Pollen-based reconstructions of biome distributions for Australia, Southeast Asia and the Pacific (SEAPAC region) at 0, 6000 and 18,000 14C yr BP

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ABSTRACT

Aim This paper documents reconstructions of the vegetation patterns in Australia, Southeast Asia and the Pacific (SEAPAC region) in the mid-Holocene and at the last glacial maximum (LGM).

Methods Vegetation patterns were reconstructed from pollen data using an objective biomization scheme based on plant functional types. The biomization scheme was first tested using 535 modern pollen samples from 377 sites, and then applied unchanged to fossil pollen samples dating to 6000 ± 500 or 18,000 ± 1000 14C yr BP.

Results 1. Tests using surface pollen sample sites showed that the biomization scheme is capable of reproducing the modern broad-scale patterns of vegetation distribution. The north–south gradient in temperature, reflected in transitions from cool evergreen needleleaf forest in the extreme south through temperate rain forest or wet sclerophyll forest (WSFW) and into tropical forests, is well reconstructed. The transitions from xerophytic through sclerophyll woodlands and open forests to closed-canopy forests, which reflect the gradient in plant available moisture from the continental interior towards the coast, are reconstructed with less geographical precision but nevertheless the broad-scale pattern emerges. 2. Differences between the modern and mid-Holocene vegetation patterns in mainland Australia are comparatively small and reflect changes in moisture availability rather than temperature. In south-eastern Australia some sites show a shift towards more moisture-stressed vegetation in the mid-Holocene with xerophytic woods/scrub and temperate sclerophyll woodland and shrubland at sites characterized today by WSFW or warm-temperate rain forest (WTRF). However, sites in the Snowy Mountains, on the Southern Tablelands and east of the Great Dividing Range have more moisture-demanding vegetation in the mid-Holocene than today. South-western Australia was slightly drier than today. The single site in north-western Australia also shows conditions drier than today in the mid-Holocene. Changes in the tropics are also comparatively small, but the presence of WTRF and tropical deciduous broadleaf forest and woodland in the mid-Holocene, in sites occupied today by cool-temperate rain forest, indicate warmer conditions. 3. Expansion of xerophytic vegetation in the south and tropical deciduous broadleaf forest and woodland in the north indicate drier conditions across mainland Australia at the LGM. None
INTRODUCTION

The region encompassing Southeast Asia, Australasia and the Pacific (here referred to as SEAPAC) is climatically and physiographically diverse. The region stretches from the equatorial tropics via subtropical deserts to the mid-latitude temperate belt, encompassing within each zone a range from continental to maritime climates. Physiographically, the region includes both ancient stable landscapes and active mountain forming regions. Despite this diversity, SEAPAC can be considered as a biogeographical unit because of the floristic affinities between the vegetation of different areas. SEAPAC encompasses the intersection between the species-rich Indo-Malesian (van Steenis, 1979; Nelson, 1981; Hope, 1996) and the Gondwanan floral realms (Barlow, 1981, 1994). Understanding the role of long-term climatic changes on the evolution of this diverse flora has motivated the reconstruction of vegetation history on a variety of time-scales. Although many kinds of palaeoenvironmental evidence can be used for this purpose, the most abundant source of information (particularly for the last glacial–interglacial cycle, which is the focus of the present paper) comes from pollen records. However, the very diversity of the flora makes it difficult to make objective comparisons between vegetation records from different subregions. None of the previous palaeovegetation syntheses (e.g. Bowler, 1982; CLIMANZ, 1983; Dodson, 1989; Kershaw et al., 1991; van der Kaars, 1991; Markgraf et al., 1992; Harrison & Dodson, 1993; Kershaw et al., 1994; Hubbard, 1995a,b; Colhoun, 1996; Flennley, 1996) encompasses the whole of the SEAPAC region. The concept of plant functional types (PFTs) provides one approach to handling taxonomic diversity, as it groups together species that share common attributes with respect to, e.g. life-form, phenology and bioclimatic limits (Prentice et al., 1992a; Steffen, 1996; Smith et al., 1997). Broad-scale vegetation types (biomes) arise out of the association of different PFTs. Thus specific biomes can be recognized in different regions in spite of differences in taxonomic composition. The concepts of PFTs and biomes underlie the Palaeovegetation Mapping Project (BIOME 6000: Prentice & Webb, 1998). The aim of BIOME 6000 is to produce global vegetation maps for the mid-Holocene (6000 yr BP or 6 ka) and last glacial maximum (LGM, c. 18,000 14Cy rBP or 18 ka, equivalent to 21,000 calendar yr BP) using an objective method based on the allocation of taxa to PFTs, and PFTs to biomes. The resulting maps provide a tool for the evaluation of climate and earth system models (e.g. Texier et al., 1997; Harrison et al., 1998; Jolly et al., 1998a; Broströms et al., 1998; Kutzbach et al., 1998; Prentice et al., 1998; Joussaume et al., 1999, Kohfeld & Harrison, 2000).

With the exception of a few sites from southern Africa, the Southern Hemisphere is not represented in the current version of the BIOME 6000 synthesis (Prentice et al., 2000). The emphasis on Northern Hemisphere data in the initial phase of BIOME 6000 reflects the abundance of pollen records from, e.g. Europe and North America, which made these regions ideal for testing the methodology. The aim of this paper is to present a compilation of pollen data from the SEAPAC region, to reconstruct biome maps for 0, 6 and 18 ka, and to interpret these maps in terms of changing palaeoclimates, and thus to extend the current BIOME 6000 synthesis.

SEAPAC region

The SEAPAC region extends from 17° N to 45° S and 100° E to 180° E and includes the Sunda-Sahul region of Sulawesi, Java, Sumatra, Borneo and Thailand, Papua New Guinea (PNG), Australia, the Melanesian islands including the Solomon Islands, New Caledonia, Fiji and Vanuatu, and Polynesia including Hawaii in the north and Easter Island to the east.
The climate of the northern part of the region is dominated by the seasonal migration of the inter-tropical convergence zone (ITCZ), which shifts from 10–15° N in June–August (Austral winter) to 10–12° S in December–February (Austral summer) (Linacre & Hobbs, 1977). To the south, the climate is dominated by the descending air of the subtropical belt of high pressure and divergence. The mean latitude of the subtropical high pressure belt (STA, or subtropical anticyclone), which is characterized by the occurrence of travelling anticyclones, shifts seasonally from c. 29–32° S in Austral winter to c. 37–38° S in Austral summer (Russell, 1893; Kidson, 1925; Karelsky, 1954; Pittock, 1973). The winds leaving the anticyclone spiral on the equatorward side to form the south-easterly trade winds (tropical easterlies) that influence the Pacific Islands, northern Queensland and PNG during the Austral winter. In Austral summer, with the southward displacement of the ITCZ and the STA, onshore winds forming part of the southern monsoon influence the southern tropics and can even penetrate into the interior of Australia (Pittock, 1975, 1978).

The seasonal migration of the STA also influences the climate of the southernmost part of the region, allowing the southern westerlies to migrate northwards during Austral winter (Gentilli, 1971). These large-scale circulation features determine the seasonal distribution of precipitation across the region (see e.g. Harrison & Dodson, 1993). Thus, the equatorial belt (dominated by the ITCZ throughout the year) is characterized by small seasonal variations in rainfall and temperature. The southern tropics and northern Australia are characterized by a summer rainfall maximum. The continental interior is characterized by highly irregular, but predominantly summer, rainfall. The southernmost part of mainland Australia has winter rainfall, and only the southernmost part of the region (i.e. Tasmania) lies far enough south to receive precipitation from the westerlies throughout the year.

Two major floristic domains are represented in the region: the Indo-Malesian floral domain (van Steenis, 1979; Nelson, 1981; Hope, 1996; Flenley, 1979, 1998) which includes both tropical and cosmopolitan species, and the Gondwanan floral domain (Barlow, 1981, 1994) which is dominated by sclerophyll species. The tropical rain forests and seasonal forests of the Sunda-Sahul region, characterized by the families Eucalyptaceae, Moraceae and Meliaceae, lie in the core of the Indo-Malesian floral domain. The core of the Gondwanan floral domain, characterized by the families Myrtaceae, Proteaceae and Epacridaceae, occurs in southern Australia. In between, the vegetation consists of an admixture of the two floras with the relative importance of one over the other varying as a function of increasing distance both latitudinally and eastwards from the core regions (Hope, 1996; Mueller-Dombois & Fosberg, 1998). Thus, elements of the Indo-Malesian flora persist in the subtropical forest belts of PNG and into northern Australia, but are increasingly admixed with elements of the Gondwanan sclerophyll vegetation southwards. Indo-Malesian floral elements are also represented in the islands of the Western Pacific, admixed with Gondwanan elements including Eucalyptus and Epacridaceae, although the species diversity of both floral domains decreases eastwards (Mueller-Dombois & Fosberg, 1998).

An obvious climatic gradient influencing vegetation patterns within the SEAPAC region is temperature. Thus, there is a latitudinal zonation from tropical rain forests in the far north, through subtropical seasonal or dry forests into warm-temperate and cool-temperate rain forests (CTRF) in the far south. This gradient parallels the gradient from primarily Indo-Malesian, through admixed, to primarily Gondwanan floras. However, the primarily west–east gradients related to moisture availability are a more important climatic control within the subtropical and temperate zones. The continental interior of Australia is arid, with mean annual precipitation as low as 100 mm year−1. Both the amount and reliability of rainfall increases towards the eastern and southern coasts. The vegetation of the arid interior is characterized by grasslands and shrublands, which grade into open woodlands with increasing moisture availability, while forests are confined to the coastal regions (Carnahan, 1997). Rainfall is high (c. 5000 mm year−1) on the islands of the western Pacific and gradually decreases further east; this steep gradient results in a transition from forest-dominated to non-forest vegetation (Mueller-Dombois & Fosberg, 1998). The decrease in precipitation across the Pacific parallels the gradual decrease in species diversity.

Topographic gradients associated with the Great Dividing Range clearly influence climatic gradients and hence the vegetation zonation in eastern Australia. However, topography has a more important role in the extensive highland regions in the tropics, and the topographic control on local climate is a particularly important factor underlying the complex vegetation patterns characteristic of Borneo, Sumatra and PNG. Transitions from tropical rain forest at sea level, through montane forests into grassland or tundra at elevations above c. 3000 m are common on many tropical mountains (e.g. Mt Wilhelm: Hope & Peterson, 1975).

The modern vegetation patterns of the SEAPAC region reflect the interaction among these floristic, climatic and topographic gradients. The same gradients must also have been important throughout the history of the region. There has been considerable work on the long-term vegetation history of the SEAPAC region, capitalizing on the existence of pollen records covering the last interglacial–glacial cycle from both the tropics and the stable ancient landscapes of the temperate region. Examples include the studies at Lynch’s Crater (Kershaw, 1976), Lake Wangoom (Edney et al., 1990; Harle et al., 1999), Lake George (Singh et al., 1981; Singh & Geissler, 1985), Kosipe (Hope, 1982), and Lac Suprin (Hope, 1996). There are considerably more sites providing data on the changes in vegetation patterns during and since the LGM. However, climatic constraints on the occurrence of lakes and peatbogs mean that pollen records are largely restricted to well-watered coastal regions and the tropics (e.g. Bowler, 1982; CLIMANZ, 1983; Dodson, 1989; Kershaw et al., 1991; van der Kaars, 1991; Markgraf et al., 1992; Harrison & Dodson, 1993; Kershaw et al., 1994; Hubbard, 1995a,b; Colhoun, 1996; Flenley, 1996). New
sources of information, including studies of stick-nest rat middens (Pearson & Dodson, 1993; McCarthy et al., 1996; Pearson, 1999) and isotope analyses of emu shells (Miller et al., 1997, 1999; Johnson et al., 1999), could provide information about vegetation changes in the more arid parts of the SEAPAC region. Unfortunately, there are relatively few such studies at the present time, and we have therefore not drawn on these potential sources of information in the present analysis.

METHODS

Modern pollen and vegetation data
Modern pollen assemblages were obtained for 377 sites (Table 1). About a third of the site records were derived from the Indo-Pacific Pollen Database (INDOPAC: Hope et al., 1999), which includes data from India, Southeast Asia, Australia, New Zealand and Oceania. A further 31% of the records come from the Southeast Australian Pollen Database (SEAPD: D’Costa & Kershaw, 1997; Kershaw, 1998). The remaining 35% of the records were obtained from the original authors. A number of these records have not been previously published.

Despite the large number of sites in the SEAPAC data base, the spatial distribution of the modern surface samples is uneven. There are surface samples available from the coastal regions of the SW, SE, N and NW of Australia but none from the continental interior. This reflects poor pollen preservation in arid environments, and the lack of suitable lake or swamp sites. There are surface samples from upland regions of PNG, New Caledonia, Borneo, Sumatra, Irian Jaya, Indonesia, Solomon Islands and Thailand, but relatively few from the tropical lowlands. The availability of samples from upland regions reflects the widely held perception that mountain vegetation belts are highly sensitive to climatic change (e.g. Flennley et al., 1976; Walker & Flennley, 1979; Powell, 1982; Flennley, 1996). The comparative lack of data from the tropical lowlands is further compounded by logistical access problems.

The modern pollen samples were obtained from a number of sources including moss polsters (9%), pollen traps (5%), surface soil samples (26%), lacustrine or swamp core tops (24%) and other sediment samples (36%). The pollen source area sampled by moss polsters or soil samples beneath the tree canopy is several orders of magnitude smaller than the source area sampled by, e.g. lacustrine core tops (Prentice, 1985; Chen, 1987; Kershaw & Strickland, 1990; Kodela, 1990; Crowley et al., 1994; Kershaw & Bulman, 1994; Sugita, 1994). In forested regions, lacustrine samples are more likely to provide a reconstruction of regional vegetation. However, moss polsters, surface soil samples and other sediment samples could be more representative of the regional vegetation under certain conditions, for example in open vegetation or when the vegetation is dominated by poor pollen producers. It is not always clear which type of sample will most faithfully reflect the regional vegetation (see e.g. Bigelow et al., 2003) and we have therefore included all types of modern pollen samples in our analyses.

Raw counts were obtained for the majority of the samples (c. 65%). The SEAPD data were available as raw counts but some of the minor taxa had already been excluded. A further 31% of the samples were available as per cent counts. Only 4% of the surface samples were digitized from published pollen diagrams. Pollen abundances estimated by digitization are generally accurate to within 10% (Williams et al., 2000) and this degree of uncertainty is unlikely to affect the resultant biome allocation. A more important constraint on the use of digitized data is the fact that published pollen diagrams do not include all of the minor taxa. Although digitized data provide a reasonably accurate means of reconstructing forest vegetation (Prentice et al., 1996; Tarasov et al., 1998), minor taxa can be important in reconstructing non-forest vegetation types and therefore complete raw pollen counts appear to provide a better discrimination among the various non-forest and xerophytic vegetation types (Jolly et al., 1998a, Yu et al., 1998, 2000). For this reason we used digitized data only for sites in key regions where the raw counts were not available. The exclusion of minor taxa from the SEAPD data set could potentially cause problems with the SEAPAC biomization. However, the majority of the SEAPD samples are from forested vegetation types and therefore the absence of minor taxa is less likely to have affected the biome allocation.

The SEAPAC data set only includes counts for pollen taxa that are used in the biomization procedure. Aquatic pollen and spores, and non-native taxa, were excluded. Taxa that were only represented by a single grain in one site were also excluded. No attempt was made to reduce or enhance the taxonomic resolution of the original data. Thus the taxa list includes species where these were distinguished by the original authors. As a result, a total of 695 taxa were used in the SEAPAC biomization.

Fossil pollen data
The time slices for the biomization procedure were defined as 6000 ± 50 and 18,000 ± 1000 14C yr BP on the radiocarbon time-scale (6 and 18 ka, respectively). The sites encompass a wide range of environments including lakes, peat bogs, caves, and organic deposits associated with fluvial or dune environments. One record for 6 ka was obtained from a marine core. Samples were selected on the basis of an age model constructed by linear interpolation between the radiocarbon dates designated by the original authors to be reliable. Multiple samples were selected when more than one sample fell within the designated window.

The data set for 6 ka consists of 114 sites (Table 2), of which 53% were available as raw counts, 42% as per cent counts, and 5% were digitized from published diagrams. Multiple samples were obtained for 47% of the sites. The data set for 18 ka consists of 33 sites (Table 2). Raw pollen counts were available for 73% of the 18 ka sites, 27% were available as per cent counts. Duplicate samples were obtained for 52% of the sites. The SEAPAC data sets for 6 and 18 ka represent a substantial improvement, both in terms of number of sites and the range
Table 1 Characteristics of the surface pollen samples from the SEAPAC region. The sites are arranged alphabetically by name. Latitude and longitude are given in decimal degrees, with N and E conventionally indicated as +, and S and W as –. The vegetation descriptions are derived from the publications, and the observed (Obs.) biome call is derived from the natural vegetation map in the Atlas of Australian Resources (Carnahan, 1997). Dating control (DC) follows the COHMAP dating scheme, as described by Yu & Harrison (1995). The codes used for reconstructed biomes are defined in Table 5.

<table>
<thead>
<tr>
<th>Site name</th>
<th>Country</th>
<th>Latitude (°)</th>
<th>Longitude (°)</th>
<th>Altitude (m)</th>
<th>Sample type</th>
<th>Site type</th>
<th>Surrounding vegetation</th>
<th>Age range (kyr)</th>
<th>No. of 14C dates</th>
<th>No. of duplicates DC 0 ka</th>
<th>Biomes</th>
<th>Data base</th>
<th>References</th>
</tr>
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<tbody>
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<td>Adamson’s Peak</td>
<td>Australia</td>
<td>–43.350</td>
<td>146.817</td>
<td>960</td>
<td>%Count</td>
<td>Swamp</td>
<td>Open heath–closed heath</td>
<td>0–10</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>XERO</td>
<td>CTRF SEAPD Macphail (1979, 1986)</td>
</tr>
<tr>
<td>Aire Crossing</td>
<td>Australia</td>
<td>–38.733</td>
<td>143.450</td>
<td>100</td>
<td>%Count</td>
<td>Swamp</td>
<td>Closed <em>Eucalyptus</em> forest</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>WSFW CTRF SEAPD</td>
<td>McKenzie (unpubl. data), D’Costa &amp; Kershaw (1997)</td>
<td></td>
</tr>
<tr>
<td>Airstrip</td>
<td>Australia</td>
<td>–31.753</td>
<td>128.083</td>
<td>60–70</td>
<td>Count</td>
<td>Soil</td>
<td>Mallee heath</td>
<td>Modern</td>
<td>0</td>
<td>1</td>
<td>Modern XERO</td>
<td>DSFW</td>
<td>DSFW Martin (1973)</td>
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<tr>
<td>Aluapugua (core 2)</td>
<td>PNG</td>
<td>–5.972</td>
<td>143.153</td>
<td>2750</td>
<td>Count</td>
<td>Swamp</td>
<td>Mid/upper montane <em>Nothofagus</em> and mixed forest</td>
<td>0–18.5</td>
<td>3</td>
<td>3</td>
<td>CTRF TDFo; CTRF SEAPD</td>
<td>Haberle (1994)</td>
<td></td>
</tr>
<tr>
<td>Anouwe 2</td>
<td>Vanuatu</td>
<td>–20.234</td>
<td>169.782</td>
<td>4</td>
<td>Count</td>
<td>Swamp</td>
<td>Closed forest</td>
<td>0–5.5</td>
<td>2</td>
<td>n/a</td>
<td>WTRF WTRF INDOPAC</td>
<td>Hope &amp; Spriggs (1982), Hope et al. (1999)</td>
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<td>Anumon Swamp</td>
<td>Vanuatu</td>
<td>–20.158</td>
<td>169.823</td>
<td>45</td>
<td>Count</td>
<td>Swamp</td>
<td>Closed forest</td>
<td>2.9–5.0</td>
<td>3</td>
<td>3</td>
<td>n/a WTRF TDFo; WTRF</td>
<td>Hope et al. (1999)</td>
<td></td>
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<td>Badgingarra NP</td>
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<td>–30.483</td>
<td>115.433</td>
<td>240</td>
<td>Count</td>
<td>Trap</td>
<td><em>Eucalyptus</em> <em>loxophleba</em> woodland</td>
<td>Modern</td>
<td>0</td>
<td>1</td>
<td>Modern DSFW</td>
<td>Pickett (1997)</td>
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<tr>
<td>Badmenangdongwa</td>
<td>PNG</td>
<td>–5.815</td>
<td>144.988</td>
<td>3550</td>
<td>Count</td>
<td>Swamp</td>
<td>Capronia, Pua, Dacrycarpus, <em>Cyathea</em></td>
<td>0–10.1</td>
<td>1</td>
<td>2</td>
<td>WTRF WTRF INDOPAC</td>
<td>Hope (1976)</td>
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<td>–32.002</td>
<td>115.503</td>
<td>1</td>
<td>Count</td>
<td>Swamp</td>
<td>Low dense heath, with thickets of <em>Callitris</em></td>
<td>0–7.5</td>
<td>3</td>
<td>3</td>
<td>Modern XERO</td>
<td>Backhouse (1993)</td>
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<td>1524</td>
<td>%Count</td>
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<td>Subalpine woodland</td>
<td>n/a</td>
<td>n/a</td>
<td>1</td>
<td>n/a DSFW</td>
<td>Strickland (unpubl. data), D’Costa &amp; Kershaw (1997)</td>
<td></td>
</tr>
<tr>
<td>Baw Baw Village</td>
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<td>146.267</td>
<td>1524</td>
<td>%Count</td>
<td>Swamp</td>
<td>Subalpine woodland</td>
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<td>n/a</td>
<td>1</td>
<td>n/a DSFW</td>
<td>Strickland (unpubl. data), D’Costa &amp; Kershaw (1997)</td>
<td></td>
</tr>
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<td>Beattie’s Tarn</td>
<td>Australia</td>
<td>–42.667</td>
<td>146.633</td>
<td>990</td>
<td>%Count</td>
<td>Lake</td>
<td>Low open forest</td>
<td>0–12</td>
<td>2</td>
<td>1</td>
<td>7</td>
<td>DSFW CTRF SEAPD Polach &amp; Singh (1980), Green et al. (1988)</td>
<td></td>
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<tr>
<td>Bega Swamp</td>
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<td>–36.518</td>
<td>149.500</td>
<td>1080</td>
<td>Count</td>
<td>Swamp</td>
<td>Tall open forest</td>
<td>0–13.5</td>
<td>48</td>
<td>3</td>
<td>1C DSFW</td>
<td>Macphail (1979, 1986)</td>
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<tr>
<td>Bellenden Ker</td>
<td>Australia</td>
<td>–17.250</td>
<td>145.917</td>
<td>1500</td>
<td>Count</td>
<td>Moss</td>
<td>Microphyll fern thicket (high altitude)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>WTRF</td>
<td>Kershaw (1973a)</td>
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<tr>
<td>Bendenumbun</td>
<td>PNG</td>
<td>–5.750</td>
<td>145.013</td>
<td>3700</td>
<td>Count</td>
<td>Swarm</td>
<td>Shrubby tussock grasslands</td>
<td>0–2</td>
<td>2</td>
<td>2D</td>
<td>STEP WTRF INDOPAC</td>
<td>Corlett (1984b)</td>
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<td>Bibra Lake (BL2)</td>
<td>Australia</td>
<td>–32.100</td>
<td>115.833</td>
<td>35</td>
<td>Count</td>
<td>Swamp</td>
<td><em>Eucalyptus marginata</em> woodland</td>
<td>0–31</td>
<td>7</td>
<td>3</td>
<td>DSFW DSFW DSFW</td>
<td>Pickett (1997)</td>
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<td>Site name</td>
<td>Country</td>
<td>Latitude (°)</td>
<td>Longitude (°)</td>
<td>Altitude (m)</td>
<td>Sample type</td>
<td>Site type</td>
<td>Surrounding vegetation</td>
<td>Age range (kyr)</td>
<td>No. of ¹⁴C dates</td>
<td>No. of duplicates</td>
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<td>Biomes</td>
<td>Observations</td>
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<td>Den Plain a 1</td>
<td>-41.500</td>
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<td>230</td>
<td>Swamp</td>
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<td>n/a</td>
<td>Grassland-open</td>
<td>n/a</td>
<td>DSFW</td>
<td>SEAPD</td>
<td>Moss (1994), D’Costa &amp; Kershaw (1997)</td>
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<td>n/a</td>
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<td>SEAPD</td>
<td>Moss (1994), D’Costa &amp; Kershaw (1997)</td>
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<td>230</td>
<td>Swamp</td>
<td>n/a</td>
<td>n/a</td>
<td>Grassland-open</td>
<td>n/a</td>
<td>DSFW</td>
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<td>Moss (1994), D’Costa &amp; Kershaw (1997)</td>
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<td>Digger’s Creek Bog</td>
<td>-36.383</td>
<td>148.483</td>
<td>1690</td>
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<td>Eucalyptus pauciflora/niphrophila woodland</td>
<td>1D</td>
<td>DSFW</td>
<td>DSFW</td>
<td>Martin (1999)</td>
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<td>Diprose Cave</td>
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<td>131.367</td>
<td>100</td>
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<td></td>
<td>Saltbush-bluebush low</td>
<td>0–10.5</td>
<td>XERO</td>
<td>WTRF</td>
<td>Martin (1973)</td>
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<td>Downfall Creek</td>
<td>-17.133</td>
<td>145.583</td>
<td>700</td>
<td>Count</td>
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<td>2</td>
<td>XERO</td>
<td>WTRF</td>
<td>Kershaw (1973b)</td>
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<td>Draepi Swamp 40A</td>
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<td>1885</td>
<td>Count</td>
<td></td>
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<td>1885</td>
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<td>TDFO</td>
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<td>TDFO</td>
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<td>1</td>
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<td>Powell (unpubl. data)</td>
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<td>-19.670</td>
<td>123.612</td>
<td>200</td>
<td>Digitized</td>
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<td>2</td>
<td>Dense grassland and Acacia shrubs</td>
<td>5</td>
<td>XERO; XERO; XERO; XERO; XERO;</td>
<td>PederSEN (1983), WyrWoll et al. (1986)</td>
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<td>Dryandra State Forest (13)</td>
<td>-32.783</td>
<td>116.883</td>
<td>360</td>
<td>Count</td>
<td></td>
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<td>Trap</td>
<td>0–13.6</td>
<td>WSRF</td>
<td>SEAPD</td>
<td>Colhoun et al. (1991)</td>
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<td>Dryandra State Forest (14)</td>
<td>-32.817</td>
<td>116.787</td>
<td>300</td>
<td>Count</td>
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<td>Trap</td>
<td>0–13.6</td>
<td>WSRF</td>
<td>SEAPD</td>
<td>Colhoun et al. (1991)</td>
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<td>Dryandra State Forest (15)</td>
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<td>116.817</td>
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<td>Count</td>
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<td>Trap</td>
<td>0–13.6</td>
<td>WSRF</td>
<td>SEAPD</td>
<td>Colhoun et al. (1991)</td>
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<td>Dublin Bog</td>
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<td>Swamp</td>
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<td>0–12</td>
<td>WSRF</td>
<td>SEAPD</td>
<td>Colhoun et al. (1991)</td>
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<td>Eagle Tarn</td>
<td>-42.683</td>
<td>146.583</td>
<td>1033</td>
<td>%Count</td>
<td>0–12</td>
<td>3</td>
<td>Lake</td>
<td>39.4 to &gt; 55</td>
<td>XERO</td>
<td>DSFW</td>
<td>Macphail (1979)</td>
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<td>Egg Lagoon Core 2</td>
<td>-39.644</td>
<td>143.992</td>
<td>17</td>
<td>%Count</td>
<td>0–12</td>
<td>3</td>
<td>Swamp</td>
<td>39.4 to &gt; 55</td>
<td>XERO</td>
<td>DSFW</td>
<td>D’Costa &amp; Kershaw (1997)</td>
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<td>Site name</td>
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<td>Longitude (°)</td>
<td>Sample type</td>
<td>Site type</td>
<td>Surrounding vegetation</td>
<td>Age range (kyr)</td>
<td>No. of 14C dates</td>
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<tr>
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<td>−39.644</td>
<td>143.999</td>
<td>17</td>
<td>%Count Swamp</td>
<td>Open-scrub heath</td>
<td>39.4 to &gt; 55</td>
<td>n/a</td>
<td>1</td>
<td>n/a</td>
<td>XERO DSFW SEAPD</td>
<td>D’Costa &amp; Kershaw (1997)</td>
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<td>El Arish</td>
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<td>−17.800</td>
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<td>60</td>
<td>Count Moss</td>
<td>Mixed mesophyll evergreen vine forest</td>
<td>Modern</td>
<td>0</td>
<td>1</td>
<td>Modern TRFO TDFS</td>
<td>Kershaw (1973b)</td>
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<td>Enoggra State Forest</td>
<td>Australia</td>
<td>−28.250</td>
<td>153.167</td>
<td>350</td>
<td>Count Moss</td>
<td>mixed mesophyll vine forest and Araucaria</td>
<td>Modern</td>
<td>0</td>
<td>1</td>
<td>Modern WTRF WTRF</td>
<td>Kershaw (1976)</td>
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<td>Evoran Pond</td>
<td>Vanuatu</td>
<td>−18.761</td>
<td>169.001</td>
<td>190</td>
<td>Count Swamp</td>
<td>Acacia spirabilis open woodland, secondary disturbance</td>
<td>0–2.46</td>
<td>2</td>
<td>3</td>
<td>n/a</td>
<td>TDFO WTRF; INDOPAC</td>
<td>Hope et al. (1999)</td>
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<tr>
<td>Fissoa River</td>
<td>PNG</td>
<td>−2.933</td>
<td>151.467</td>
<td>2</td>
<td>Count Swamp</td>
<td>Terminalia Elaeocarpus forest</td>
<td>0–2.5</td>
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<td>3</td>
<td>n/a</td>
<td>TRFO WTRF; INDOPAC</td>
<td>Hope et al. (1999)</td>
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<tr>
<td>Fitzgerald Inlet Core 2</td>
<td>Australia</td>
<td>−34.292</td>
<td>119.458</td>
<td></td>
<td>Count Swamp</td>
<td>Deltaic vegetation/open mallee shrubland</td>
<td>0–7</td>
<td>1</td>
<td>1</td>
<td>Modern XERO XERO</td>
<td>Hassell (unpubl. data)</td>
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<td>Flinders Bay Swamp</td>
<td>Australia</td>
<td>−34.317</td>
<td>115.150</td>
<td>8</td>
<td>Count Swamp</td>
<td>Eucalyptus calophylla, Banksia grandis and Agonis flexuosa heath-woodland</td>
<td>0–2 + top 3</td>
<td>1</td>
<td>n/a</td>
<td>XERO DSFW; DSFW</td>
<td>Churchill (1968)</td>
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<td>Fool Swamp</td>
<td>Micronesia</td>
<td>9.486</td>
<td>138.087</td>
<td>4</td>
<td>Count Swamp</td>
<td>Savanna with Pandanus, Melaleuca, Verban and Gleichenia</td>
<td>0–5.3</td>
<td>3</td>
<td>3</td>
<td>1D</td>
<td>TDFS TDFS; TDFS</td>
<td>Dodson &amp; Intoh (1999)</td>
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<td>Forester Marsh</td>
<td>Australia</td>
<td>−41.067</td>
<td>147.133</td>
<td>60</td>
<td>%Count Swamp</td>
<td>Tall open forest</td>
<td>0–4.4</td>
<td>n/a</td>
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<td>n/a</td>
<td>DSFW DSFW SEAPD</td>
<td>Thomas (unpubl. data), D’Costa &amp; Kershaw (1997)</td>
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<td>Freshwater Lake Australia</td>
<td>−37.583</td>
<td>142.317</td>
<td>220</td>
<td>%Count Swamp Open forest-woodland</td>
<td>0–7</td>
<td>n/a</td>
<td>1</td>
<td>n/a</td>
<td>DSFW DSFW SEAPD</td>
<td>Thomas (unpubl. data), D’Costa &amp; Kershaw (1997)</td>
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<tr>
<td>G5–2-053P</td>
<td>(Seram Trench) Indonesia</td>
<td>−3.599</td>
<td>132.164</td>
<td>3900</td>
<td>Count Swamp</td>
<td>Secondary grassland, with forest nearby</td>
<td>0-ca14</td>
<td>0</td>
<td>(isotrope stratig.)</td>
<td>7</td>
<td>TDFS TDFS</td>
<td>van der Kaars (1991, 1995)</td>
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<tr>
<td>Giwilawi</td>
<td>PNG</td>
<td>−5.800</td>
<td>145.037</td>
<td>3900</td>
<td>Count Swamp</td>
<td>Secondary grassland, with forest nearby</td>
<td>0–1.5</td>
<td>1</td>
<td>2</td>
<td>2D</td>
<td>WTRF WTRF; INDOPAC</td>
<td>Corlett (1984b)</td>
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<td>Gordon Inlet</td>
<td>Australia</td>
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<td>Deltaic vegetation/open mallee shrubland</td>
<td>Modern</td>
<td>0</td>
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<td>Modern XERO XERO</td>
<td>Hassell (unpubl. data)</td>
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<td>Governor Bog</td>
<td>Australia</td>
<td>−42.184</td>
<td>145.650</td>
<td>180</td>
<td>%Count Swamp</td>
<td>Scrub-closed forest</td>
<td>0–13</td>
<td>2</td>
<td>1</td>
<td>7</td>
<td>XERO WSFW SEAPD</td>
<td>Colhoun et al. (1991)</td>
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<td>Greens Bush</td>
<td>Australia</td>
<td>−38.433</td>
<td>144.933</td>
<td>160</td>
<td>%Count Swamp</td>
<td>Open woodland</td>
<td>n/a</td>
<td>n/a</td>
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<td>Gunung Kerinci Plot 1</td>
<td>Sumatra Indonesia</td>
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<td>100.767</td>
<td>3315</td>
<td>Count Soil</td>
<td>Ericaceous forest (upper montane rain forest)</td>
<td>Modern</td>
<td>0</td>
<td>1</td>
<td>Modern CTRF WTRF</td>
<td>Newsome (1985), Stuifts et al. (1988)</td>
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<td>100.767</td>
<td>3010</td>
<td>Count Soil</td>
<td>Ericaceous forest (upper montane rain forest)</td>
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<td>Altitude</td>
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<td>Soil</td>
<td>Vegetation</td>
<td>Age</td>
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<td>-1.067</td>
<td>100.767</td>
<td>2700</td>
<td>Count Soil</td>
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<td>Ericaceous forest (upper montane rain forest)</td>
<td>Modern 0</td>
<td>1 Modern CTRF WTRF</td>
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<td>Modern 0</td>
<td>1 Modern WTRF TDO</td>
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<td>1935</td>
<td>Count Soil</td>
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<td>Lower montane forest/marsh, swamp/dryland crops</td>
<td>Modern 0</td>
<td>1 Modern WTRF TDO</td>
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<td>-1.067</td>
<td>100.767</td>
<td>3175</td>
<td>Count Soil</td>
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<td>Lower montane forest/marsh, swamp/dryland crops</td>
<td>Modern 0</td>
<td>1 Modern WTRF WTRF</td>
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<td>3070</td>
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<td>Lower montane forest/marsh, swamp/dryland crops</td>
<td>Modern 0</td>
<td>1 Modern WTRF TRFO</td>
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<td>-1.067</td>
<td>100.767</td>
<td>2855</td>
<td>Count Soil</td>
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<td>Modern 0</td>
<td>1 Modern WTRF TDFO</td>
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<td>100.767</td>
<td>2545</td>
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<td>Modern 0</td>
<td>1 Modern WTRF TDFO</td>
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<td>100.767</td>
<td>2395</td>
<td>Count Soil</td>
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<td>Lower montane forest/marsh, swamp/dryland crops</td>
<td>Modern 0</td>
<td>1 Modern WTRF TDFO</td>
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<td>100.767</td>
<td>2240</td>
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<td>Lower montane forest/marsh, swamp/dryland crops</td>
<td>Modern 0</td>
<td>1 Modern WTRF TDFO</td>
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**References:**
- Newsome (1985), Stuijts et al. (1988)
- Newsome (1985), Stuijts et al. (1988)
- Newsome (1985), Stuijts et al. (1988)
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- Newsome (1985), Stuijts et al. (1988)
- Newsome (1985), Stuijts et al. (1988)
- Newsome (1985), Stuijts et al. (1988)
- Corlett (1984b)
- Powell (1970)
- Powell (1970)
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- Kershaw (1976)
- Kershaw (1973b)
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*Journal of Biogeography 31*, 1381–1444, © 2004 Blackwell Publishing Ltd
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<td>Open woodland-grassland</td>
<td>0–16</td>
<td>1</td>
<td></td>
<td>DFW</td>
<td>DFW</td>
<td>Yezdani (1970), D’Costa &amp; Kershaw (1997)</td>
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<tr>
<td>Lake Habbema</td>
<td>Indonesia</td>
<td>−4.4117</td>
<td>138.700</td>
<td>3120</td>
<td>Count</td>
<td>Lake</td>
<td>Subalpine rain forest/grassland</td>
<td>0–10</td>
<td>3 + top</td>
<td>3</td>
<td>2C</td>
<td>CTRF</td>
<td>Haberle et al. (2001)</td>
</tr>
<tr>
<td>Lake Hill</td>
<td>Australia</td>
<td>−37.150</td>
<td>147.933</td>
<td>1300</td>
<td>%Count</td>
<td>Swamp</td>
<td>Subalpine woodland</td>
<td>0–15</td>
<td>n/a</td>
<td>1</td>
<td>n/a</td>
<td>DFW</td>
<td>Kershaw &amp; McKenzie (unpubl. data), Kershaw (1998)</td>
</tr>
<tr>
<td>Lake Horder Core A</td>
<td>Australia</td>
<td>−38.784</td>
<td>143.467</td>
<td>3 + top</td>
<td>%Count</td>
<td>Swamp</td>
<td>Tall open forest</td>
<td>0–4.5</td>
<td>3</td>
<td>1</td>
<td>1D</td>
<td>DFW</td>
<td>Head &amp; Stuart (1980)</td>
</tr>
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<td>Lake Hordorli</td>
<td>Irian Jaya</td>
<td>−2.550</td>
<td>140.600</td>
<td>780</td>
<td>Count</td>
<td>Swamp</td>
<td>Anacardia, lower montane forest</td>
<td>0 to &gt; 35</td>
<td>7 (1 not used)</td>
<td>2</td>
<td>7</td>
<td>WTRF</td>
<td>Hope et al. (1988), Hope &amp; Tulip (1994)</td>
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<td>Lake Johnston, Core JA</td>
<td>Australia</td>
<td>−41.850</td>
<td>145.333</td>
<td>875</td>
<td>%Count</td>
<td>Lake</td>
<td>Subalpine-closed forest</td>
<td>0–9.5</td>
<td>7 + top</td>
<td>1</td>
<td>2C</td>
<td>CTRF</td>
<td>Anker et al. (2001)</td>
</tr>
<tr>
<td>Lake Keilambete</td>
<td>Australia</td>
<td>−38.200</td>
<td>142.867</td>
<td>150</td>
<td>%Count</td>
<td>Lake</td>
<td>Open woodland</td>
<td>0–9.7</td>
<td>4 + top</td>
<td>1</td>
<td>1C</td>
<td>DSFW</td>
<td>Dodson (1974a)</td>
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<tr>
<td>Lake Lascelles</td>
<td>Australia</td>
<td>−35.717</td>
<td>142.367</td>
<td>80</td>
<td>%Count</td>
<td>Lake</td>
<td>Open scrub-heath</td>
<td>0–8.5</td>
<td>5 + top</td>
<td>1</td>
<td>1C</td>
<td>XERO</td>
<td>McKenzie (unpubl. data), D’Costa &amp; Kershaw (1997)</td>
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<td>Lake Leake</td>
<td>Australia</td>
<td>−37.650</td>
<td>140.583</td>
<td>150</td>
<td>%Count</td>
<td>Swamp</td>
<td>Woodland</td>
<td>0–8.5</td>
<td>5 + top</td>
<td>4</td>
<td>1C</td>
<td>DSFW; DFW</td>
<td>Dodson (1974b)</td>
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<td>−37.650</td>
<td>140.583</td>
<td>150</td>
<td>Count</td>
<td>Swamp</td>
<td>Woodland</td>
<td>0–8.5</td>
<td>5 + top</td>
<td>4</td>
<td>1C</td>
<td>DFW; DFW</td>
<td>Dodson (1974b)</td>
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<td>Lake Majo</td>
<td>Indonesia</td>
<td>−1.183</td>
<td>127.483</td>
<td>140</td>
<td>Count</td>
<td>Swamp</td>
<td>Gymnostoma–Pandanus scrub and sedgeland</td>
<td>0–4.27</td>
<td>3</td>
<td>2</td>
<td>5D</td>
<td>TDFO</td>
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<td>Lake Mountain</td>
<td>Australia</td>
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<td>145.875</td>
<td>1440</td>
<td>%Count</td>
<td>Swamp</td>
<td>Subalpine woodland</td>
<td>0–6.5</td>
<td>1 + top</td>
<td>1</td>
<td>1D</td>
<td>DFW</td>
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<td>Lake Purrembete</td>
<td>Australia</td>
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<td>143.217</td>
<td>140</td>
<td>%Count</td>
<td>Swamp</td>
<td>Open woodland-grassland</td>
<td>0–6.5</td>
<td>1</td>
<td></td>
<td>XERO</td>
<td>DSFW</td>
<td>Penny (unpubl. data), D’Costa &amp; Kershaw (1997)</td>
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<td>Lake Ranfurlie E.</td>
<td>Australia</td>
<td>−34.183</td>
<td>142.117</td>
<td>40</td>
<td>%Count</td>
<td>Lake</td>
<td>Shrubland</td>
<td>0–6.5</td>
<td>1</td>
<td></td>
<td>XERO</td>
<td>DSFW</td>
<td>McKenzie (unpubl. data), D’Costa &amp; Kershaw (1997)</td>
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<tr>
<td>Location</td>
<td>Country</td>
<td>Longitude</td>
<td>Latitude</td>
<td>Count Type</td>
<td>Province</td>
<td>Vegetation Details</td>
<td>Modern Methods</td>
<td>Authors (Years)</td>
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<td></td>
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<tr>
<td>Lake Selina</td>
<td>Australia</td>
<td>-41.883 145.600</td>
<td>516</td>
<td>Count Lake</td>
<td>Closed forest, degraded to heath in immediate vicinity of lake</td>
<td>0–70</td>
<td>4 (2 not used) + JAMS (1 not used) + 6 U/Th (3 not used)</td>
<td>1 Modern WSFW COCO SEAPD</td>
<td>Pola (1993), Colhoun et al. (1999)</td>
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<tr>
<td>Lake Tagamaucia</td>
<td>Fiji Islands</td>
<td>-16.817 179.933</td>
<td>820</td>
<td>Count Swamp</td>
<td></td>
<td>0–14.3</td>
<td>6</td>
<td></td>
<td>3 n/a TDFO TDFO; INDOPAC Southern (1986), Hope et al. (1999)</td>
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<td>Lake Tali Kamg</td>
<td>Australia</td>
<td>-37.583 146.833</td>
<td>915</td>
<td>Count Swamp</td>
<td>Open forest</td>
<td>0–1.5</td>
<td>1</td>
<td></td>
<td>1 n/a DSFW DSFW SEAPD Salas (1981), D’Costa &amp; Kershaw (1997)</td>
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<tr>
<td>Lake Terang</td>
<td>Australia</td>
<td>-38.250 142.917</td>
<td>130</td>
<td>Count Swamp</td>
<td>Open woodland</td>
<td>0– c. 75 3 + top</td>
<td>1</td>
<td>DSFW DSFW SEAPD D’Costa &amp; Kershaw (1989)</td>
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<td>Lake Tiberias</td>
<td>Australia</td>
<td>-42.367 147.367</td>
<td>442</td>
<td>Count Swamp</td>
<td>Open forest</td>
<td>0–10</td>
<td>0 (corr.)</td>
<td></td>
<td>1 Modern DSFW DSFW SEAPD Macphail &amp; Jackson (1978)</td>
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<tr>
<td>Lake Turangmoroke</td>
<td>Australia</td>
<td>-37.700 142.750</td>
<td>200</td>
<td>Count Swamp</td>
<td>Open woodland-grassland</td>
<td>0–20</td>
<td>0 (poll) + top</td>
<td>11D</td>
<td>XERO DSFW SEAPD Crowley &amp; Kershaw (1994)</td>
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<td>Lake Tyrrell (Site 2)</td>
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<td>-35.250 142.867</td>
<td>17</td>
<td>Count Lake</td>
<td>Open scrub-heath</td>
<td>0–10</td>
<td>0 (sed corr.)</td>
<td>17</td>
<td>XERO DSFW SEAPD Luly (1993)</td>
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<tr>
<td>Lake Vera</td>
<td>Australia</td>
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<td>560</td>
<td>Count Lake</td>
<td>Closed forest</td>
<td>0–12</td>
<td>3 + top</td>
<td>14C</td>
<td>CTRF CTRF SEAPD Macphail (1979)</td>
<td></td>
<td></td>
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<td>Lake Wangsom</td>
<td>Australia</td>
<td>-38.350 142.600</td>
<td>100</td>
<td>Count Lake</td>
<td>Open woodland</td>
<td>0–43</td>
<td>8 (1 not used)</td>
<td>17</td>
<td>DSFW DSFW SEAPD Edney et al. (1990)</td>
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<td>Lake Wellington</td>
<td>Australia</td>
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<td>20</td>
<td>Count Swamp</td>
<td>Open forest-woodland</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
<td>1 n/a DSFW DSFW SEAPD Reid (1989), D’Costa &amp; Kershaw (1997)</td>
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<tr>
<td>Lamington National Park 1 Australia</td>
<td>-28.200 153.167</td>
<td>900</td>
<td>Count</td>
<td>Moss polster Microphyll moss forest</td>
<td>Modern 0</td>
<td></td>
<td></td>
<td>1 Modern WTRF CTRF Kershaw (1976)</td>
<td></td>
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<tr>
<td>Lamington National Park 2 Australia</td>
<td>-28.200 153.167</td>
<td>750</td>
<td>Count</td>
<td>Moss polster Simple notophyll evergreen vine forest (lower montane)</td>
<td>Modern 0</td>
<td></td>
<td></td>
<td>1 Modern WTRF WTRF Kershaw (1976)</td>
<td></td>
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<tr>
<td>Lamington National Park 3 Australia</td>
<td>-28.200 153.167</td>
<td>600</td>
<td>Count</td>
<td>Moss polster Complex notophyll vine forest</td>
<td>Modern 0</td>
<td></td>
<td></td>
<td>1 Modern TRFO WTRF Kershaw (1976)</td>
<td></td>
<td></td>
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<td>Lanyon House</td>
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<td>-35.483 149.068</td>
<td>578</td>
<td>Count Soil</td>
<td>Savanna woodland, pasture, former agricultural field</td>
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<td></td>
<td></td>
<td>8 XERO XERO; INDOPAC Hope &amp; O’Dea (unpubl. data)</td>
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<tr>
<td>Larvita Tam</td>
<td>PNG</td>
<td>-18.384 147.367 3640</td>
<td>Count Swamp</td>
<td>Alpine grassland</td>
<td>0–13</td>
<td>3</td>
<td></td>
<td>1 TUND XERO INDOPAC Hope (1980), Hope &amp; O’Dea (unpubl. data)</td>
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<td>Lashmar’s Lagoon</td>
<td>Australia</td>
<td>-35.767 138.067</td>
<td>2</td>
<td>Count Swamp</td>
<td>Open woodland</td>
<td>0–7</td>
<td>5</td>
<td></td>
<td>1 n/a DSFW DSFW SEAPD Clark (1983a,b), D’Costa &amp; Kershaw (1997)</td>
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<tr>
<td>Lighthouse Swamp</td>
<td>Australia</td>
<td>-32.000 115.500</td>
<td>&lt; 25</td>
<td>Digitized Swamp</td>
<td>Acantocarpus-Stipa low dense heath</td>
<td>0–5 est.</td>
<td></td>
<td></td>
<td>1 XERO XERO Churchill (1960, 1968)</td>
<td></td>
<td></td>
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<tr>
<td>Site name</td>
<td>Latitude</td>
<td>Longitude</td>
<td>Alcohol</td>
<td>Sample type</td>
<td>Site type</td>
<td>Surrounded vegetation</td>
<td>Age range (lyr)</td>
<td>No. of 14C dates</td>
<td>No. of duplicates</td>
<td>Biomes</td>
<td>Recon.</td>
<td>Data base</td>
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<td>Liliha Core 4</td>
<td>21.35</td>
<td>−157.967</td>
<td></td>
<td>Count Swamp</td>
<td>Swamp</td>
<td>Eucalyptus erythocoys, E. marginata and Banksia woodlands</td>
<td>0–460</td>
<td>1</td>
<td>3</td>
<td>TDFO</td>
<td>STEP</td>
<td>INDOPAC</td>
<td>Ward (unpubl. data)</td>
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<td>Loch McNess Swamp</td>
<td>−31.533</td>
<td>115.667</td>
<td>&lt; 20</td>
<td>Count Swamp</td>
<td>Swamp</td>
<td>Eucalyptus erythocoys, E. marginata and Banksia woodlands</td>
<td>0–8.9</td>
<td>2</td>
<td>2</td>
<td>DSFW</td>
<td>DSFW</td>
<td>DSFW;</td>
<td>Newcombe &amp; Pickett (1993)</td>
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<td>147.683</td>
<td>1</td>
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<td>Swamp</td>
<td>Open forest-woodland</td>
<td>0–7.5</td>
<td>2</td>
<td>+ top 1</td>
<td>Modern</td>
<td>DSFW</td>
<td>DSFW;</td>
<td>Hookey et al. (1980)</td>
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<td>Long Swamp</td>
<td>−38.084</td>
<td>141.083</td>
<td>2</td>
<td>%Count Swamp</td>
<td>Swamp</td>
<td>Open forest</td>
<td>0–6</td>
<td>2</td>
<td>1</td>
<td>Modern</td>
<td>DSFW</td>
<td>DSFW;</td>
<td>Head (1988)</td>
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<td>−2.933</td>
<td>151.417</td>
<td>30</td>
<td>Count Swamp</td>
<td>Swamp</td>
<td>Disturbed lowland tropical rain forest and grassland</td>
<td>0–2.4</td>
<td>n/a</td>
<td>2</td>
<td>n/a</td>
<td>TDFO</td>
<td>TRFO;</td>
<td>Hope et al. (1999)</td>
</tr>
<tr>
<td>Malal Swamp</td>
<td>−17.600</td>
<td>145.617</td>
<td>520</td>
<td>Count Moss polster</td>
<td>polster</td>
<td>Complex mesophyll vine forest</td>
<td>Modern</td>
<td>0</td>
<td>1</td>
<td>Modern</td>
<td>TRFO</td>
<td>TDFO</td>
<td>Kershaw (1973b)</td>
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<td>Manton Core 1 W-E Transect</td>
<td>−5.733</td>
<td>144.167</td>
<td>1580</td>
<td>Count Soil</td>
<td>Soil</td>
<td>Regrowth shrubs in grassland/disturbed</td>
<td>Modern</td>
<td>0</td>
<td>1</td>
<td>STEP</td>
<td>TDFO</td>
<td>INDOPAC</td>
<td>Powell (1970)</td>
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<td>144.167</td>
<td>1580</td>
<td>Count Soil</td>
<td>Soil</td>
<td>Swampland</td>
<td>n/a</td>
<td>n/a</td>
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<td>TRFO</td>
<td>DSFW</td>
<td>SEAPD</td>
<td>Powell (1970)</td>
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<td>Mathinna Plain</td>
<td>−41.367</td>
<td>147.817</td>
<td>950</td>
<td>%Count Swamp</td>
<td>Swamp</td>
<td>Buttongrass moorland-grassland</td>
<td>Modern</td>
<td>0</td>
<td>1</td>
<td>TRFO</td>
<td>STEP</td>
<td>DSFW;</td>
<td>Thomas (unpubl. data), D’Costa &amp; Kershaw (1997)</td>
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<td>100</td>
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<td>Swamp</td>
<td>Open forest-woodland</td>
<td>0–5</td>
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<td>1</td>
<td>n/a</td>
<td>DSFW</td>
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<td>Robertson (1986), D’Costa &amp; Kershaw (1997)</td>
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<td>polster</td>
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<td>Modern</td>
<td>0</td>
<td>1</td>
<td>Modern</td>
<td>TRFO</td>
<td>WTRF;</td>
<td>Kershaw (1973b)</td>
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<td>Melaleuca Inlet</td>
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<td>146.083</td>
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<td>Swamp</td>
<td>Buttongrass moorland-grassland</td>
<td>0–11.8</td>
<td>4</td>
<td>1</td>
<td>5D</td>
<td>STEP</td>
<td>WSFW</td>
<td>Thomas (1995)</td>
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<td>Micalong Swamp</td>
<td>−35.334</td>
<td>148.520</td>
<td>980</td>
<td>Count Swamp</td>
<td>Swamp</td>
<td>Eucalyptus dalrympleana open forest</td>
<td>0–7</td>
<td>n/a</td>
<td>1</td>
<td>n/a</td>
<td>DSFW</td>
<td>DSFW;</td>
<td>Kemp (unpubl. data)</td>
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<td>Middle Patriarch</td>
<td>−39.985</td>
<td>148.167</td>
<td>20</td>
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<td>Swamp</td>
<td>Open forest-heath</td>
<td>0–10.1</td>
<td>3</td>
<td>+ top 1</td>
<td>1D</td>
<td>DSFW</td>
<td>DSFW;</td>
<td>Ladd et al. (1992)</td>
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<td>Mirriwinni</td>
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<td>145.900</td>
<td>60</td>
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<td>polster</td>
<td>Complex mesophyll vine forest</td>
<td>Modern</td>
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<td>New Caledonia</td>
<td>-22.267</td>
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<td>Poets Hill Lake</td>
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<td>-41.883 145.550</td>
<td>620</td>
<td>%</td>
<td>Count</td>
<td>Swamp</td>
<td>Closed heath-sedge land, with closed temperate rain forest nearby</td>
<td>0–12</td>
<td>3 + top</td>
<td>1 2C</td>
<td>XERO</td>
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<td>Poilblue Swamp</td>
<td>Australia</td>
<td>-31.967 151.417</td>
<td>1450</td>
<td>Digitized</td>
<td>Swamp</td>
<td><em>Eucalyptus</em> open forest/ <em>Leptospermum</em> shrubland/ grassland</td>
<td>0–5.5</td>
<td>5</td>
<td>3 1D</td>
<td>DSWF</td>
<td>Dodson (1987), Dodson et al. (1986)</td>
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<td>Poley Creek</td>
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<td>-37.500 145.417</td>
<td>750</td>
<td>%</td>
<td>Count</td>
<td>Swamp</td>
<td>Tall open forest - open forest</td>
<td>0–15</td>
<td>n/a</td>
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<td>Powelltown</td>
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<td>-37.859 145.703</td>
<td>168</td>
<td>%</td>
<td>Count</td>
<td>Swamp</td>
<td>Open forest-tall open forest</td>
<td>0–6</td>
<td>2 + top</td>
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<td>DSWF</td>
<td>McKenzie (1989), McKenzie &amp; Busby (1992)</td>
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<td>Quincan Crater</td>
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<td>-17.300 145.583</td>
<td>790</td>
<td>Swamp</td>
<td>Closed forest</td>
<td>0–7.3</td>
<td>4 (1 not used)</td>
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<td>Kershaw (1971, 1973a)</td>
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<td>Rano Aroi</td>
<td>Easter Island (Chile)</td>
<td>-27.087 -109.400</td>
<td>425</td>
<td>Count</td>
<td>Swamp</td>
<td>Grasslands</td>
<td>0–37.7</td>
<td>11 (1 not used)</td>
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<td>STEP</td>
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<td>Rano Kao</td>
<td>Easter Island (Chile)</td>
<td>-27.183 109.433</td>
<td>110</td>
<td>Count</td>
<td>Swamp</td>
<td>Grasslands</td>
<td>0–1.4</td>
<td>5 (1 not used)</td>
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<td>Rano Raraku RRA3</td>
<td>Easter Island (Chile)</td>
<td>-27.133 -109.283</td>
<td>75</td>
<td>Count</td>
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<td>Grasslands</td>
<td>0–35.3</td>
<td>10 + 6 $^{210}$Pb</td>
<td>3 2D</td>
<td>STEP</td>
<td>Flenley et al. (1991)</td>
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<td>Australia</td>
<td>-41.283 147.450 870–900</td>
<td>147.400</td>
<td>Digitized</td>
<td>Swamp</td>
<td>Temperate rain forest and <em>Nothofagus cunninghamii</em> closed forest</td>
<td>0–0.2</td>
<td>1 + 8 $^{210}$Pb</td>
<td>3 1D</td>
<td>CTRF</td>
<td>Dodson et al. (1998)</td>
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<td>Australia</td>
<td>-41.296 147.400 870–900</td>
<td>147.400</td>
<td>Digitized</td>
<td>Swamp</td>
<td>Temperate rain forest and <em>Nothofagus cunninghamii</em> closed forest</td>
<td>Modern</td>
<td>1 + 15 $^{210}$Pb</td>
<td>3 1D</td>
<td>CTRF</td>
<td>Dodson et al. (1998)</td>
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<td>Ringarooma River Site 1</td>
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<td>-41.300 147.433 870–900</td>
<td>147.433</td>
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<td>Swamp</td>
<td>Temperate rain forest and <em>Nothofagus cunninghamii</em> closed forest</td>
<td>0–1</td>
<td>3</td>
<td>3 1D</td>
<td>CTRF</td>
<td>Dodson et al. (1998)</td>
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<td>2</td>
<td>3 1D</td>
<td>CTRF</td>
<td>Dodson et al. (1998)</td>
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<td>-37.334 148.833</td>
<td>1100</td>
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<td>Swamp</td>
<td>Tall open forest</td>
<td>0–5.5</td>
<td>1 + top</td>
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<td>DSWF</td>
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<td>1445</td>
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<td>0–7.4</td>
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<td>DSWF</td>
<td>Clark (1986), Clark &amp; Hope (unpubl. data)</td>
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<td>Rottnest Island (RS)</td>
<td>Australia</td>
<td>-32.000 115.500</td>
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<td>Swamp</td>
<td><em>Acanthocarpus-Stipa</em> low dense heath</td>
<td>Modern</td>
<td>0</td>
<td>1 Modern</td>
<td>XERO</td>
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<td>Country</td>
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<td>Altitude (m)</td>
<td>Sample type</td>
<td>Site type</td>
<td>Surrounding vegetation</td>
<td>Age range (kyr)</td>
<td>No. of 14C dates</td>
<td>No. of duplicates</td>
<td>DC 0 ka</td>
<td>Obs.</td>
<td>Recon.</td>
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<td>Ryans Swamp 2</td>
<td>Australia</td>
<td>−35.150, 150.650</td>
<td>1</td>
<td>Count</td>
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<td><em>Eucalyptus botryoides</em> open forest</td>
<td>0–4.5</td>
<td>3</td>
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<td>150</td>
<td>Count</td>
<td>Swamp</td>
<td>Tropical savanna</td>
<td>0–1</td>
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<td>TDFO</td>
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<td>Open forest-woodland</td>
<td>0–0.23</td>
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<td>3</td>
<td>1D</td>
<td>DSFW</td>
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<td>−32.067, 151.567</td>
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<td>Count</td>
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<td><em>Eucalyptus fastigata</em> open forest</td>
<td>0–9.3</td>
<td>2 + top</td>
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<td>&lt; 20</td>
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<td>Swamp</td>
<td>Open scrub</td>
<td>0–9.3</td>
<td>2 + top</td>
<td>3</td>
<td>1C</td>
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<td>DSFW;</td>
<td>XERO;</td>
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<td>n/a</td>
<td>1</td>
<td>n/a</td>
<td>DSFW</td>
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<tr>
<td>Site 10 Mt. Wilhelm PNG</td>
<td>−5.750, 145.017</td>
<td>3570</td>
<td>Count</td>
<td>Soil</td>
<td><em>Deschampsia</em> forest</td>
<td>Modern 0</td>
<td>1</td>
<td>Modern CTRF TDFO INDOPAC Corlett (1984a)</td>
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<tr>
<td>Site 11 Mt. Wilhelm PNG</td>
<td>−5.750, 145.017</td>
<td>3530</td>
<td>Count</td>
<td>Soil</td>
<td>Shrub-rich grassland <em>(Gleichenia, Deschampsia, Poa)</em></td>
<td>Modern 0</td>
<td>1</td>
<td>Modern STEP WTRF INDOPAC Corlett (1984a)</td>
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<td>Site 12 Mt. Wilhelm PNG</td>
<td>−5.750, 145.017</td>
<td>3570</td>
<td>Count</td>
<td>Soil</td>
<td>Shrub-rich grassland <em>(Deschampsia klossii)</em></td>
<td>Modern 0</td>
<td>1</td>
<td>Modern STEP TDFO INDOPAC Corlett (1984a)</td>
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<tr>
<td>Site 13 Mt. Wilhelm PNG</td>
<td>−5.750, 145.017</td>
<td>3570</td>
<td>Count</td>
<td>Soil</td>
<td>Shrub-rich grassland</td>
<td>Modern 0</td>
<td>1</td>
<td>Modern STEP TUND INDOPAC Corlett (1984a)</td>
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<td>−5.750, 145.017</td>
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<td>Count</td>
<td>Soil</td>
<td>Shrub-rich tussock grassland</td>
<td>Modern 0</td>
<td>1</td>
<td>Modern STEP WTRF INDOPAC Corlett (1984a)</td>
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<td>Site 15 Mt. Wilhelm PNG</td>
<td>−5.750, 145.017</td>
<td>3470</td>
<td>Count</td>
<td>Soil</td>
<td>Shrub-rich tussock grassland with <em>Cyathea</em></td>
<td>Modern 0</td>
<td>1</td>
<td>Modern STEP WTRF INDOPAC Corlett (1984a)</td>
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<tr>
<td>Site 17 Mt. Wilhelm PNG</td>
<td>−5.750, 145.017</td>
<td>3510</td>
<td>Count</td>
<td>Soil</td>
<td>Forest, mangrove/Coprosma and Poa tussock grassland</td>
<td>Modern 0</td>
<td>1</td>
<td>Modern CTRF TDFO INDOPAC Corlett (1984a)</td>
<td></td>
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<tr>
<td>Site 18 Mt. Wilhelm PNG</td>
<td>−5.750, 145.017</td>
<td>3360</td>
<td>Count</td>
<td>Soil</td>
<td>Shrub-rich <em>Deschampsia klossii</em> tussock grassland</td>
<td>Modern 0</td>
<td>1</td>
<td>Modern STEP TDFO INDOPAC Corlett (1984a)</td>
<td></td>
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<tr>
<td>Site 20 Mt. Wilhelm PNG</td>
<td>−5.750, 145.017</td>
<td>3680</td>
<td>Count</td>
<td>Soil</td>
<td><em>Ramunculus, Gentiana, Potentilla, Deschampsia klossii</em> tussock grassland</td>
<td>Modern 0</td>
<td>1</td>
<td>Modern STEP TDFO INDOPAC Corlett (1984a)</td>
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<tr>
<td>Site 21 Mt. Wilhelm PNG</td>
<td>−5.750, 145.017</td>
<td>3680</td>
<td>Count</td>
<td>Soil</td>
<td>Shrub-rich tussock grassland</td>
<td>Modern 0</td>
<td>1</td>
<td>Modern STEP WTRF INDOPAC Corlett (1984a)</td>
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<td>3680</td>
<td>Count</td>
<td>Soil</td>
<td>Shrub-rich grassland</td>
<td>Modern 0</td>
<td>1</td>
<td>Modern STEP WTRF INDOPAC Corlett (1984a)</td>
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<td>Site 23 Mt. Wilhelm PNG</td>
<td>−5.750, 145.017</td>
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<td>Count</td>
<td>Soil</td>
<td><em>Coprosma</em>/<em>Poa</em> tussock grassland</td>
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<td>1</td>
<td>Modern STEP WTRF INDOPAC Corlett (1984a)</td>
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<td>Site 25 Mt. Wilhelm PNG</td>
<td>−5.750, 145.017</td>
<td>3760</td>
<td>Count</td>
<td>Soil</td>
<td><em>Deschampsia klossii</em> tussock grassland</td>
<td>Modern 0</td>
<td>1</td>
<td>Modern STEP WTRF INDOPAC Corlett (1984a)</td>
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<td>Longitude</td>
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<td>Count Type</td>
<td>Soil Description</td>
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<td>Step</td>
<td>WTRF</td>
<td>INDOPAC</td>
<td>Reference</td>
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<td>Mt. Wilhelm</td>
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<td>145.017</td>
<td>3630</td>
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<td>Soil Brachypodium-Carex fen</td>
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<td>Mt. Wilhelm</td>
<td>-5.750</td>
<td>145.017</td>
<td>3660</td>
<td>Count</td>
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<td>Modern</td>
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<td>Mt. Wilhelm</td>
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<td>145.017</td>
<td>3460</td>
<td>Count</td>
<td>Soil Deschampsia klossii tussock grassland</td>
<td>Modern</td>
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<td>Mt. Wilhelm</td>
<td>-5.750</td>
<td>145.017</td>
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<td>Count</td>
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<td>Modern</td>
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<td>Mt. Wilhelm</td>
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<td>145.017</td>
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<td>Count</td>
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<td>0</td>
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<td>Mt. Wilhelm</td>
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<td>3740</td>
<td>Count</td>
<td>Soil Tussock grassland (Carex sp.)/disturbed</td>
<td>Modern</td>
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<td>Mt. Wilhelm</td>
<td>-5.750</td>
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<td>Mt. Wilhelm</td>
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<td>145.017</td>
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<td>Soil Forest</td>
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<td>-5.750</td>
<td>145.017</td>
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<td>Count</td>
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<td>Soil Strophelia, Coprosma, Gaultheria</td>
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<td>3670</td>
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<td>Soil Coprosma, Poa, Monostachya, Ranunculus, Astelia/disturbed</td>
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<td>145.017</td>
<td>3320</td>
<td>Count</td>
<td>Soil Tussock grassland/disturbed</td>
<td>Modern</td>
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<td>1</td>
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<td>Sluice Creek</td>
<td>33.021</td>
<td>119.915</td>
<td>127</td>
<td>1040</td>
<td>Count Trap</td>
<td>Moss polster</td>
<td>Modern</td>
<td>0</td>
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<td>Smelter Creek</td>
<td>Australia</td>
<td>-42.184</td>
<td>145.633</td>
<td>210</td>
<td>%Count</td>
<td>Swamp Scrub-closed forest</td>
<td>0–12</td>
<td>2</td>
<td>1</td>
<td>0</td>
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<td>0</td>
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<td>Snobs Creek</td>
<td>Australia</td>
<td>-37.391</td>
<td>145.928</td>
<td>930</td>
<td>%Count</td>
<td>Swamp Tall open forest</td>
<td>0–12</td>
<td>1 + top</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<tr>
<td>Snow Hill Marshes</td>
<td>Australia</td>
<td>-41.900</td>
<td>147.850</td>
<td>885</td>
<td>%Count</td>
<td>Swamp Tall open forest</td>
<td>n/a</td>
<td>n/a</td>
<td>1</td>
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<td>n/a</td>
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<td>Stencils Cave</td>
<td>Australia</td>
<td>-31.467</td>
<td>129.700</td>
<td>70–100</td>
<td>Count Soil</td>
<td>Soil Mallee heath</td>
<td>Modern</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<tr>
<td>Stirling Moss</td>
<td>Australia</td>
<td>-37.133</td>
<td>146.500</td>
<td>1650</td>
<td>%Count</td>
<td>Swamp Subalpine woodland</td>
<td>Modern</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<td>Stockyard Swamp</td>
<td>Australia</td>
<td>-40.550</td>
<td>144.750</td>
<td>65</td>
<td>Count Swamp</td>
<td>Swamp Eucalypt woodland and pasture</td>
<td>0 to &gt; 4</td>
<td>1 + top</td>
<td>2</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Storm Creek</td>
<td>Australia</td>
<td>-37.444</td>
<td>145.807</td>
<td>1177</td>
<td>%Count</td>
<td>Swamp Open forest-tall open forest</td>
<td>0–17.5</td>
<td>3 + top</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<tr>
<td>Summit Bog</td>
<td>PNG</td>
<td>-5.782</td>
<td>145.033</td>
<td>4420</td>
<td>Count Swamp</td>
<td>Swamp Alpine tussock grassland (tundra)</td>
<td>0–10.7</td>
<td>3 (1 not used)</td>
<td>7</td>
<td>TUND</td>
<td>WTRF; COCO; WTRF</td>
<td>0</td>
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<tr>
<td>Site name</td>
<td>Country</td>
<td>Latitude</td>
<td>Longitude</td>
<td>Altitude (m)</td>
<td>Sample type</td>
<td>Site type</td>
<td>Surrounding vegetation</td>
<td>Age range (kyr)</td>
<td>No. of 14C dates</td>
<td>No. of duplicates</td>
<td>DC 0 ka</td>
<td>Biomes</td>
<td>Obs.</td>
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<tr>
<td>Sundown Point</td>
<td>Australia</td>
<td>-41.117</td>
<td>144.667</td>
<td>5</td>
<td>Count</td>
<td>Swamp</td>
<td><em>Epacris-Leptospermum</em> heath</td>
<td>0–3.5</td>
<td>2 + top</td>
<td>3</td>
<td>1C</td>
<td>XERO; DSFW; INDOPAC</td>
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<tr>
<td>Supulah Hill</td>
<td>Irian Jaya (Indonesia)</td>
<td>-4.117</td>
<td>138.967</td>
<td>1580</td>
<td>Count</td>
<td>Swamp</td>
<td>Lower montane closed forest/agriculture and regrowth forest</td>
<td>0–3.3</td>
<td>3</td>
<td>3</td>
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<td>WTRF; TDFO; INDOPAC</td>
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<tr>
<td>Tamariinga Billabong</td>
<td>Australia</td>
<td>-37.150</td>
<td>145.483</td>
<td>160</td>
<td>%Count</td>
<td>Swamp</td>
<td>Forest</td>
<td>n/a</td>
<td>n/a</td>
<td>1</td>
<td>n/a</td>
<td>WTRF</td>
<td></td>
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<td>Taroutta Swamp</td>
<td>Australia</td>
<td>-35.668</td>
<td>148.033</td>
<td>780</td>
<td>Count</td>
<td>Swamp</td>
<td><em>Eucalyptus delegans</em> tree/temperate sclerophyll forest</td>
<td>0.2–9.8</td>
<td>2</td>
<td>2</td>
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<td>DSFW; DSFW; INDOPAC</td>
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<tr>
<td>Tam Shelf</td>
<td>Australia</td>
<td>-42.667</td>
<td>146.500</td>
<td>1158</td>
<td>%Count</td>
<td>Swamp</td>
<td>Sedgeland-herbfield</td>
<td>0–10</td>
<td>3</td>
<td>1</td>
<td>n/a</td>
<td>TUNDF; CTRF; SEAPD</td>
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<td>Tam Shelf, Mt Field</td>
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<td>145.583</td>
<td>1000</td>
<td>%Count</td>
<td>Swamp</td>
<td>Subalpine forest-alpine heath</td>
<td>0–9.8</td>
<td>2 + top</td>
<td>1</td>
<td>2C</td>
<td>XERO; CTRF; SEAPD</td>
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<tr>
<td>Teapangamba</td>
<td>PNG</td>
<td>-5.787</td>
<td>145.008</td>
<td>3820</td>
<td>%Count</td>
<td>Swamp</td>
<td><em>Corypha alpina, Scripus</em> and <em>Caren</em> grass bog</td>
<td>0–1.2</td>
<td>2</td>
<td>2</td>
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<td>TUNDF; TDFO; INDOPAC</td>
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<td>Thompson River</td>
<td>Australia</td>
<td>-37.750</td>
<td>146.083</td>
<td>1250</td>
<td>%Count</td>
<td>Swamp</td>
<td>Tall open forest</td>
<td>0–11.5</td>
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<td>1</td>
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<td>Micronesia</td>
<td>9.545</td>
<td>138.183</td>
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<td>Swamp</td>
<td>Local gardens, savanna with grassland</td>
<td>0–2.3</td>
<td>3</td>
<td>3</td>
<td>1D</td>
<td>TDFO; TDO; SEAPD</td>
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<td>Tidal River</td>
<td>Australia</td>
<td>-39.033</td>
<td>146.317</td>
<td>2</td>
<td>Count</td>
<td>Swamp</td>
<td><em>Eucalyptus obliqua</em> tall forest</td>
<td>0–4.9</td>
<td>2</td>
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<td>Tiger Snake Swamp</td>
<td>Australia</td>
<td>-38.117</td>
<td>145.267</td>
<td>60</td>
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<td>Swamp</td>
<td>Woodland</td>
<td>0–7</td>
<td>1</td>
<td>1</td>
<td>Modern</td>
<td>DSFW; DSFW; SEAPD</td>
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<td>Tinaroo Range</td>
<td>Australia</td>
<td>-17.117</td>
<td>145.567</td>
<td>1160</td>
<td>Count</td>
<td>Moss polster</td>
<td>Simple notophyll-microphyll vine forest</td>
<td>Modern 0–1</td>
<td>1</td>
<td>1</td>
<td>Modern</td>
<td>WTRF; WTRF</td>
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<td>-17.117</td>
<td>145.517</td>
<td>1070</td>
<td>Count</td>
<td>Moss polster</td>
<td>Wet sclerophyll forest</td>
<td>Modern</td>
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<td>1</td>
<td>Modern</td>
<td>WTRF; WTRF</td>
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<td>145.818</td>
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<td>Swamp</td>
<td>Tall open forest</td>
<td>0–32</td>
<td>1 + top</td>
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<td>1D</td>
<td>DSFW; DSFW; SEAPD</td>
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<td>-32.000</td>
<td>151.467</td>
<td>1500</td>
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<td><em>Eucalyptus pauciflora</em> open forest</td>
<td>0–3</td>
<td>3 (1 dup)</td>
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<td>1C</td>
<td>DSFW</td>
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<td>-38.317</td>
<td>142.367</td>
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<td>Lake</td>
<td>Open forest-woodland</td>
<td>0–20</td>
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<td>DSFW; DSFW; SEAPD</td>
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<tr>
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<td>142.367</td>
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<td>%Count</td>
<td>Swamp</td>
<td>Open forest-woodland</td>
<td>0–20</td>
<td>6</td>
<td>1</td>
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<td>DSFW; DSFW; SEAPD</td>
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<td>Location</td>
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<td>Site Name</td>
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<td>Lat/Long</td>
<td>Sample Size</td>
<td>Count Type</td>
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<td>Age (0 to &gt;)</td>
<td>Species/Forest Type</td>
<td>Autochronology</td>
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<td>PNG</td>
<td>(Core 1)</td>
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<td>2300</td>
<td>Swamp Mid-montane mixed forest with <em>Castanopsis</em>, <em>Lithocarpus</em> and <em>Araucaria</em></td>
<td>0 to &gt; 13</td>
<td>5 D, CTRF</td>
<td></td>
<td>Haberle (1998), Haberle et al. (1999, 2001)</td>
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</tr>
<tr>
<td>Tullabardine Dam</td>
<td>Australia</td>
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<td></td>
<td>145.800</td>
<td>Swamp Tall open forest – closed forest (eucalypts and cool-temperate rain forest)</td>
<td>0–43.8</td>
<td>1 C, WSF, CTRF</td>
<td></td>
<td>Colbourn &amp; van de Geer (1986)</td>
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<td>145.450</td>
<td>Swamp <em>Prosopis</em>, <em>Leucaena</em>, and <em>Pithecellobium</em></td>
<td>0–7</td>
<td>6 Modern, n/a, TDO, XERO, HDOP, WTRF</td>
<td></td>
<td>Kershaw (1976), Ward (unpubl. data), Hope et al. (1999)</td>
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<tr>
<td>Uko’a Pond 2</td>
<td>Hawaii (USA)</td>
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<td>145.450</td>
<td>Swamp <em>Prosopis</em>, <em>Leucaena</em>, and <em>Pithecellobium</em></td>
<td>0–4.3</td>
<td>2 Modern, TDO, STEP, HDOP, WTRF, INDOPAC</td>
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<td>Ward (unpubl. data), Hope et al. (1999)</td>
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<td>Umbamambuno (Imbuka)</td>
<td>PNG</td>
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<td>Swamp <em>Prosopis</em>, <em>Leucaena</em>, and <em>Pithecellobium</em></td>
<td>0–4.3</td>
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<td>Ward (unpubl. data), Hope et al. (1999)</td>
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<td>Australia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>146.250</td>
<td>Swamp Subalpine forest-alpine heath</td>
<td>0–10.5</td>
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<td>Macphail (1986)</td>
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<td>Southern (1986), Hope et al. (1999)</td>
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<td>1 TDO, TDFO, INDOPAC</td>
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<td>Swamp Garden area</td>
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<td>Powell (1970)</td>
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<td>Longitude (°)</td>
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<tr>
<td>Weylk 8</td>
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<td>Soil</td>
<td>Garden area</td>
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<td>TRFO WTRF</td>
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<td>Open forest</td>
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<td>Modern DSFW CTRF; TUND; INDOPAC</td>
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Table 1 continued
Table 2 Characteristics of the 6000 and 18,000 $^{14}$C yr BP pollen sites from the SEAPAC region. The sites are arranged alphabetically by name. Latitude and longitude are given in decimal degrees, with N and E conventionally indicated as +, and S and W as −. Dating control (DC) follows the COHMAP dating scheme, as described by Yu & Harrison (1995). The codes used for reconstructed biomes are defined in Table 5.

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<th>Country</th>
<th>Latitude (°)</th>
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<th>Altitude (m)</th>
<th>Sample type</th>
<th>Site type</th>
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References:
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- Polach & Singh (1980), Green et al. (1988), Hope et al. (2000)
- Pickett (1997)
- Dodson (1987), Dodson et al. (1986)
- Raine (1974, 1982)
- SEAPD Dodson & Wilson (1975)
- INDOPAC Goddington (1983)
- Churchill (1968)
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Palaeovegetation patterns for Australia and Southeast Asia

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| McKenzie & Busb...
of vegetation types sampled, on earlier continental-scale compilations of pollen data from this region. Prior to the present compilation, the most extensive compilation of fossil pollen data for the region included data from only 77 sites, of which only five included the LGM (Harrison & Dodson, 1993). The regional compilations covering Southeast Australia (Kershaw, 1998) and the tropical western Pacific (Hope et al., 1999) also contain a more limited selection of sites than the SEAPAC data sets.

**Biomization**

**Conceptual basis**

The biomization procedure (Prentice et al., 1996) is based on (1) the allocation of pollen taxa to PFTs, (2) the definition of biomes in terms of their constituent PFTs, (3) the calculation of the affinity between a pollen spectrum and every biome and (4) the allocation of the pollen spectrum to the biome to which it has the highest affinity. The affinity score is calculated taking into account both the presence of taxa characteristic of specific PFTs and the relative abundance of these taxa. In cases where the pollen spectrum has equal affinity with more than one biome, a tie-breaking rule is applied to determine the biome allocation. This tie-breaking rule gives preference to biomes whose constituent PFTs form a subset of the suite of PFTs characteristic of another biome.

The large-scale geographical distribution of PFTs is determined by climatic controls on plant physiology (Woodward, 1987; Prentice et al., 1992a; Haxeltine & Prentice, 1996; Harrison et al., in press). In the SEAPAC region, the most important climate gradients are winter temperature and moisture availability. The length and warmth of the growing season is a secondary constraint which in this region is important only at the highest elevations. The division of vegetation into biomes (how many, and the precise location of boundaries) is to a greater or lesser extent arbitrary. The biomization procedure requires that this division is made on taxonomic grounds, such that each biome is defined by a unique set of PFTs. However, the PFT differentiating one biome from another is not required to be the dominant or most abundant life-form. Furthermore, it is rare for a PFT to occur in only one biome, and individual PFTs generally occur in a range of biomes. Given that the distribution of PFTs is determined by climate, the conceptualization of the relationship among biomes in bioclimatic space is a fundamental step in the analysis (Fig. 1). In practice, the biomization procedure is a test of how well this conceptual scheme works.

**Application of the biomization procedure in the SEAPAC region**

Pollen taxa were assigned to PFTs (Tables 3 and 4) on the basis of our knowledge of the ecology and biology of individual plants, and on descriptions of the flora and vegetation given in Jessop (1981), Petheram & Kok (1983), Brock (1993), Ashton

The SEAPAC biomization recognizes 25 PFTs (Table 3). We considered the suite of PFTs defined in biomizations of other regions of the world (Prentice et al., 1996; Jolly et al., 1998b; Tarasov et al., 1998; Yu et al., 1998; Edwards et al., 2000; Elenga et al., 2000; Takahara et al., 2000; Thompson & Anderson, 2000; Williams et al., 2000; Yu et al., 2000; Bigelow et al., 2003), adopting those PFTs that appeared to be appropriate for the SEAPAC region (e.g. tropical evergreen malacophyll broad-leaved tree), subdividing one PFT (warm-temperate evergreen broad-leaved tree), and creating four new PFTs (evergreen sclerophyll broad-leaved tree, cool-temperate sclerophyll broad-leaved low or high shrub, temperate malacophyll broad-leaved low or high shrub, tropical evergreen broad-leaved low or high shrub). We have adopted a PFT-naming convention (based on life-form, leaf-form, phenology and bioclimatic tolerance) proposed as part of a global PFT scheme that is currently under development (Harrison et al., in press) and was first explicitly adopted in the context of biomization by Bigelow et al. (2003).

Warm-temperate broad-leaved evergreen trees are an important component of the SEAPAC flora. They occur where winter temperatures are relatively warm [mean temperature of the coldest month (MTCO) > 5 °C] but still too cool for tropical trees. Some species are characteristic of the temperate rain forests, growing in areas with mean annual rainfall as much as 3000 mm year⁻¹, while others are characteristic of drier environments where mean annual rainfall is < 800 mm year⁻¹. We therefore subdivided the warm-temperate broad-leaved evergreen tree category into three PFTs: drought-tolerant warm-temperate evergreen broad-leaved tree (dt-w-te.e.b.t), ubiquitous warm-temperate evergreen broad-leaved tree (w-te.e.b.t) and warm-temperate evergreen broad-leaved rain forest tree (w-te.e.b.raint) (Table 3). Typical taxa are Arytera in w-te.e.b.t and Lelea, Nothofagus brassii, and Poikilogyne in w-te.e.b.raint, while dt-w-te.e.b.t is characterized by sclerophyll evergreen taxa.

Evergreen sclerophyll broad-leaved trees (e.sb.t) are highly characteristic of the Gondwanan flora (Barlow, 1994). They are defined as tall-medium (35–60 m) single stem, hard-leaved, evergreen trees that are fire tolerant and well adapted to arid environments. Typical examples include trees in the genera Acacia, Eucalyptus and Melaleuca. Evergreen sclerophyll broad-leaved trees do not occur in regions where rainfall is < 500 mm year⁻¹ and are characteristic of areas where mean annual precipitation is in the range of 800–1200 mm year⁻¹.

Cool-temperate sclerophyll broad-leaved low or high shrub (c-te.sb.lhs) are hard-leaved plants that grow in regions where MTDO < 5 °C. They are a component of cool-temperate forests. Typical genera are Agastachys, Cesarrhena, Poranthera and Securingea.

Temperate malacophyll broad-leaved low or high shrubs (te.mb.lhs) are erect, low to medium (1–2 m), soft-leaved plants which are generally evergreen but may be semi-deciduous in the tropics. They have a wide temperature range but are drought intolerant. Characteristic genera include Buddleia, Crotolaria, Entada and Muehlenbeckia.
<table>
<thead>
<tr>
<th>PFT Code</th>
<th>PFT name</th>
<th>Characteristic taxa</th>
<th>Description and characteristic adaptations</th>
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<tbody>
<tr>
<td>tr.dd.mb.t</td>
<td>Tropical drought-deciduous</td>
<td>Amoora, Argyrodendron, Delarbrea</td>
<td>Frost intolerant; withstands a long dry season by shedding leaves</td>
</tr>
<tr>
<td>tr.e.mb.t</td>
<td>Tropical evergreen malacophyll</td>
<td>Darlingia, Kissodendron</td>
<td>Frost intolerant</td>
</tr>
<tr>
<td>c-te.e.b.t</td>
<td>Cool-temperate evergreen</td>
<td>Nothofagus moorei, Placosperrum coriaccum</td>
<td>Frost tolerant; evergreen, medium–tall (30–60 m) trees; occur in subalpine and upper cool-temperate forests</td>
</tr>
<tr>
<td>w-te.e.b.raint</td>
<td>Warm-temperate evergreen</td>
<td>Lea, Nothofagus brassii, Poikilopne</td>
<td>Medium to very tall trees (30 to &gt; 60 m); confined to areas c. 3000 mm year⁻¹ rainfall</td>
</tr>
<tr>
<td>w-te.e.b.t</td>
<td>Ubiquitous warm-temperate</td>
<td>Arytera</td>
<td>Medium to very tall trees (30 to &gt; 60 m); rainfall range 800 to &gt; 3000 mm year⁻¹</td>
</tr>
<tr>
<td>dt-w-te.e.b.t</td>
<td>Drought-tolerant warm-temperate</td>
<td>Eucalyptus calophyll</td>
<td>Medium to very tall trees (30 to &gt; 60 m); mean annual rainfall &lt; 800 mm year⁻¹</td>
</tr>
<tr>
<td>e.sb.t</td>
<td>Evergreen sclerophyll</td>
<td>Acacia, Eucalyptus, Melaleuca</td>
<td>Evergreen hard-leaved; tall-medium (35–60 m) single stem trees; fire tolerant; MTCO &lt; 12.0 °C and rainfall range of 800–1200 mm year⁻¹</td>
</tr>
<tr>
<td>te.cd.mb.t</td>
<td>Temperate cold-deciduous</td>
<td>Nothofagus gunii</td>
<td>Evergreen small-medium (&lt; 10–30 m) trees; occur in subalpine and upper cool-temperate (&gt; 600 m) forest; warm temperatures required for budburst; frost tolerant</td>
</tr>
<tr>
<td>c-te.e.n.t</td>
<td>Cool-temperate evergreen</td>
<td>Lagarostrobus, Microstrobus, Phyllocladus</td>
<td>Evergreen small-medium (&lt; 10–30 m) trees; occur in subalpine and upper cool-temperate (&gt; 600 m) forest; warm temperatures required for budburst; frost tolerant</td>
</tr>
<tr>
<td>i-te.e.n.t</td>
<td>Intermediate-temperate</td>
<td>Agathis, Araucaria, Callitris, Pinus, Podocarpus</td>
<td>Small-tall (&lt; 10–60 m) evergreen trees; warm-temperate to temperate regions, variable rainfall (&lt; 500 to &gt; 4000 mm year⁻¹); warm temperatures required for seed release</td>
</tr>
<tr>
<td>tr.e.b.lhs</td>
<td>Tropical evergreen broad-leaved low or high shrub</td>
<td>Cassia, Colubrina, Gouania, Lonicera</td>
<td>Soft or hard-leaved, erect, low to medium (1–2 m) shrubs; frost sensitive, MTCO &gt; 5 °C</td>
</tr>
<tr>
<td>te.mb.lhs</td>
<td>Temperate malacophyll broad-leaved low or high shrub</td>
<td>Buddleia, Crotalaria, Entada, Muehlenbeckia</td>
<td>Erect, low-medium (1–2 m) shrubs, usually evergreen, or semi-deciduous soft-leaved varieties; wide temperature range, drought tolerant</td>
</tr>
<tr>
<td>c-te.sb.lhs</td>
<td>Cool-temperate sclerophyll</td>
<td>Agastachys, Conarrhenes, Poranthera, Securingea</td>
<td>Usually evergreen hard-leaved varieties; frost tolerant</td>
</tr>
<tr>
<td>w-te.sb-lhs</td>
<td>Warm-temperate sclerophyll</td>
<td>Hypocalymma</td>
<td>Usually evergreen hard-leaved varieties; MTCO &gt; 5 °C; occur in tropical rain forest and seasonal forests or subtropical/ montane environments</td>
</tr>
<tr>
<td>ar.ds</td>
<td>Arctic dwarf shrub</td>
<td>Vaccinium</td>
<td>Prostrate or small shrub; frost tolerant, occurs in areas where rainfall 800–2500 mm year⁻¹ and MTCO c. −6.0 °C</td>
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<td>h</td>
<td>Heath</td>
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<td>Woody shrub with narrow micro-sclerophyllous (hard, leathery) leaves, usually evergreen</td>
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<tr>
<td>tr-di.fb</td>
<td>Tropical drought-intolerant</td>
<td>Carronia, Cudrani</td>
<td>Frost-intolerant forb</td>
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<tr>
<td>te-di.fb</td>
<td>Temperate drought-intolerant</td>
<td>Apiaceae</td>
<td>Frost-tolerant forb</td>
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<tr>
<td>eu-dt.fb</td>
<td>Eurythermic drought-tolerant</td>
<td>Asteraceae, Chenopodiaceae</td>
<td>Arid or seasonally dry environments</td>
</tr>
<tr>
<td>ar.fb</td>
<td>Arctic forb</td>
<td>Astelia, Asteraceae</td>
<td>Cold and frost tolerant, usually evergreen and restricted to montane areas</td>
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<tr>
<td>s</td>
<td>Sedge graminoid</td>
<td>Carex, Machaerina, Restionaceae</td>
<td>Grow in locally wet environments</td>
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<tr>
<td>g</td>
<td>Grass graminoid</td>
<td>Poaceae</td>
<td>Not used in biomization</td>
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<td>man</td>
<td>Mangrove</td>
<td>Avicennia, Rhizophora</td>
<td>Not used in biomization</td>
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<td>tf</td>
<td>Tree fern</td>
<td>Cynatea, Dickson</td>
<td>Not used in biomization</td>
</tr>
<tr>
<td>eu.f</td>
<td>Eurythermic fern or fern ally</td>
<td>Blechnum, Drymaria, Pteridium</td>
<td>Not used in biomization</td>
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Table 3: Definitions and characteristics of plant functional types used in the SEAPAC biomization
<table>
<thead>
<tr>
<th>Codes</th>
<th>Plant functional types</th>
<th>Pollen taxa</th>
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<tbody>
<tr>
<td>tr.dd.mb.t</td>
<td>Tropical drought-deciduous malacophyll broad-leaved tree</td>
<td>Acalypha, Alangium, Alangium villosum, Alanguma rotundifolium, Albizia,</td>
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<tr>
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<td>Alchorneaphoecia, Arenga, Argyrodendron, Argyrodendron trifoliatum,</td>
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<td>Balanops australiana, Barringtonia, Berrya, Bllepharocarya involucrigena,</td>
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<td>Bombax, Castanospora, Celtis, Cissus, Cocos nucifera, Combretaceae/</td>
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<td>Melastomataceae, Delarbre, Diospyros, Elaeodendron/Ophiorthiza,</td>
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<td>Emmenosperma, Erythrina sandwicensis, Eugenia/Tristania, Evodia,</td>
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<td>Evodia brownwickii, Fagraea, Heritiera, Hypophila, Ilex, Ilex cymosa,</td>
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<td>Irvinghaileya, Lagerstroemia, Laporta, Longetia, Macaranga, Macaranga</td>
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<td>tanarius, Macaranga/Mallotus, Maesa, Mallotus, Mallotus paniculatus,</td>
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<td>Melastoma, Melia, Meliaceae, Meliaceae/Sapotaceae, Meliosma, Melochia,</td>
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<td>Memecylon, Metrosideros, Mimosaceae, Mucuna gigantea, Myricaceae, Neonauclea,</td>
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<td>Trema, Viburnum</td>
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<td>tr.c.mb.t</td>
<td>Tropical evergreen malacophyll broad-leaved tree</td>
<td>Acacia, Acacia kao, Acacia aulacocarpa, Acalypha, Acanthaceae,</td>
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<td>Acmena, Acmena/Eugenia/Syzgium, Acronychia, Adinandra, Albizzia,</td>
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<td>Alphitonia, Anacardiaecae, Anisoptera, Antidesma, Anthera, Apocynaceae,</td>
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<td>Apolytes, Araliaceae, Archidendron, Archontophoenix, Areceaeae, Arenga,</td>
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<td>Atherospermaceseae, Baccaurea, Balanops, Berrya, Bischofia, Calamus,</td>
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<td>Calophyllum, Cauhitium, Cardwellia, Carnarvonla, Casuarina–Gymnostoma,</td>
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<td>Celtis, Cheirodendron, Cissus, Cloaxylon, Cloaxylon sandwicensis,</td>
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<td>Cleistocalyx, Clusiaeae, Codia, Collospernum, Combretaceae/Melastomataceae,</td>
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<td>Cordyline, Cunoniaceae, Cunoniaceae/Elaeocarpaceae, Cappaniopsis,</td>
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<td>Darlingia, Dillenia, Dipterocarpaceae, Dipterocarpus, Distylium stellare,</td>
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<td>Doryphora, Drypetes, Dysoxylum, Ebenaceae, Elaeocarpaceae, Elaeocarpus,</td>
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<td>Embelia, Endospermum, Engelhardtia, Eugenia/Syzgium, Eugenia, Eudolia,</td>
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<td>Euphorbiaceae, Ficus, Fagraea, Flindersia, Flindersia pimenteliana,</td>
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<td>Freycinetia, Freycinetia arborea, Ganophyllum, Gardeni, Gendarussa,</td>
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<td>Glechidion, Guiza, Gymnostoma, Halfordia scleroxyla, Heritiera, Hibbertia,</td>
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<td>Hirschies, Hymenanthera, Homalanthus, Homalium, Ilex, Irvinghaileya,</td>
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<td>Juglandaceae, Kissodendron, Lagerstroemia, Lauraceae, Barringtonia,</td>
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<td>Macaranga, Macaranga tanarius, Macaranga/Mallotus, Mallotus, Mallotus</td>
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<td>Metroxylon, Mucuna gigantea, Musgravea, Myricaceae, Myristica, Myrtaceae,</td>
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<td>Notelaea, Oraucarpus, Oleaceae, Palmae, Palaquium, Pandanus, Pandanus</td>
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<td>anisariensis, Pandanus bosinos, Pandanus tectorius, Papilionaceae,</td>
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<td>Polyscias, Pometia, Pouteria, Pouteria sandwicensis, Pritchardia, Proteaceae,</td>
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<td>Prunus, Psidium, Psychotria, Pygeum turnerianum, Randia, Raphanea,</td>
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<td>Rhamnaceae, Sapindaceae, Sapindaceae, Saurauia, Schefflera, Scolopia,</td>
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<td>Sloanea, Sphenostemon, Sterocarpus, Sterculiaceae, Strobilanthes,</td>
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<td>Symingtonia, Syncarpia, Synom, Symphlocos, Symphlocos sessilifolia,</td>
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<td>Tapinospermum, Tapinosperma, Terminalia, Tetraplasandra, Theaceae,</td>
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<td>Viburnum, Wickstronia, Wilkea, Zanthoxylum</td>
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<td>c-te.e.b.t</td>
<td>Cool-temperate evergreen broad-leaved tree</td>
<td>Acacia, Acacia/Albizzia, Anodopetalu, Araliaceae, Arenga, Aristotelia,</td>
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<td>Ascarina, Atherosperma, Daviesia, Dodonaea, Drimys, Drimys/Bubbia/</td>
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<td>Tasmaninia, Elaeocarpaceae, Elaeocarpus, Eucalyptus, Euphrybia, Homalanthus,</td>
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<td>Monimiaceae, Metrosideros, Myrtaceae, Decaspermum, Xanthomyrtus,</td>
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<td>Nothofagus, Notelaea, Nothofagus moorei, Oxylophium, Papilionaceae,</td>
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<td>Pandanus, Pomaderris, Pittosporaceae, Placospermum coriaceum, Polysoma,</td>
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<td>Polyscias, Quintinia, Rapanea, Sapindaceae, Saurauia, Schefflera, Sloanea,</td>
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<td>Sloanea, Tasmaninia, Timonius</td>
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<td>Codes</td>
<td>Plant functional types</td>
<td>Pollen taxa</td>
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<td>w-te.e.b.t</td>
<td>Ubiquitous warm-temperate evergreen broad-leaved tree</td>
<td>Acacia, Acanthaceae, Acronychia, Acalypha, Angophora/Bloodwood, Araliaceae, Arecaceae, Artyera, Ascarina, Castanopsis, Castanopsis/Lithocarpus, Cebereios, Drimys, Elaeocarpaceae, Elaeocarpus, Engelhardia, Euphorbiaceae, Euphorbiaceae, Euphorbiaceae, Flindersia, Gendarusa, Hymenanthera, Homalanthus, Homalanthus, Lithocarpus, Lithocarpus/Castanopsis, Macaranga, Macaranga/Mallotus, Macropanax, Mallotus, Metrosideros, Myrtaceae, Neoucaloa, Noteliae, Papilionaceae, Papilionaceae, Pittosporaceae, Psychotria, Rhamnaceae, Sapindaceae, Sterculiaceae, Strobilanthes, Syncarpia, Tasmannia, Trenna, Urticaceae, Urticaceae/Moraceae, Wickstromia</td>
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<td>dt-w-te.e.b.t</td>
<td>Drought-tolerant warm-temperate evergreen broad-leaved tree</td>
<td>Angophora, Casuarina, Casuarinaceae, Eucalyptus bloodwood type, Eucalyptus calophylla, Eucalyptus cornuta, Eucalyptus diversicolor, Eucalyptus eugenii, Eucalyptus ficifolia, Eucalyptus gomphocephela, Eucalyptus guifolii, Eucalyptus jacksoni, Eucalyptus luxophleba, Eucalyptus marginata, Eucalyptus megacarpa, Eucalyptus reantheroid, Eucalyptus wandoo, Grevilla, Gyrostemonaceae, Leucopogon, Malvaceae, Melaleuca, Proteaceae, Santalaceae</td>
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<tr>
<td>e.sh.t</td>
<td>Evergreen sclerophyll broad-leaved tree</td>
<td>Acacia, Agonis, Angophora, Angophora/Bloodwood, Banksia, Bursaria, Bursaria spinosa, Calothanusi, Casuarina, Casuarinaceae, Corymbia calophylla, Daviesia, Dodonaea, Dodonaea viscosa, Eucalyptus, Eucalyptus accedens, Eucalyptus bloodwood type, Eucalyptus cornuta, Eucalyptus ficifolia, Eucalyptus gomphocephela, Eucalyptus luxophleba, Eucalyptus marginata, Eucalyptus megacarpa, Eucalyptus reantheroid, Eucalyptus wandoo, Grevilla, Gyrostemonaceae, Leucopogon, Malvaceae, Melaleuca, Proteaceae, Santalaceae</td>
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<tr>
<td>te.cd.mb.t</td>
<td>Temperate cold-deciduous broad-leaved tree</td>
<td>Achnas, Myricaceae, Nothofagus gnnii, Sesbania</td>
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<td>c-te.e.n.t</td>
<td>Cool-temperate evergreen needle-leaved tree</td>
<td>Athrotaxis/Disclma, Athrotaxis, Dacrydium, Dacrycarpus, Dacrycarpus imbricatus, Gymnospermaeae, Lagarotrobus, Microacrychs, Microstrobos, Papuacedrus, Phyllocladus, Podocarpus, Podocarpacaeae, Podocarpus lawrencii</td>
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<tr>
<td>i-te.e.n.t</td>
<td>Intermediate-temperate evergreen needle-leaved tree</td>
<td>Agathis, Araucaria, Araucaraceae, Callitris, Callitris/Cupressaceae, Dacrydium, Dacrycarpus, Dacrycarpus imbricatus, Gymnospermaeae, Neocalitropsis, Picea, Pinus, Pinaceae, Podocarpus, Podocarpacaeae, Podocarpus lawrencii</td>
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<tr>
<td>tr.e.b.lhs</td>
<td>Tropical evergreen broad-leaved low or high shrub</td>
<td>Aboutulon, Adinandra, Alyxia, Araliaoeae, Ardisia, Boreria, Brownlowia, Caesalpinaceae, Canthium, Cassia, Celastris, Cheirodendron, Calobrina, Cordyline, Conifereaeae, Conifereaeae/Elaeocarpaceae, Cyrtandra, Daphnephyllia, Dolicholobium, Dodonaea, Garcinia, Gardenia, Goodeniaeae, Gouania, Hedysotis, Hedysotis vestitas, Helisia javanica, Hibiscus, Hiptage, Ixora, Johnsonia, Kanaloa kahoolowensis, Lamiaceae, Luecaema, Lonicera, Macropanax, Malvaceae, Maustizia, Medinilla, Melastoma, Melastomataceae, Memecylon, Menispermeaeae, Moraceae, Myrica, Myricaceae, Myrica javanica, Nepenthes, Nesolamia pynesiscum, Nestigis, Nestigis sandwicensis, Nyctaginaceae, Pansonia, Petalostigma, Piper, Platypedium, Polycia, Portulacaceae, Rauwolfia, Rhus, Schefflera, Schuurmansia, Sesbania, 1416</td>
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Table 4 continued
### Table 4 continued

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<tr>
<th>Codes</th>
<th>Plant functional types</th>
<th>Pollen taxa</th>
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<tr>
<td>te.mb.lhs</td>
<td>Temperate malacophyll broad-leaved low or high shrub</td>
<td><em>Sphenostemon, Staurophyra elegans, Stenogyne, Stephelia, Styrphelia tumeaimeae, Symplaco, Symplaco sessilifolia, Tarenna fragans, Theaceae, Tournefortia, Uncaria/Wendlandia, Verbenaceae, Viburnum, Vitaceae, Wendlandia</em></td>
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<td>c-te.sb.lhs</td>
<td>Cool-temperate sclerophyll broad-leaved low or high shrub</td>
<td><em>Buddleia, Crotalaria incana, Entada, Gastrolobium, Hibbertia, Lonchocarpus, Maehlenbeckia, Massarula, Pomaderris, Proteaceae, Rhododendron, Rutaceae, Salvia, Styphelia, Tinospora</em></td>
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<td>w-te.sb.lhs</td>
<td>Warm-temperate sclerophyll broad-leaved low or high shrub</td>
<td><em>Acacia, Agastachys, Astroloma/Acrotriche, Astroloma, Baeckea, Banksia, Banksia marginata, Bauera, Boronia, Bossiaea, Centarrhenes, Coprosma, Correa, Daviesia, Drimys, Epacris, Epacridaceae, Epacridaceae/Ericaceae, Epacrid/Styphelia/Leucopogon, Ericaceae, Eriostemon, Eucryphia, Goodeniaceae, Grevillea/Persoonia, Grevillea, Hakea, Hibbertia, Hymenanthera, Howe, Hovea/Bossiaea, Kunzea, Lamiaceae, Leucopogon, Leptospermum, Leptospermum/Baeckea, Leptospermum, Monotoca, Myrtaceae, Orites, Oxylabium, Papilionaceae, Pimelea, Poranthera, Poranthera microphylla, Prostanthera, Rhamnaceae, Richea, Richea continentis, Rutaceae, Sprengelia, Sprengelia incarnata, Stackhousiacae, Symplacoaceae, Tasmannia, Telopea, Tremandraceae</em></td>
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<tr>
<td>tr-di.fb</td>
<td>Tropical drought-intolerant forb</td>
<td><em>Angieteridaceae, Apiaceae, Asplenium nidus, Araceae, Boea, Brassaia actinophylia, Burmannia, Calocalosia/Alocasia, Campanulaceae, Carronnia, Cibotium, Clematis, Colysis, Commersonia, Commelina, Convolvulaceae, Convovulus, Cudrania, Deeringia, Dianella, Baccharis, Elephtopus, Ficus, Flagellaria, Gesneriaceae, Goodeniaceae, Hodgekinsonia, Hydrocotyle trifolia, Hypsiperma, Impatiens, Johnsonia, Launenbergia, Liliaceae, Lobelia, Malaisia, Morinda, Musaenda, Nephrolepis, Opiorrhiza, Opilloglossum, Plectrago zeylanica, Pothes, Pyroisoc, Rhopogon, Salvia, Schizaea, Schizaceae, Schizalema frageosum, Stephania, Syzygium, Tinospora, Uncaria/Wendlandia, Urticaceae, Urticaceae/Moraceae, Wilksostemia</em></td>
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Table 4 continued

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<th>Codes</th>
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<th>Pollen taxa</th>
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<td>eu-dt.f</td>
<td>Eurythermic drought-tolerant forb</td>
<td>Lomandra longifolia, Lomandra/Xanthorrhoea, Orchidaceae, Oxalis, Pelargonium, Pentapanax, Plantago, Plantago major, Plantago varia, Platyacea, Polygonaceae, Pueraria, Rumex, Scaevola, Schizelenu frutescens, Sida, Samolus, Stellaria, Stylidium, Stylidiaceae, Tetraphaca, Tetragonia, Thalictrum, Tremandraeceae, Trigonotis, Urticaceae, Violaceae, Wahlenbergia</td>
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</table>

Tropical evergreen broad-leaved low or high shrubs (tr.e.b.lhs) are frost sensitive species confined to regions where MTCO > 15 °C. The PFT includes both soft-leaved and hard-leaved evergreen varieties of erect, low to medium (1–2 m) shrubs. Characteristic genera include Cassia, Colubrina, Gouania and Loniceria.

We initially adopted the conceptual biome classification shown in Fig. 1. This scheme shows the relationship among biomes in bioclimate space. As Fig. 1 shows, we defined 11 biomes (Table 5), each characterized in terms of its component PFTs (Table 6). We adopted a standardized biome terminology, designed to broadly conform with the classification scheme used in the equilibrium vegetation model BIOME4 (Kaplan et al., 2003; Bigelow et al., 2003; Ni et al., in press; Surta et al., in press). However, we recognize four biomes that were not distinguished in BIOME4: warm-temperate rain forest (WTRF), CTRF, wet sclerophyll forest (WSFW), and temperate sclerophyll woodland and shrubland (DSFW). These four biomes are widely recognized by ecologists as distinctive elements of the modern landscape in the SEAPAC region (Barlow, 1981, 1994; Hope, 1996; Mueller-Dombois & Fosberg, 1998).

Temperate rain forests were first defined (Schimper, 1903) and extensively studied in Australia (Beadle, 1981; Webb & Tracey, 1981; Webb et al., 1984; Adam, 1992). Rain forests are closed-canopy forests, which nevertheless include a wide range of life-forms other than trees, and with high species diversity both in the canopy and the understorey (Adam, 1992; Busby & Brown, 1994; Webb & Tracey, 1994). Temperate rain forests are distinguished from tropical rain forests because they have fewer canopy species (Busby & Brown, 1994). Cool-temperate rain forests (CTRF) are distinguished from WTRF by the absence of buttress tree forms and lianas (Busby & Brown, 1994). WTRF and CTRF both occur in montane areas in the tropics, where they are often referred to as lower and upper montane forests, respectively (e.g. Flenley, 1996; Hope, 1996). Warm-temperate rain forests occur in scattered pockets along the coastal margin of north-eastern Australia, as far south as c. 36° S, and on mountains in the Pacific islands. The southern limit is controlled by winter temperature, as these forests do not occur in areas subject to frost. Warm-temperate rain forests are characterized by a mixture of tropical and temperate trees, shrubs and forbs (including such PFTs as tropical drought-deciduous malacophyll broad-leaved tree, tropical evergreen broad-leaved low or high shrub, tropical drought-intolerant forb, warm-temperate evergreen broad-leaved rain forest tree, temperate malacophyll broad-leaved low or high

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<tr>
<th>Biome code</th>
<th>Biome name</th>
<th>Definition</th>
<th>Characteristic species or assemblages</th>
<th>Equivalents</th>
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<tr>
<td>TRFO</td>
<td>Tropical evergreen broadleaf forest</td>
<td>Tall (&gt; 45 m), closed-canopy lowland evergreen forests. Mesophyll leaf size, MTCO &gt; 18°C, intolerant of frost</td>
<td>Agathis, Alstonia, Araucaria, Castanopsis, Celtis, Dacrydium, Eleocharpus, lianas, e.g. Freycinetia, epiphytes, e.g. Astelia</td>
<td>Lowland forests of PNG, Queensland (Australia), New Caledonia, Thailand, Malaysia, Philippines, Fiji, Solomon Islands, Vanuatu</td>
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<tr>
<td>TSFO</td>
<td>Tropical semi-evergreen broadleaf forest</td>
<td>Tall (45 m), semi-evergreen (inc. rainforest or semi-evergreen trees) closed-canopy forests and monsoon forests. Seasonally dry up to 5 months, rainfall meets 80–95% demand</td>
<td>Acalypha, Barringtonia, Bombax, Celtis, Metrosideros</td>
<td>Seasonal forests of Queensland (Australia) and Southeast Asia</td>
</tr>
<tr>
<td>TDFO</td>
<td>Tropical deciduous broadleaf forest and woodland</td>
<td>Medium-tall (10–30 m) discontinuous tree canopy, semi-evergreen woodland with xeromorphic, fire-tolerant grasslands. Characteristic of long dry season</td>
<td>Acacia, Casuarina, Lysiphyllum, Melaleuca quinquenervia (‘nialouli’), Terminalia</td>
<td>Gulf country of north-eastern Australia, New Caledonia ‘nialouli savanna’, Thailand</td>
</tr>
<tr>
<td>WTRF</td>
<td>Warm-temperate rain forest</td>
<td>Medium-tall (15–33 m) evergreen closed forest. Moisture-demanding, tolerates no freezing. Mesophyll leaf size in tropical lower montane forests</td>
<td>Araucaria, Fagaceae, Lauraceae, Eucalyptus</td>
<td>Subtropical rain forest (e.g. Queensland and northern New South Wales), sub/lower-montane tropical forests (750–1500 m), e.g. PNG, Malaya, New Caledonia</td>
</tr>
<tr>
<td>CTRF</td>
<td>Cool-temperate rain forest</td>
<td>Medium-tall, closed/open semi-evergreen forest. Temperature dependent, tolerates freezing</td>
<td>Agathis, Castanopsis, Dacrydium, Dicksonia, Ericaceae, Eucalyptus, Ilex, Lithocarpus, Metrosideros, Nothofagus, Quintana</td>
<td>Temperate rain forest of, e.g. NSW, Victoria, Tasmania. Upper montane and subalpine tropical rain forest areas (1500– to &gt; 3000– m), e.g. PNG, Queensland, New Caledonia</td>
</tr>
<tr>
<td>COCO</td>
<td>Cool evergreen needleleaf forest</td>
<td>Medium, open forest-woodlands of mixed conifers with smaller understorey trees, shrubs, herbs and grasses</td>
<td>Athrotaxis, Dacrydium, Dacrycarpus, Lagarostrobus franklinii, Microstrobos pfitzeralii, Phyllocladus, Podocarpus lawrencei, with Eucalyptus emergents</td>
<td>Southern conifer forests, e.g. montane and mainland south-eastern Australia, New Caledonia</td>
</tr>
<tr>
<td>WSWF</td>
<td>Wet sclerophyll forest</td>
<td>Tall closed canopy evergreen with dense understorey. Frost tolerant; low rainfall seasonality, moderately drought tolerant</td>
<td>Eucalyptus</td>
<td>Eucalyptus forests of south-eastern and south-western Australia</td>
</tr>
<tr>
<td>DSFW</td>
<td>Temperate sclerophyll woodland and shrubland</td>
<td>Medium-tall (5–30 m) mixed-evergreen, open forest (30–70%) to tall woodlands with grass/shrub understorey usually dominated by Eucalyptus. Characteristic of low rainfall areas, drought tolerant</td>
<td>Agonis, Banksia, Casuarina, Callitris, Dodonaea, Eucalyptus</td>
<td>Large area of southern Australia, New Caledonia dry sclerophyll forest (e.g. Noumea)</td>
</tr>
<tr>
<td>XERO</td>
<td>Xerophytic woods/scrub</td>
<td>Low-medium, open canopy evergreen woodland to tall shrublands (&lt; 2 m)</td>
<td>Acacia, Actinostrobus, Callitris, Epacridaceae (e.g. Styphelia), Myrtaceae (Eucalyptus), Proteaceae (e.g. Banksia, Isopogon, Petrophile, Beaufortia)</td>
<td>New Caledonia maquis, Australian mallee woodlands, Australian mulga, kanji in northern Australia, kwongan of south-western Australia, parts of South Australia and Tasmania</td>
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</tbody>
</table>
shrub, temperate drought-intolerant forb) and the presence of
tree ferns. Thus, they are distinguished from tropical rain
forests by the presence of temperate elements, and from CTRF
by the presence of tropical elements. Cool-temperate rain
forests occur in isolated pockets along the coastal margin of
south-eastern Australia, but are most extensive in Tasmania.
As they are found in regions subject to frost, CTRF does not
include, e.g. tropical tree forms. Temperate rain forests have
not been recognized in biome analyses of other regions,
although they occur in south-eastern China, southern South
America, New Zealand and the Pacific Northwest region of
North America (Mitchell et al., 1991; Busby & Brown, 1994).

Sclerophyll forest and woodland, which are characterized by
evergreen or semi-evergreen, sclerophyll species, are typical of
large parts of the temperate zone in the SEAPAC region
(Ashton & Attiwill, 1994). In the wetter areas, where mean
annual precipitation is > 1100 mm year\(^{-1}\), they form forests
with tall (30–65 m) trees. Tree height and the density of the
canopy decrease progressively as precipitation declines and the
sclerophyll forests become increasingly open, grading into
open woodland and semi-arid woodland. In areas where the
rainfall is < 500 mm year\(^{-1}\), open woodland is replaced by the
low (4–10 m), multi-stemmed trees of the mallee or the mulga
(Parsons, 1994). Both sclerophyll forest and woodland are
characterized by a diverse understorey.

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</thead>
<tbody>
<tr>
<td>STEP</td>
<td>Temperate or tropical grassland and xerophytic shrubland</td>
<td>Shrubland or grassland, lacking trees, and with drought-tolerant or salt-tolerant herbs and forbs</td>
<td>Amaranthaceae, Atriplex, Chenopodiaceae, Poaceae</td>
<td>Semi-arid shrubland steppe, shrub and grassland, chenopod low open scrub, and chenopod shrublands of South Australia, western New South Wales, south-east Western Australia, Queensland and Northern Territory (&lt; 300 mm year(^{-1}), &lt; 10 °C)</td>
</tr>
<tr>
<td>TUND</td>
<td>Tundra</td>
<td>Low (&lt; 1 m) to dwarf shrublands of mixed herbs, forbs, sedges and grasses. Tolerates drought and freezing</td>
<td>Carex, Empodisma, Eucalyptus, Nothofagus gunii, Prostanthera cuneata, Phebalium, Poa, Podocarpus lawrencei</td>
<td>Alpine/subalpine shrublands of Gippsland Highland and Snowy Mountains (&gt; 1370 m), Tasmania (&gt; 915 m), high montane areas of PNG and Malaysia (&gt; 3500 m)</td>
</tr>
</tbody>
</table>

Table 5 Assignment of plant functional types to the biomes used in the SEAPAC biomization. The order of the biomes reflects the order used in the tie-break procedure

<table>
<thead>
<tr>
<th>Codes</th>
<th>Biomes</th>
<th>Plant functional types</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRFO</td>
<td>Tropical evergreen broadleaf forest</td>
<td>tr-di.fb, tr.e.b.lhs, te.mb.lhs, i-te.e.n.t, tr.e.mb.t</td>
</tr>
<tr>
<td>TSFO</td>
<td>Tropical semi-evergreen broadleaf forest</td>
<td>tr-di.fb, w-te.sb.lhs, tr.e.b.lhs, te.mb.lhs, i-te.e.n.t, tr.e.mb.t, tr.dd.mb.t</td>
</tr>
<tr>
<td>TDOF</td>
<td>Tropical deciduous broadleaf forest and woodland</td>
<td>g, tr-di.fb, w-te.sb.lhs, tr.e.b.lhs, e.sb.t, w-te.e.b.t, w-te.e.b.raint, tr.e.mb.t, tr.dd.mb.t</td>
</tr>
<tr>
<td>WTRF</td>
<td>Warm-temperate rain forest</td>
<td>tr-di.fb, te-di.fb, w-te.sb.lhs, tr.e.b.lhs, te.mb.lhs, i-te.e.n.t, e.sb.t, w-te.e.b.t, w-te.e.b.raint, tr.dd.mb.t, tf</td>
</tr>
<tr>
<td>COCO</td>
<td>Cool evergreen needleleaf forest</td>
<td>te-di.fb, c-te.sb.lhs, te.mb.lhs, c-te.e.n.t, c-te.e.b.t</td>
</tr>
<tr>
<td>CTRF</td>
<td>Cool-temperate rain forest</td>
<td>te-di.fb, c-te.sb.lhs, tr.e.b.lhs, te.mb.lhs, 4c-te.e.n.t, te.cd.mb.t, c-te.e.b.t, tf</td>
</tr>
<tr>
<td>WSFW</td>
<td>Wet sclerophyll forest</td>
<td>te-di.fb, w-te.sb.lhs, c-te.sb.lhs, te.mb.lhs, c-te.e.n.t, i-te.e.n.t, e.sb.t, w-te.e.b.t, tf</td>
</tr>
<tr>
<td>STEP</td>
<td>Temperate or tropical grassland and xerophytic shrubland</td>
<td>g, eu-dt.fb</td>
</tr>
<tr>
<td>XERO</td>
<td>Xerophytic woods/scrub</td>
<td>g, eu-dt.fb, te-di.fb, h, w-te.sb.lhs, i-te.e.n.t</td>
</tr>
<tr>
<td>DSFW</td>
<td>Temperate sclerophyll woodland and shrubland</td>
<td>g, te-di.fb, h, w-te.sb.lhs, c-te.sb.lhs, te.mb.lhs, i-te.e.n.t, e.sb.t, dt-w-te.e.b.t</td>
</tr>
<tr>
<td>TUND</td>
<td>Tundra</td>
<td>g, s, ar.fb, ar.ds, te.cd.mb.t</td>
</tr>
</tbody>
</table>
sclerophyll forest and woodland is *Eucalyptus*; species from the Proteaceae, Myrtaceae and Epacridaceae, however, are present in the diverse understorey. Wet sclerophyll forest (Beadle, 1981) extensively in wetter areas of south-eastern and the extreme south-west of Australia, and as a discontinuous belt between rain forest and open sclerophyll forest in some parts of north-eastern Australia. Dry sclerophyll woodland covers c. 25% of the Australian continent and is also common on many of the offshore islands, extending into the southern parts of PNG and into New Caledonia and Timor (Gillison, 1994).

Tree ferns (tf) are a significant component of several SEAPAC biomes. In addition to the tropical forests, they are one of the PFTs that distinguish WTRF, CTRF and WSFW (Table 6). Tree ferns were recognized as a distinctive PFT in the biomization of China (Yu *et al.*, 1998, 2000; Ni *et al.*, in press). In China they only contributed to the definition of tropical biomes; in the SEAPAC region, they are characteristic of high-rainfall areas (> 1100 mm year\(^{-1}\)) in both tropical and temperate zones.

Once the taxa to PFT (Table 4) and PFT to biome (Table 6) allocations were determined, the biomization procedure was implemented as described in Prentice *et al.* (1996). Biomization was carried out for all samples, including multiple samples from individual sites. Comparison of the results from several samples at the same site provides a measure of the robustness of the procedure. The biomization of the modern pollen data set was compared with descriptions of the observed vegetation around the collection site (Table 1). Many of these descriptions reflect the local rather than the regional vegetation. While useful for determining the degree to which the modern pollen sample might be affected by, e.g. natural or human-induced disturbance or reflect azonal conditions, such a comparison is not an entirely adequate measure of the degree to which the biomization procedure captures regional vegetation patterns. There is no reliable vegetation map covering the whole of the SEAPAC region, but it was possible to make use of the natural vegetation map from the Atlas of Australian Resources (Carnahan, 1997). This map classifies the vegetation of Australia prior to European colonization in the eighteenth century, on the basis of structure and the dominant component of both the canopy and the understorey, and could be readily reclassified to match the biomes used in the SEAPAC biomization (Fig. 2,

![Figure 2](image)

**Figure 2** The vegetation of Australia in the 1780s prior to European colonization. Data are derived from the Australian vegetation map (Carnahan, 1997) and have been reclassified (Table 7) to conform with the SEAPAC biome scheme.
Table 7) for validation purposes. The biomization procedure was applied without modification to the fossil pollen samples. To determine whether the differences in the distribution of modern and fossil biomes apparent on the resultant maps were robust, we analysed biome changes at those sites with a record for the present and either 6 or 18 ka (Table 8).

## RESULTS

### Reconstructed modern biomes vs. observed modern biomes

The pollen-derived biome map (Fig. 3) shows patterns which broadly conform with the observed patterns in vegetation distribution (Fig. 2). Thus, the biomization procedure correctly reproduces the transition from cool-temperate forests in the extreme south (cool evergreen needleleaf forest, CTRF), through into WSFV and into DSFW in dry areas of south-eastern Australia, and the occurrence of isolated patches of WTRF in the coastal regions of eastern Australia. The gradient from DSFW into more xerophytic vegetation in north-eastern Australia, the pollen-based reconstruction shows the patchy distribution of sclerophyll forest, WTRF and tropical semi-evergreen broadleaf forest characteristic of the observed vegetation patterns. The extent of tropical forests (tropical evergreen broadleaf forest, tropical semi-evergreen broadleaf forest, tropical deciduous broadleaf forest and woodland) is less than might be expected from comparison with the observed biome map. However, this appears to reflect the large proportion of the sites (15%) which, according to the vegetation descriptions provided by the original authors, come from disturbed environments. There are very few sites from the arid interior (i.e. the region characterized by xerophytic vegetation).
Table 8: Assessment of the robustness of biome allocations at sites with multiple samples for 0, 6 or 18 ka. Biome codes are given in Table 5

<table>
<thead>
<tr>
<th>Site</th>
<th>0 ka</th>
<th>6 ka</th>
<th>18 ka</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluaipugua (core 2)</td>
<td>CTRF 2</td>
<td>TDFO 1</td>
<td>CTRF 3</td>
</tr>
<tr>
<td>Anouve</td>
<td>WTRF 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anumon Swamp</td>
<td>WTRF 2</td>
<td>TDFO 1</td>
<td></td>
</tr>
<tr>
<td>Badmenangidongwa</td>
<td>WTRF 2</td>
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</tr>
<tr>
<td>Bandung DPDR-I</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Bandung DPDR-II</td>
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<tr>
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<td>XERO 2</td>
<td>DSFW 1</td>
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<tr>
<td>Bega Swamp</td>
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<td></td>
<td>DSFW 3</td>
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<td>TDFO 1</td>
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<tr>
<td>Bibra Lake (BL2)</td>
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<tr>
<td>Big Dam Marsh</td>
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<td>Black Swamp</td>
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<td>TDFO 1</td>
<td>WTRF 4</td>
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<td>Nadoru Swamp</td>
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<td>Rotten Swamp</td>
<td>DSFW 2 TUND 1</td>
<td>DSFW 2</td>
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<td>Supulah Hill</td>
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<td>COCO 1</td>
<td>CTRF 1 WTRF 1</td>
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<tr>
<td>Yarlington Tier</td>
<td>CTRF 1 TUND 1 DSWF 1</td>
<td>DSWF 2</td>
<td></td>
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</tbody>
</table>
woods/scrub or temperate or tropical grassland and xerophytic shrubland vegetation). This lack of data makes it difficult to evaluate how well the biomization procedure captures the arid biomes characteristic of a large part of the SEAPAC region.

The robustness of the modern biome reconstructions can be assessed by the fact that at 55% of the 83 sites with multiple samples, the biomization procedure consistently yields the same result (Table 8). However, there are regional differences in the robustness of the biomization: only 48% of sites from the tropics yield robust results, while 63% of sites from the extratropical Pacific islands and mainland Australia yield consistent results. Most of the sites with multiple biome assignments, both in the tropics and the extratropics, are from small swamps or bogs, surrounded by relatively open vegetation, where the regional pollen rain is likely to be variably affected by local flowering with consequent dilution of the PFTs characteristic of the regional forest vegetation. Some sites with multiple biome assignments in the tropics are in regions that are heavily impacted by human activities. Thus, at least some of the samples from these sites are likely to reflect local disturbance rather than regional vegetation. The youngest samples reflect the recent expansion of agriculture. The two archaeological sites in the modern data set (Lanyon House and Cave Bay Cave) both yield non-robust biome reconstructions, presumably because the pollen input to such sites is far from natural.

Quantitative comparisons of the reconstructed and observed biomes (at the location of the pollen sites) indicate that 56% of the 227 sites with robust biome reconstructions from Australia in the modern pollen data set are correctly attributed by the biomization procedure (Table 9a). The distribution of DSFW

**Figure 3** Modern biomes reconstructed from surface pollen data. In cases where multiple samples from a site yielded different biome reconstructions, the biome given by most of the samples is plotted. In cases where it was impossible to determine a robust biome, the site is plotted as an open circle. The biome reconstructions for all the samples from a site are shown in Table 8, permitting an evaluation of the robustness of the mapped reconstructions to be made.
(83%), WTRF (67%), and CTRF (50%) are correctly predicted most often. Quantitative comparisons of the reconstructed and observed biomes (at the location of the pollen sites) from the remainder of the SEAPAC region, indicate that 37% of the 142 sites in the modern pollen data set are correctly attributed by the biomization procedure (Table 9b). The distribution of tropical deciduous broadleaf forest and woodland (79%), WTRF (52%) and tropical evergreen broadleaf forest (50%) are correctly predicted most often. The persistent problems in the modern biomization procedure provide guidelines about the likely accuracy of the fossil biome assignments. In particular:

1. The occurrence of DSFW is overestimated, at the expense of both temperate rain forests (WTRF, CTRF) and WSFW at the wetter end of the range, and xerophytic woods/scrub (XERO) towards the arid end of the range. This appears to reflect the overwhelming dominance of Eucalyptus in all of these biomes. Eucalyptus spp. are prolific pollen producers, forming the uppermost canopy layer in the vegetation and thus releasing pollen well above the ground. Being small, the pollen is also readily transported long distances by the wind (e.g. Dodson, 1983; Kershaw & Strickland, 1990). In contrast, the PFTs which serve to distinguish DSFW from temperate rain forests and WSFW (i.e. tree ferns, grasses, heath) and from xerophytic woods/scrub (i.e. eurythermic drought-tolerant forbs) are generally present in low abundances, are often low pollen producers, are confined to the lower strata of the vegetation, and are often not wind pollinated (Keighery, 1982; Dodson, 1983; Wills, 1989; Kodela, 1990; Boyd, 1992; Kershaw et al., 1994).

2. The occurrence of tropical deciduous broadleaf forest and woodland (TDFO) appears to be overestimated in the modern biomization. This is partly due to the misclassification of tropical semi-evergreen broadleaf forest (TSFO) and CTRF/WTRF, to tropical deciduous broadleaf forest and woodland, but more importantly due to the misclassification of sites from more arid biomes (DSFW, xerophytic woods/scrub, and temperate or tropical grassland and xerophytic shrubland). The misallocation of the rain forest sites largely reflects the fact that the characteristic PFTs (e.g. tropical drought-Deciduous

Table 9 Comparison of biomes as predicted by the SEAPAC biomization procedure and observed biomes: (a) for mainland Australia and (b) for the greater SEAPAC region. The order of the biomes reflects the order used in the tie-break procedure. Modern biomes for Australia were derived from the Australian vegetation map (Figure 1, Table 7) and observed biomes for the greater SEAPAC region were derived from original site descriptions given in Table 1. Sites with biomization results that are non-robust (see Table 8) are not included in these comparisons

<table>
<thead>
<tr>
<th>Reconstructed biomes</th>
<th>TRFO</th>
<th>TSFO</th>
<th>TDFO</th>
<th>WTRF</th>
<th>COCO</th>
<th>CTRF</th>
<th>WSFW</th>
<th>STEP</th>
<th>XERO</th>
<th>DSFW</th>
<th>TUND</th>
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<td>2</td>
<td></td>
<td>3</td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>5</td>
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<td>3</td>
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<td>5</td>
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<td></td>
</tr>
<tr>
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<td>1</td>
<td>2</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STEP</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>TUND</td>
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<td>1</td>
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<td></td>
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<td>0</td>
<td>12</td>
<td>0</td>
<td>10</td>
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<tr>
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<td>n/a</td>
<td>67</td>
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<td>50</td>
<td>8</td>
<td>0</td>
<td>27</td>
<td>83</td>
<td>0</td>
</tr>
</tbody>
</table>

| (b)                  |      |      |      |      |      |      |      |      |      |      |      |
| TRFO                 | 1    |      |      |      |      |      |      |      |      |      |      |
| TSFO                 |      |      |      |      |      |      |      |      |      |      |      |
| TDFO                 | 1    | 3    | 34   | 11   | 6    | 16   | 1    | 1    |      |      |      |
| WTRF                 |      | 4    | 15   | 7    | 1    | 18   | 3    | 2    |      |      |      |
| COCO                 |      |     |      |      |      |      |      |      |      |      |      |
| CTRF                 | 2    |      |      |      |      |      |      |      |      |      |      |
| WSFW                 |      |      |      |      |      |      |      |      |      |      |      |
| STEP                 |      | 1    |      |      |      |      |      |      |      |      |      |
| XERO                 |      | 2    |      |      | 2    |      |      |      |      |      |      |
| DSFW                 | 1    | 1    | 1    |      |      |      |      |      |      |      |      |
| TUND                 |      | 2    | 1    | 2    |    |      |      |      |      |      |      |
| Total obs.           | 2    | 4    | 43   | 29   | 0    | 17   | 1    | 37   | 4    | 0    | 5    |
| % Correct            | 50   | 0    | 79   | 52   | n/a  | 12   | 0    | 0    | 0    | n/a  | 0    |
malacophyll broadleaved tree, tropical evergreen malacophyll broad-leaved tree) are comparatively low pollen producers (Flenley, 1973; Kershaw & Strickland, 1990). The fact that *Eucalyptus* is an important component of the SEAPAC tropical deciduous broadleaf forest and woodland as well as the biomes DSFW, and xerophytic woods/scrub, may be a partial explanation for the misclassification of sites from more arid environments.

Despite these systematic biases, the modern biomization appears to capture the observed vegetation patterns sufficiently well to merit applying the method to fossil pollen data in order to reconstruct biome maps for 6 and 18 ka. Furthermore, we cannot rule out the possibility that some of the apparent mismatches in our quantitative validation result from the use of a vegetation map which represents Australian vegetation prior to European colonization and is, to some extent, based on inferences about the nature of post-colonial vegetation changes.

**Mid-Holocene biomes**

The robustness of the 6 ka biome reconstructions, as measured by the number of sites in which multiple samples yield the same result (69%), is similar to that obtained in the modern biomization (Table 8). The mid-Holocene vegetation patterns (Fig. 4) are broadly similar to those of today, suggesting that the 6 ka climate was not radically different. Nevertheless, there are spatially coherent changes in biome distribution between 6 ka and today. Of the 93 sites with a record for both 0 and 6 ka (Table 10), 32% show a change.

The broad-scale patterns of vegetation distribution across south-eastern Australia at 6 ka were very similar to today. In

**Figure 4** Biomes reconstructed from fossil pollen data at 6 ka. In cases where multiple samples from a site yielded different biome reconstructions, the biome given by most of the samples is plotted. In cases where it was impossible to determine a robust biome, the site is plotted as an open circle. The biome reconstructions for all the samples from a site are shown in Table 8, permitting an evaluation of the robustness of the mapped reconstructions to be made.
<table>
<thead>
<tr>
<th>Site</th>
<th>0 ka Biome</th>
<th>6 ka Biome</th>
<th>18 ka Biome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluapugua (core 2)</td>
<td>CTRF</td>
<td></td>
<td>CTRF</td>
</tr>
<tr>
<td>Barker Swamp</td>
<td>XERO</td>
<td></td>
<td>XERO</td>
</tr>
<tr>
<td>Baw Baw Village</td>
<td>DSFW</td>
<td>DSFW</td>
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</tr>
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<td>DSFW</td>
<td>DSFW</td>
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</tr>
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<td>Bibra Lake (BL2)</td>
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</tr>
<tr>
<td>Black Swamp</td>
<td>DSFW</td>
<td>DSFW</td>
<td>DSFW</td>
</tr>
<tr>
<td>Blue Lake (Mt Gambier)</td>
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<td>DSFW</td>
<td></td>
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<tr>
<td>Bobundarra Swamp</td>
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<td>DSFW</td>
<td></td>
</tr>
<tr>
<td>Boggy Lake</td>
<td>TDFO</td>
<td>DSFW</td>
<td></td>
</tr>
<tr>
<td>Boggy Swamp</td>
<td>DSFW</td>
<td>DSFW</td>
<td></td>
</tr>
<tr>
<td>Brass Tarn</td>
<td>WTRF</td>
<td>WTRF</td>
<td></td>
</tr>
<tr>
<td>Breadalbane NW</td>
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<td>DSFW</td>
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<td>Breadalbane SE</td>
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<td>DSFW</td>
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</tr>
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<td>XERO</td>
</tr>
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<td>CTRF</td>
<td></td>
</tr>
<tr>
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<td></td>
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<tr>
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</tr>
<tr>
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<tr>
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<td>STEP</td>
<td></td>
</tr>
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</tr>
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</tr>
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<td>WTRF</td>
<td>CTRF</td>
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</tr>
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<td>TDFO</td>
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</tr>
<tr>
<td>Jacksons Bog A</td>
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<td>TUND/DSFW</td>
<td></td>
</tr>
<tr>
<td>Jacksons Bog B</td>
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</tr>
<tr>
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<td>WTRF</td>
<td>WTRF/TDFO</td>
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</tr>
<tr>
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<td>TDFO</td>
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</tr>
<tr>
<td>Koumac Northeast</td>
<td>TDFO</td>
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<td></td>
</tr>
<tr>
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</tr>
<tr>
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</tr>
<tr>
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<td>DSFW</td>
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<tr>
<td>Loch Mcness Swamp</td>
<td>DSFW</td>
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</table>

Table 10 Changes in biomes at sites with a record for 0 ka and either 6 or 18 ka
the western part of south-eastern Australia, xerophytic woods/scrub (XERO) occurred at 6 ka at five sites characterized today by DSFW. This difference indicates conditions somewhat drier than today at 6 ka. Sites in the Snowy Mountains, in the Southern Tablelands and east of the Great Dividing Range show more moisture-demanding vegetation at 6 ka than today. Today most of these sites are characterized by DSFW, whereas the vegetation at 6 ka was variously WSFW (two sites), WTRF (1), CTRF (4) and cool evergreen needleleaf forest (2).

Only three sites in Western Australia show a different biome at 6 ka than today. Weld River Swamp (Churchill, 1961, 1968) was characterized by less moisture-demanding vegetation (DSFW) at 6 ka than today. However, Scott River Swamp (Churchill, 1961, 1968) which is classified as xerophytic woods/scrub (XERO) today was characterized by DSFW at 6 ka. This biome shift implies wetter conditions. The single site in north-western Australia (Dragon Tree Soak: Pedersen, 1983; Wyrwoll et al., 1986) shows conditions drier than today at 6 ka.

In the tropical highlands of PNG, Sumatra and Irian Jaya, sites that are occupied today by either tundra or CTRF (i.e. upper montane forest) were characterized by the presence of WTRF (i.e. lower montane forest) and even tropical deciduous broadleaf forest and woodland at 6 ka. These changes imply a rise of > 500 m in the limits of the montane forest belts and in
treeline at 6 ka. The largest shift in these limits occurs at the highest sites.

**Last glacial maximum biomes**

There are 33 sites with a record for the LGM. The samples from Lake George (Singh & Geissler, 1985) have been omitted from further analysis because of the extremely low pollen counts (23 and 33 grains, respectively). The robustness of the 18 ka biome reconstructions, as measured by the number of sites in which multiple samples yield the same result (44%), is less than that obtained in the modern biomization (Table 8). Thus, there is more uncertainty attached to both the biome reconstructions and any climatic interpretation of these data. Nevertheless, the differences between the 18 ka (Fig. 5) and modern (Fig. 3) biome maps are striking. Of the 22 sites with a record for both 0 and 18 ka (Table 10), 50% show a change.

Xerophytic woods/scrubs (XERO) were more extensive at 18 ka than today in south-eastern and south-western Australia. In the north, tropical deciduous broadleaf forest and woodland (TDFO) is recorded at 18 ka in sites characterized today by tropical evergreen broadleaf forest (TRFO). These changes suggest conditions drier than today at the LGM across mainland Australia.

In the tropics, some sites that lie today within the montane forest belts (WTRF, CTRF) were characterized by tundra at 18 ka, while WSFW occurred in sites characterized by tropical evergreen broadleaf forest (TRFO) today. These changes reflect a lowering of treeline and montane forest belts by between 300 and 1500 m at 18 ka. The magnitude of the downslope shifts in vegetation belts are comparable with those reconstructed by

**Figure 5** Biomes reconstructed from fossil pollen data at 18 ka. In cases where multiple samples from a site yielded different biome reconstructions, the biome given by most of the samples is plotted. In cases where it was impossible to determine a robust biome, the site is plotted as an open circle. The biome reconstructions for all the samples from a site are shown in Table 8, permitting an evaluation of the robustness of the mapped reconstructions to be made.
Farrera et al. (1999), and indicate that conditions were between 1 and 9 °C colder than today. The largest temperature lowering occurs at highest elevation. The encroachment of tropical deciduous broadleaf forest and woodland (TDFW) into the tropical lowlands suggests that it was also drier than today.

**DISCUSSION**

The biomization procedure

Previous applications of the biomization method to a number of regions in the Northern Hemisphere and the tropics (Prentice et al., 1996; Jolly et al., 1998b; Tarasov et al., 1998; Yu et al., 1998; Edwards et al., 2000; Elenga et al., 2000; Takahara et al., 2000; Thompson & Anderson, 2000; Williams et al., 2000; Yu et al., 2000; Bigelow et al., 2003) have shown that the technique works well across the entire range of global climates and vegetation types. The SEAPAC biomization provides a further test of the method, in a region characterized by significant temperature gradients (from equatorial to cool-temperate zones) and precipitation gradients (from arid to extremely wet). Our application of the method to modern pollen data from the SEAPAC region resulted in the correct classification of 56% of the samples from mainland Australia, and 37% of the samples from the rest of the SEAPAC region. The allocation of samples to biomes controlled primarily by temperature appears to be good. However, there are considerably more difficulties in correctly predicting the boundaries of biomes that are controlled by moisture availability, specifically the transitions from DSFW to tropical deciduous broadleaf forest and woodland and to tropical semi-evergreen broadleaf forest in the north, and the transitions from WSFW to DSFW to xerophytic woods/scrub and ultimately to grassland and xerophytic shrubland in the temperate zone. This appears to reflect the fact that these biomes are dominated by a few genera (e.g. Eucalyptus, Acacia) which are tolerant of a wide range of conditions and which respond to increasing moisture stress through changes in height, structure and spacing.

There are a number of plausible explanations for why the discrimination between biomes controlled by moisture availability is less good than that between biomes controlled by temperature.

1. The temperature limits on the growth of specific PFTs are, in general, determined by the presence/absence of specific physiological adaptations amongst the dominant, canopy-forming taxa. For example, there are physiological adaptations that enable some trees to survive frost (e.g. dormancy, freeze-drying). Tropical evergreen malacophyll broadleaf trees have no mechanism to survive frost and therefore cannot grow in regions subject to frost. The frost limit therefore provides an absolute constraint on the distribution of biomes which includes tropical evergreen malacophyll broadleaf trees, e.g. tropical evergreen broadleaf forest and WTRF. Although specific adaptations do exist to compensate for moisture stress (e.g. ephemeral growth forms, water storage mechanisms), the primary response to moisture stress appears to be expressed through structural changes in the dominant PFTs, e.g. changes in tree height, foliage density or canopy spacing (Specht, 1972). These responses are largely determined by competition amongst individuals for a limited resource (i.e. water) rather than reflecting a physiological control on the individual itself. Thus, specific PFTs appear to be capable of surviving under a wide range of moisture conditions through structural plasticity. For example, evergreen sclerophyll broadleaf trees are an important component of the vegetation in regions with mean annual rainfall ranging from > 1100 to < 500 mm year⁻¹. In high rainfall areas, they are tall, single-stem trees forming closed-canopy forests. Increasing moisture stress is registered by increasing openness of the canopy and, in general, by a gradual reduction in tree height.

2. Since the dominant, canopy-forming PFTs display considerable plasticity with respect to moisture stress, discrimination between biomes at the more arid end of the moisture gradient tends to be made on the basis of PFTs which form the subcanopy and understorey components of the vegetation. These PFTs are in general less abundant. Furthermore, as they release pollen within or beneath the canopy, the pollen tends to be less widely dispersed. Additionally, some of the characteristic species are poor pollen producers (e.g. Acacia, Proteaceae) or rely primarily on dispersal by birds, insects and animals (e.g. Banksia). As a result, the presence/abundance of these PFTs in the pollen spectrum from a specific site tends to be less consistent than the presence/abundance of the dominant canopy-forming PFTs, with consequent effects on the reliability of the biome allocation.

3. The difficulties caused by a reliance on non-canopy forming PFTs to discriminate between biomes are further compounded by the fact that pollen discrimination amongst the non-tree taxa is limited. The grasses (Poaceae) are a classic example of this problem. Spinifex grasslands are confined to regions with mean annual rainfall of < 200 mm year⁻¹ and are replaced by tussock grasslands in more well-watered areas (Mott & Groves, 1994). In the modern landscape, the presence of spinifex could be used to discriminate between xerophytic woods/scrub and DSFW in the temperate zone, or between tropical deciduous broadleaf forest and woodland and tropical semi-evergreen broadleaf forest in the tropics. As it is not possible to distinguish reliably between different types of grass on the basis of their pollen (Pedersen, 1983; Boyd, 1990), this criterion cannot be used in pollen-based biomizations.

Our attempt to improve the discrimination of moisture-limited biomes has not been entirely successful. Nevertheless, given that these biomes are distinctive features of the modern vegetation landscape and occupy extensive areas of the SEAPAC region, the attempt to discriminate between them should not be abandoned. Analysis of the underlying causes of the uncertainties in allocations between the moisture-limited biomes suggest improvements could be made by:

1. Using pollen data with a better level of taxonomic resolution for biomization. It would be possible, for example,
to improve the level of discrimination within some families and genera that are important in the SEAPAC region. The regular identification of different taxonomic groups within *Eucalyptus* (Pike, 1956; Martin & Gadek, 1988; Pickett & Newsome, 1997) would considerably improve our ability to discriminate between moisture-limited biomes. Furthermore, in cases where the level of pollen identification cannot be improved, it might be possible to use plant macrofossils from the same sediments to help determine which species were present (e.g. Jackson *et al.*, 1997).

2. Using macrofossil data to reconstruct the biomes in regions where pollen data are sparse. Macrofossil data from packrat middens have already been successfully used to reconstruct arid vegetation types in western North America (Thompson & Anderson, 2000). The stickrat midden data from the arid interior of Australia (Pearson & Dodson, 1993; McCarthy *et al.*, 1996; Pearson, 1999) could be used in a similar fashion.

3. Using carbon isotopes to distinguish between grass types. Carbon isotope measurements have been used successfully to discriminate between the preponderance of $C_3/C_4$ grasses in the diets of emus, and hence to infer changes in the distribution of these types of grasslands during the past 60 ka (Miller *et al.*, 1997, 1999; Johnson *et al.*, 1999). Direct measurements of the carbon isotopic composition of plant macrofossils and possibly even pollen could potentially improve our discrimination of understorey components that are key to the separation of arid zone biomes.

In addition to the attempt to make finer discriminations between moisture-stressed biomes (e.g. with the introduction of WSFW and DSFW), the SEAPAC biomization has introduced two new rain forest biomes (WTRF and CTRF). We are able to discriminate between these biomes, and to distinguish them from other biomes that are limited by temperature rather than moisture availability, with some accuracy. Some of these biomes occur today in other regions of the world, including New Zealand, South America and south-eastern China. Furthermore, it seems likely that there are structural equivalents to these biomes in the mountains of equatorial Africa. Successful discrimination of these biomes in the SEAPAC region suggests that attempts to reconstruct the modern and palaeodistribution of these distinctive vegetation types in other regions would be worthwhile.

**Vegetation and climate of the SEAPAC region in the mid-Holocene**

The 6 ka biome reconstruction suggests the broad-scale patterns of vegetation distribution across south-eastern Australia during the mid-Holocene were similar to today. Western Australia and the western part of south-eastern Australia were characterized by less moisture-demanding vegetation at 6 ka than today, implying that the climate was drier. In contrast, sites in the Snowy Mountains, in the Southern Tablelands, and east of the Great Dividing Range show more moisture-demanding vegetation at 6 ka than today, implying wetter climate. The vegetation records from mountain sites in the tropics indicate that the upper altitudinal limits of montane forest belts and treeline were higher than today, implying warmer temperatures.

These reconstructed changes are broadly consistent with previous reconstructions of mid-Holocene vegetation patterns, based on a more limited number of sites (e.g. Markgraf *et al.*, 1992; Harrison & Dodson, 1993; Kershaw, 1998). The expansion of more moisture-demanding vegetation in much of south-eastern Australia is consistent with Markgraf *et al.*’s (1992) inference that WSFW and temperate rain forest elements were extended in the south-eastern highlands of mainland Australia between c. 8 and 5 ka. As pointed out by Markgraf *et al.* (1992), the vegetation evidence for wetter conditions is also consistent with lake-level evidence from the region (Markgraf *et al.*, 1992; Harrison, 1993). Furthermore Harrison & Dodson (1993) also show an expansion of moisture-demanding forests in this region at 6 ka. Markgraf *et al.* (1992) also suggested that temperate rain forest was present at higher elevations in Tasmania and in northern Queensland. We have no data to verify the upward expansion of rain forest in Tasmania. Biome reconstructions for sites in Queensland do not indicate a change in the extent of rain forest. Markgraf *et al.* (1992) suggested that the forests and shrublands in PNG were more extensive than today; this is consistent with our reconstruction that the tropical montane forest belts occurred at higher elevations than today. Both Markgraf *et al.* (1992) and Harrison & Dodson (1993) suggest that the limited amount of data available from Western Australia implies conditions wetter than present during the mid-Holocene. Our reconstruction shows little change in this region compared with today, although two sites seem to indicate conditions may have been slightly drier.

On the basis of experiments using the BIOCLIM model, Nix & Kalma (1992) have suggested that northern Australia and PNG had higher winter precipitation during the mid-Holocene than today. In these experiments, the increased precipitation occurred because the Arafura Sea, which was shallower and warmer than today, acted as an enhanced local moisture source. Our reconstructions suggest that the biome changes in northern Australia and PNG are a reflection of changes in temperature rather than precipitation. However, they are not inconsistent with the hypothesis put forward by Nix & Kalma (1992).

**Vegetation and climate of the SEAPAC region at the last glacial maximum**

The reconstructed patterns of biome distributions at 18 ka are strikingly different from today. Xerophytic woods/scrub and DSFW characterized the southern part of mainland Australia. Further north, tropical deciduous broadleaf forest and woodland is recorded in sites characterized today by tropical evergreen broadleaf forest or WTRF. These changes suggest that conditions may have been drier than today at the LGM across mainland Australia. This is not consistent with
lake-level data from the south-east interior (where we have no pollen records) which indicate conditions somewhat wetter than today (Harrison & Dodson, 1993). However, vegetation registers changes in growing-season soil moisture whereas lakes register changes in runoff (Cheddadi et al., 1997; Farrera et al., 1999). Thus, the changes in regional moisture conditions recorded by vegetation data need not be congruent with the signal derived from lakes, particularly in regions with highly seasonal precipitation regimes (see e.g. Prentice et al., 1992b; Farrera et al., 1999; Harrison et al., 2001).

The biome changes between LGM and present in mainland Australia do not allow us to estimate the degree of cooling at the LGM. However, the reconstructed biome changes in the tropics, which indicate that treeline and the altitudinal limits of the montane forest belts were lower than today, clearly indicate temperatures between 1.7 and 9 °C (depending on elevation) colder than today. The encroachment of tropical deciduous broadleaf forest and woodland into areas occupied today by lowland tropical evergreen broadleaf forest suggests it was also somewhat drier than today in the tropics.

Previous reconstructions of vegetation at the LGM (van der Kaars, 1991; Markgraf et al., 1992; Harrison & Dodson, 1993) consistently show conditions more arid and colder than today. Harrison & Dodson (1993) argue that the interval between 15 and 18 ka was cooler and drier than any subsequent time. Our reconstructions are consistent with, but in general less extreme than, the changes implied by previous syntheses of the LGM vegetation data. For example, van der Kaars (1991) shows grassland/shrubland across northern Australia and onto the Sunda-Sahul shelf with woodland and open forest replacing lowland tropical forests in southern PNG. According to this reconstruction, tropical lowland forests were very much reduced in extent compared with today. Our reconstruction implies a more widespread persistence of tropical lowland forests. This apparent difference may be because the van der Kaars (1991) reconstruction is based on pollen records from marine cores in the eastern Indonesian region, which can be expected to blend the signals from montane and lowland sites within the same area. As tropical lowland forest species tend to produce less pollen than montane equivalents, the reduction in tropical lowland forests is likely to be exaggerated. Similarly, our reconstruction is in good agreement with Markgraf et al.’s (1992) reconstruction of treeline lowering in PNG, savanna woodland in tropical northern Australia, and the extension of shrubland in interior south-eastern Australia. However, Markgraf et al. (1992) suggest that coastal regions of the south-east (including Tasmania) were characterized by steppe vegetation at the LGM. The biome reconstructions indicate xerophytic woods/scrub vegetation across south-eastern Australia; there are no data from Tasmania in the current data set.

A multi-proxy compilation of data on temperature and moisture-balance changes in the tropics (Farrera et al., 1999) indicates that temperatures at sea level within the SEAPAC region were of the order of 1–2 °C colder than present. However, the lapse rate was considerably steeper than today, resulting in much larger temperature changes (6–9 °C) at high elevation sites. These estimates are consistent with the shifts in treeline and montane forest belts shown by our biomization procedure, and the estimates of temperature changes made from these shifts. The Farrera et al. (1999) compilation also indicates that plant-available moisture was less than today in the tropical part of the SEAPAC region, consistent with our reconstructed biome shifts.

CONCLUSIONS

This paper represents a first attempt to map the vegetation of the SEAPAC region from pollen data using an objective method based on the recognition of biomes characterized by a unique assemblage of PFTs. The method is broadly successful. Difficulties in reliably discriminating between biomes controlled by moisture gradients largely reflect the fact that adaptations to moisture stress tend to be expressed through structural changes rather than species replacement. However, some improvement in discrimination could be made if the data available for biomization were more highly resolved taxonomically. The regular identification of subgroups of Eucalyptus would certainly help in this respect, as would the use of plant macrofossils to identify the likely species-level identification of taxa which cannot be resolved to species level from pollen. Similarly, isotopic methods could be used to identify whether the grasses present in a pollen assemblage were predominantly C₃ or C₄ types.

We have applied the biomization technique to reconstruct vegetation patterns at 6 and 18 ka. The changes in biome distribution at 6 ka compared with present are small, implying that the climate of the mid-Holocene was not significantly different from present. The changes in biome distribution at 18 ka are more striking, and suggest that the SEAPAC region was drier than today and, at least in the tropics, colder. These reconstructions are consistent with earlier, subjective reconstructions of vegetation and climate changes in the SEAPAC region.

The Southern Hemisphere is 75% ocean and thus the ocean is the primary determinant of Southern Hemisphere regional climates. Accurate simulation of palaeoclimates using atmospheric general circulation models (AGCMs) would therefore require well constrained ocean reconstructions for the Southern Hemisphere whereas the available ocean data, particularly from the extra tropics, is limited (CLIMAP Project Members, 1981; Broccoli & Marciniak, 1996; Rosell-Melé et al., 1998). As a result AGCM palaeoclimate simulations appear to capture the regional climates of the Southern Hemisphere less well than those of the Northern Hemisphere (Harrison & Dodson, 1993, Markgraf, 1993). The use of coupled ocean-atmosphere models (e.g. Hewitt & Mitchell, 1998; Bracconnot et al., in press), which explicitly simulate ocean circulation should improve our ability to simulate Southern Hemisphere palaeoclimates. The palaeovegetation reconstructions provided here will be useful as a means of evaluating their performance.
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**BIOSKETCHES**

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