian pollen diagrams, ordered along the gradient of mean annual precipitation.

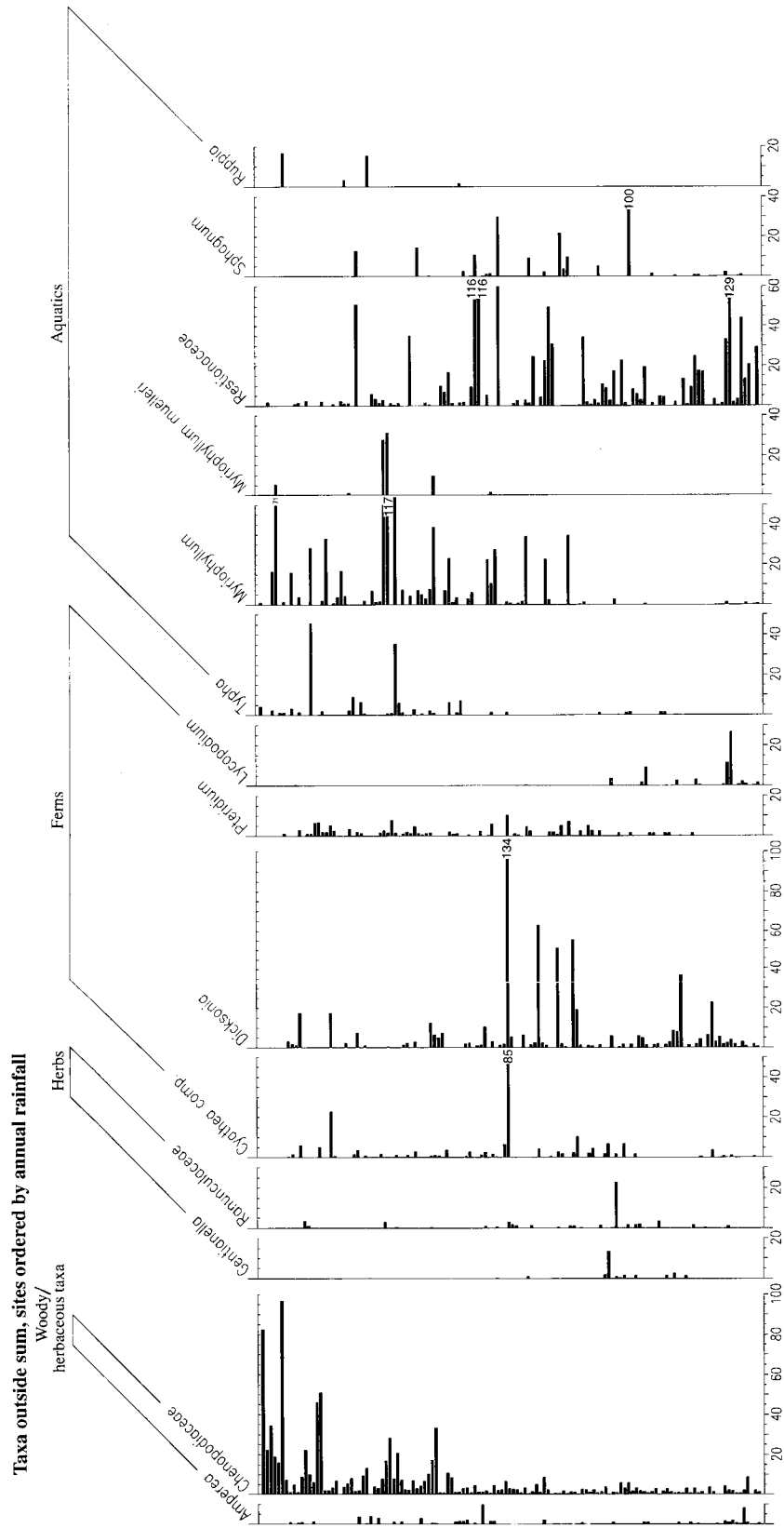


Fig. 3. (b) (continued)

there are clear trends in many taxa which can be related to their occurrence within the vegetation. The degree to which realistic quantitative estimates of past climates can be derived from the data remains to be determined.

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Appendix. Location and environmental features of pollen sites used in this study
 Mainland sites (1–83) and Tasmanian sites (101–152) are ordered from west to east respectively

Site no.	Site name	Lat. (S)	Long. (E)	Alt. (m)	Precip. (mm)	Temp. (°C)	Site type	Regional native vegetation	References
1	Lashmar's Lagoon	35° 46'	138° 04'	2	501	15.2	Intertune lake	Open woodland	Clark 1976
2	Mt Burr	37° 37'	140° 32'	80	804	13.6	Sinkhole swamp	Open forest	Dodson 1975a
3	Lake Leake	37° 39'	140° 35'	200	854	13.0	Crater lake	Woodland	Dodson 1974b, 1975b
4	Mt Gambier (Blue Lake)	37° 50'	140° 45'	100	781	13.4	Crater lake	Open forest	Salas and Kershaw 1982
5	Long Swamp	38° 05'	141° 05'	2	798	13.8	Backdune swamp	Open forest	Head 1988
6	Boomer Swamp	38° 13'	141° 18'	9	869	13.7	Intertune swamp	Woodland	Head 1988
7	Bridgewater Lakes	38° 18'	141° 23'	20	859	13.7	Sinkhole lake	Woodland	Head 1988
8	Lake Crosby	35° 03'	141° 44'	40	309	16.3	Salt lake	Tall shrubland	M. McKenzie, unpub. data
9	Jaka Lake	36° 48'	141° 48'	140	501	14.3	Salt lake	<i>Casuarina</i> woodland	M. McKenzie, unpub. data
10	Lake Condah	38° 04'	141° 50'	60	760	13.7	Basalt dammed lake	Open woodland	Head 1989
11	Lake Ranfurly E	34° 11'	142° 07'	40	276	17.2	Salt lake	Shrubland	M. McKenzie, unpub. data
12	Salt Lake	37° 35'	142° 19'	220	631	13.3	Salt lake	Open forest-woodland	M. McKenzie, unpub. data
13	Freshwater Lake	37° 35'	142° 19'	220	631	13.3	Basalt dammed lake	Open forest-woodland	Kershaw and M. McKenzie, unpub. data
14	Sheet of Water	37° 10'	142° 21'	240	700	13.5	Headwater Swamp	Open forest	M. McKenzie, unpub. data
15	Lake Lascelles	35° 43'	142° 22'	80	345	15.7	Ephemeral lake	Open scrub-heath	M. McKenzie, unpub. data
16	Tower Hill Lake	38° 19'	142° 22'	20	721	13.8	Crater lake	Open forest-woodland	D'Costa <i>et al.</i> 1989
17	Northwest Crater	38° 19'	142° 22'	20	721	13.8	Crater swamp	Open forest-woodland	D'Costa <i>et al.</i> 1989
18	Lake Cartcarong	38° 15'	142° 27'	75	727	13.6	Crater lake	Open woodland	R. Walkley, unpub. data
19	Lake Wangoom	38° 21'	142° 36'	100	810	13.4	Crater swamp	Open woodland	Edney <i>et al.</i> 1990
20	Lake Turangmoroke	37° 42'	142° 45'	220	516	13.3	Salt lake	Open woodland-grassland	Crowley and Kershaw 1994
21	Lake Tyrrell	35° 15'	142° 52'	17	319	16.4	Salt lake	Open scrub-heath	Luly 1993
22	Lake Keilambete	38° 13'	142° 53'	120	759	13.4	Crater lake	Open woodland	Dodson 1974a
23	Lake Terang	38° 15'	142° 54'	130	796	13.3	Crater swamp	Open woodland	D'Costa 1989
24	Cobrico Swamp	38° 18'	143° 02'	140	847	13.2	Crater swamp	Open forest-woodland	Yezdani 1970
25	Lake Gnotuk	38° 13'	143° 06'	200	820	13.0	Crater lake	Open woodland-grassland	Yezdani 1970
26	Lake Purrembete	38° 16'	143° 13'	140	746	13.3	Crater lake	Open woodland-grassland	D. A. Penny, unpub. data
27	Chapplevale	38° 38'	143° 19'	29	968	13.6	Meander cut-off	Tall open forest	McKenzie and Kershaw, unpub. data
28	West Basin	38° 19'	143° 27'	110	689	13.4	Crater lake	Open woodland-grassland	Gell <i>et al.</i> 1994

Appendix. (continued)

Site no.	Site name	Lat. (S)	Long. (E)	Alt. (m)	Precip. (mm)	Temp. (°C)	Site type	Regional native vegetation	References
29	Aire Crossing	38° 44'	143° 27'	100	1178	13.1	Meander cut-off	Closed forest	M. McKenzie, unpub. data
30	Wyelangta	38° 39'	143° 28'	450	1814	11.3	Meander cut-off	Closed forest	M. McKenzie, unpub. data
31	Lake Hordern	38° 47'	143° 28'	3	1126	13.6	Estuarine lake	Tall open forest	Head and Stuart 1980
32	Carlisle Perched Lake	38° 33'	143° 24'	70	1111	13.2	Perched lake	Tall open forest	Bottomley 1994
33	Bolobek peatland	37° 26'	144° 36'	440	751	12.3	Basalt dammed swamp	Open woodland-grassland	Centre for Palynology and Palaeobotany, Monash Uni. Jenkin 1992
34	Greens Bush	38° 26'	144° 56'	160	895	13.4	Interdune swamp	Open woodland	Jenkin 1992
35	Willmere Billabong	37° 47'	145° 03'	20	677	14.6	Meander cut-off lake	Woodland	McNess 1988
36	Tiger Snake Swamp	38° 07'	145° 16'	60	808	14.2	Interdune swamp	Woodland	Aitken and Kershaw 1992
37	Poley Creek	37° 30'	145° 25'	750	1270	10.7	Valley swamp	Tall open forest-open forest	Pitcock 1989
38	Tamaranga Billabong	37° 09'	145° 29'	160	696	14.3	Meander cut-off lake	Forest	M. Reid, unpub. data
39	Buxton	37° 27'	145° 42'	235	1085	13.5	Valley bog	Open forest-tall open forest	M. McKenzie, unpub. data; McKenzie and Busby 1992
40	Powelltown	37° 52'	145° 42'	168	1251	13.5	Valley bog	Open forest-tall open forest	M. McKenzie, unpub. data; McKenzie and Busby 1992
41	Storm Creek	37° 27'	145° 48'	1177	1630	8.4	Valley bog	Open forest-tall open forest	McKenzie 1997
42	Tom Burns	37° 23'	145° 49'	1075	1609	9.2	Valley bog	Tall open forest	McKenzie 1997
43	Lake Mountain	37° 28'	145° 53'	1440	1660	6.5	Headwater bog	Subalpine woodland	McKenzie 1997
44	Snoobs Creek	37° 23'	145° 56'	930	1620	10.4	Valley bog	Tall open forest	McKenzie 1989; McKenzie and Busby 1992
45	Torbreck River	37° 29'	145° 57'	564	1466	11.8	Valley bog	Open forest	McKenzie 1989; McKenzie and Busby 1992
46	Oaks Creek	37° 35'	146° 10'	610	1535	11.3	Valley bog	Open forest	McKenzie 1989; McKenzie and Busby 1992
47	Thompson River	37° 45'	146° 05'	1250	1662	7.6	Valley bog	Tall open forest	K. M. Strickland, unpub. data
48	Baw Baw Village	37° 51'	146° 16'	1524	1542	5.7	Headwater bog	Subalpine woodland	Kershaw and Strickland 1990; K. M. Strickland, unpub. data
49	Cotter's Lake	38° 56'	146° 16'	4	1011	14.0	Interdune swamp	Open forest	Hope 1974
50	Baw Baw Track	37° 50'	146° 17'	1524	1540	5.7	Headwater bog	Subalpine woodland	K. M. Strickland, unpub. data
51	Mt Whitelaw	37° 49'	146° 17'	1448	1530	6.2	Valley bog	Subalpine woodland	K. M. Strickland, unpub. data
52	Mustering Flat	37° 48'	146° 18'	1448	1520	6.2	Headwater fen	Subalpine woodland	Kershaw and Strickland 1990; Strickland, unpub. data
53	Cascade Bog	37° 51'	146° 19'	1370	1474	6.7	Valley bog	Subalpine woodland	Strickland 1980

54	Mt Kernot	37° 52'	146° 20'	1372	1466	6.6	Headwater bog	Subalpine woodland	K. M. Strickland, unpub. data
55	Mt Latrobe	39° 01'	146° 22'	597	1282	10.5	Valley swamp	Closed forest-tall open forest	Howard and Hope 1970
56	Morwell Swamp	38° 15'	146° 25'	40	807	14.1	Coal firehole swamp	Open forest	Lloyd 1991
57	Stirling Moss	37° 08'	146° 30'	1650	1624	5.4	Deflation hollow	Subalpine woodland	M. McKenzie, unpub. data
58	Caledonia Fen	37° 20'	146° 45'	1280	1330	7.7	Basin fen	Open forest	Joyce 1989; Kershaw <i>et al.</i> 1983
59	McKenzie Road Bog	38° 26'	146° 46'	100	723	13.5	Interdune swamp	Open forest-woodland	Robertson 1986
60	Bunyip Bog	36° 47'	146° 46'	1330	1830	7.7	Valley bog	Subalpine woodland-open forest	Binder 1978; Binder and Kershaw 1978
61	Crystal Bog	36° 44'	146° 47'	1350	1873	7.6	Valley bog	Subalpine woodland	Williams 1982
62	Lake Tali Kamp	37° 35'	146° 50'	915	1035	10.1	Landslide lake	Open forest	Salas 1981
63	Tawonga Bog	36° 41'	147° 08'	350	1201	13.5	Valley bog	Open forest	Kershaw and Green, 1983
64	Lake Wellington	38° 06'	147° 18'	20	593	14.2	Dune dammed lake	Open forest-woodland	Reid 1989
65	Lake Coleman	38° 10'	147° 18'	20	584	14.2	Dune dammed lake	Open forest-woodland	Penny 1992
66	Loch Sport Swamp	37° 58'	147° 41'	1	652	14.3	Interdune swamp	Open forest-woodland	Hooley <i>et al.</i> 1980
67	Hidden Swamp	37° 58'	147° 42'	2	652	14.3	Interdune swamp	Open forest-woodland	Hooley <i>et al.</i> 1980
68	Lake Hill	37° 09'	147° 56'	1300	1159	7.6	Basin fen	Subalpine woodland	A. P. Kershaw and M. McKenzie, unpub. data
69	Moss Bed Lake	37° 07'	148° 04'	1170	997	8.7	Basin fen	Open forest	A. P. Kershaw and M. McKenzie, unpub. data
70	Blue Lake	36° 25'	148° 19'	1900	1533	4.4	Cirque lake	Alpine herbfield-low shrubland	Raine 1974
71	Club Lake	36° 24'	148° 19'	1980	1528	4.0	Cirque lake	Alpine herbfield-low shrubland	Martin 1986
72	Lake Curlip	37° 50'	148° 30'	2	883	14.4	Estuarine lake	Open forest	Ladd 1978
73	Delegate River	37° 13'	148° 50'	900	833	9.9	Valley fen	Open forest	Ladd 1979a; Gell <i>et al.</i> 1993
74	Rooty Breaks Swamp	37° 20'	148° 50'	1100	979	8.8	Valley bog	Tall open forest	Ladd 1979b
75	Boulder Flat Swamp	37° 28'	148° 58'	130	1013	13.9	Meander cut-off	Open forest	Kenyon 1989
76	Jackson's Bog A	37° 06'	149° 08'	750	800	10.9	Valley fen	Open forest-woodland	Southern 1982
77	Jackson's Bog B	37° 06'	149° 08'	750	800	10.9	Valley bog	Open forest	Southern 1982
78	Wriggley Stick Swamp	37° 45'	149° 26'	10	991	14.8	Backdune swamp	Open forest	G. E. Kenyon, unpub. data
79	Lake George	35° 05'	149° 25'	673	618	12.6	Tectonic basin lake	Open forest-woodland	Singh and Geissler 1985
80	Lake Elusive	37° 45'	149° 27'	8	991	14.8	Backdune	Open forest	G. E. Kenyon, unpub. data
81	Breadalbane NW	34° 48'	149° 30'	700	672	12.5	Tectonic basin lake	Woodland	Dodson 1986
82	Breadalbane SE	34° 48'	149° 30'	700	672	12.5	Tectonic basin lake	Woodland	Dodson 1986
83	Bega Bog	36° 31'	149° 30'	1080	995	9.5	Valley bog	Tall open forest	Green <i>et al.</i> 1988; Hope 1995, unpub. data
101 ^A	Lake Flannigan, King Is.	39° 36'	143° 57'	40	777	13.0	Dune dammed lake	Coastal open scrub-heath	This study
102	Egg Lagoon, King Is.	39° 39'	143° 58'	20	830	13.1	Dune dammed swamp	Coastal open scrub-heath	This study
103	Egg Lagoon, King Is.	39° 39'	143° 58'	20	830	13.1	Dune dammed swamp	Coastal open scrub-heath	This study

Appendix. (continued)

Site no.	Site name	Lat. (S)	Long. (E)	Alt. (m)	Precip. (mm)	Temp. (°C)	Site type	Regional native vegetation	References
104	Naracoopa, King Is.	39° 53'	144° 05'	2	902	13.0	Interdune swamp	Coastal heath-tall shrubland	Grindrod, unpub. data
105	Sundown Point	41° 07'	144° 40'	5	1288	12.4	Interdune swamp	Coastal heath-tall shrubland	G. S. Hope, unpub. data
106	Stockyard Swamp, Hunter Is.	40° 33'	144° 45'	38	1014	12.5	Interdune swamp	Coastal heath-tall shrubland	G. S. Hope, unpub. data
107 ^A	Cave Bay Cave, Hunter Is.	40° 30'	144° 50'	29	967	12.6	Cave infill	Coastal open scrub-heath	Hope 1978
108	Mowbray Swamp	40° 55'	145° 05'	10	1154	12.5	Springfed swamp	Closed shrubland-swamp forest	van de Geer <i>et al.</i> 1986
109	Broadmeadows Swamp	40° 50'	145° 08'	15	1077	12.5	Springfed swamp	Closed shrubland-swamp forest	van de Geer <i>et al.</i> 1986
110 ^A	Pulbenea Swamp	40° 55'	145° 10'	30	1184	12.4	Springfed swamp	Closed shrubland-swamp forest	Colhoun <i>et al.</i> 1982
111	Newall Creek	42° 09'	145° 31'	140	2450	11.1	Riverine deposit	Closed forest	van de Geer <i>et al.</i> 1989
112	Lake Johnson	41° 52'	145° 33'	900	3220	6.9	Cirque Lake	Subalpine closed forest	Anker 1991
113	Poets Hill	41° 53'	145° 33'	620	3225	8.5	Moraine Lake	Closed heath-sedgeland	Colhoun 1992
114	Tarn Shelf, Tyndall Range	41° 55'	145° 35'	1000	3194	6.3	Moraine Lake	Subalpine forest-alpine heath	Macphail 1986
115	Lake Selina	41° 53'	145° 37'	540	2987	8.9	Rock Basin Lake	Closed forest	Pola 1993
116	Smelter Creek	42° 11'	145° 38'	200	2877	10.6	Blanket Peat	Scrub-closed forest	Colhoun <i>et al.</i> 1992
117	Big Heathy Swamp	41° 23'	145° 38'	860	2424	7.4	Blanket Peat	Tall open forest	I. Thomas, unpub. data
118	Tullabardine Swamp	41° 40'	145° 39'	230	1936	10.7	Valley swamp	Tall open forest-closed forest	Colhoun and van de Geer 1986
119	Governor Bog	42° 11'	145° 39'	180	2829	10.7	Sink hole	Scrub-closed forest	Colhoun <i>et al.</i> 1991a
120	King River Railway Bridge	42° 09'	145° 39'	200	2832	10.6	Riverine deposit	Closed forest	van de Geer <i>et al.</i> 1991
121	Darwin Crater Pit	42° 17'	145° 40'	180	2803	10.7	Meteorite Crater	Scrub-closed forest	Colhoun and van de Geer 1988
122	Lake Fidler	42° 30'	145° 41'	5	2430	11.7	Meander cut-off	Closed forest	K. J. Harle, unpub. data
123	Lake Vera	42° 16'	145° 52'	560	2849	8.6	Moraine Lake	Closed forest	Macphail 1979
124	Lake Dove	41° 40'	145° 57'	934	2798	6.8	Valley Lake	Closed forest-tall open forest	Dyson 1995
125	Melaleuca Inlet	43° 16'	146° 05'	10	2261	11.5	Blanket peat	Buttongrass moorland-grassland	Thomas 1995
126	Dublin Bog	41° 43'	146° 14'	575	1608	8.9	Moraine swamp	Tall open forest	Colhoun <i>et al.</i> 1991b
127	Upper Lake Wurawina	42° 32'	146° 15'	1040	2043	5.7	Cirque lake	Subalpine forest-alpine heath	Macphail 1986
128	Den Plain A	41° 30'	146° 14'	230	1380	10.9	Riverine deposit	Grassland-open forest	Moss 1994
129	Den Plain B	41° 30'	146° 14'	230	1380	10.9	Riverine deposit	Grassland-open forest	Moss 1994
130	Den Plain C	41° 30'	146° 14'	230	1380	10.9	Riverine deposit	Grassland-open forest	Moss 1994
131 ^A	Tarraleah	42° 18'	146° 26'	440	1272	9.3	Overflow swamp	Tall open forest	Macphail 1984

132	Upper Timk Lake	42° 56'	146° 27'	545	1869	8.5	Valley bog	Closed forest	Harle 1989
133	Tam Shelf, Mount Field	42° 40'	146° 30'	1158	1717	4.9	Rock basin	Sedgeland-herbfield	Macphail 1979
134	Brown Marsh	42° 13'	146° 34'	750	952	7.7	Erosion basin	Low open forest-open heath	Macphail 1979
135	Eagle Tarn	42° 41'	146° 35'	1033	1555	5.7	Moraine lake	Low open forest	Macphail 1979
136	Beatties Tarn	42° 40'	146° 38'	990	1475	6.0	Moraine lake	Low open forest	Macphail 1979
137	Cameron's Lagoon	41° 58'	146° 41'	1045	944	6.0	Lake basin, origin uncertain	Subalpine grassland	Thomas and Hope 1994
138 ^A	Ooze Lake	43° 30'	146° 43'	880	1939	6.2	Cirque lake	Closed scrub	Macphail and Colhoun 1985
139	Adamsons Peak	43° 21'	146° 49'	960	1884	5.8	Cirque lake	Open heath-closed heath	Macphail 1979
140	Forester Marsh	41° 04'	147° 08'	60	831	12.6	Deflation hollow	Tall open forest	I. Thomas, unpub. data
141	Yarlington Tier	42° 30'	147° 12'	650	1234	8.1	Sphagnum bog	Closed forest	Harle <i>et al.</i> 1993
142	Lake Tiberais	42° 25'	147° 20'	442	587	9.6	Valley lake	Open forest	Macphail and Jackson 1978
143	Waterhouse Marsh	40° 52'	147° 38'	10	554	13.2	Dune dammed creek	Low coastal heathland	I. Thomas, unpub. data
144	Ben Lomand-Big Dam upper	41° 41'	147° 41'	710	1079	8.3	Valley bog	Open forest	Becker, unpub. data
145	Ben Lomand-Big Dam lower	41° 41'	147° 41'	710	1058	8.4	Valley bog	Open forest	Becker, unpub. data
146	Mathinna Plain	41° 22'	147° 49'	950	1649	7.0	Blanket peat	Buttongrass moorland	I. Thomas, unpub. data
147 ^A	Mount Victoria	41° 22'	147° 50'	400	1656	10.0	Archaeological section	Tall open forest-closed forest	I. Thomas, unpub. data
148	Peppertree Marsh	41° 53'	147° 50'	890	1167	13.4	Blanket peat	Tall open forest-closed forest	Becker, unpub. data
149	Killiecrankie, Flinders Is.	39° 56'	147° 50'	15	720	13.6	Stream infill	Open forest-heath	Ladd <i>et al.</i> 1992
150	Snow Hill Marshes	41° 54'	147° 51'	885	1164	7.1	Blanket peat	Tall open forest	Becker, unpub. data
151	Middle Patriarch, Flinders Is.	39° 59'	148° 10'	20	758	13.6	Dune disrupted drainage	Open forest-heath	Ladd <i>et al.</i> 1992
152	Phil's Hill, Cape Barren Is.	40° 22'	148° 16'	30	750	13.4	Dune disrupted drainage	Open sedgeland	G. S. Hope, unpub. data

^AExcluded from further analysis.