XXXIII INTERNATIONAL MOOR-EXCURSION

SYDNEY BASIN AUSTRALIA

2009

Queens Swamp a "Hanging Swamp" dominated by *Gymnoschoenus sphaerocephalus, Lepidosperma limicola* and *Xyris ustulata* near Lawson in the Blue Moountains.

THE PROGRAMME IN BRIEF

Monday, 22 June
Leave Sydney's eastern suburbs and travel to Royal National Park for an overview of vegetation communities of the Sydney Basin. Short walks in ridgetop woodland, coastal heath and temperate rainforest. Lunch at Stanwell Park. Coast road (including Sea Cliff Bridge) along Permian-Triassic exposures, and then climb the eastern escarpment to our overnight accommodation at Fountaindale Manor in Robertson.

Tuesday, 23 June
Around Robertson: rainforest remnants and Wingecarribee Swamp to discuss swamp failure, palynology and charcoal, with a focus on vegetation, vegetation history and impacts on swamps. Lunch in the Robertson Cheese Factory. In the afternoon we will travel back to the edge of the eastern escarpment at the *Illawarra Fly*. If time permits we will visit Barren Grounds Nature Reserve. Overnight in Robertson at Fountaindale Manor.

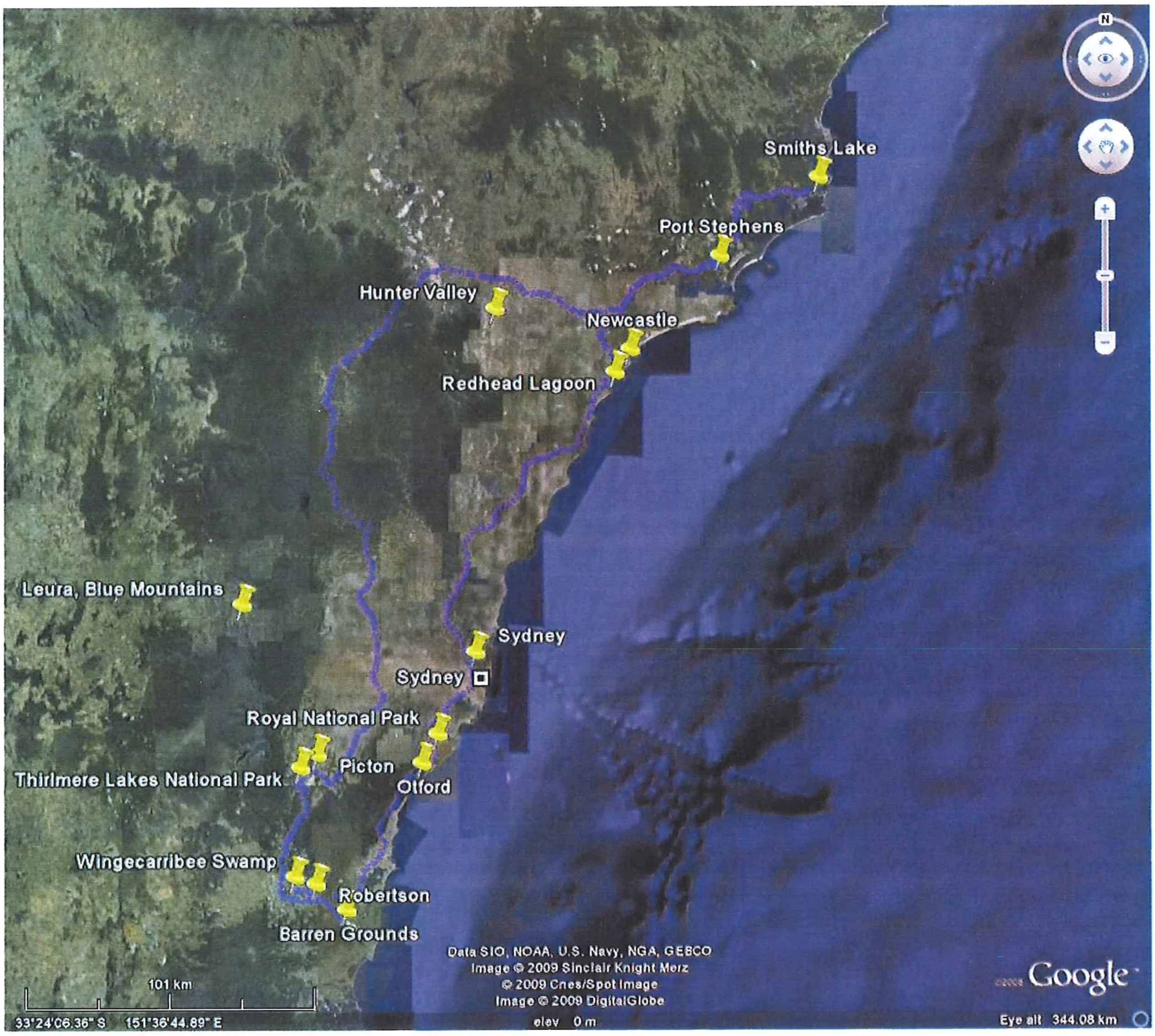
Wednesday, 24 June
Travel from Robertson to Thirlmere Lakes National Park to examine freshwater lakes and Lake Baraba, a mostly infilled sedge-dominated site. Lunch in the historic George IV pub in Picton. Travel to the Greater Blue Mountains World Heritage Area where we will spend the night in the Spires Apartments, Leura in the Blue Mountains.

Thursday, 25 June
The vegetation, landscape and archaeology of the Blue Mountains. Morning tour of the major look-outs of the Blue Mountains, followed by the floor of the Jamison River valley at the Three Sisters. Lunch will be spent at 'Queens Swamp' near Lawson (weather permitting). Late afternoon at *The Edge* with a performance by an Aboriginal group. Evening presentation on the archaeology of the Sydney Basin and Blue Mountains. Overnight in Leura at Spires Apartments.

Friday, 26 June
From the Blue Mountains we will travel back down the Lapstone Monocline and then north along the Putty Road. We will stop at Kings Waterhole, a part of the Mellong Swamps in Wollemi National Park. We will then cross into the Hunter Valley (a Famous wine growing region) for lunch and to examine post-European changes to river channels and efforts at revegetation. We will then travel to the UNSW field station at Smiths Lake for an overnight stop.

Saturday, 27 June
From Smiths Lake we will travel to Tea Gardens to join the ferry across to Port Stephens. We will then briefly visit a coastal site before starting our journey back to Sydney. If time permits we will visit Redhead Lagoon, the longest published palaeo-environmental record in the Sydney Basin. The aim is to be back to Sydney late afternoon/early evening.

OVERVIEW OF ROUTE



PARTICIPANTS OF THE XXXIII INTERNATIONAL MOOR-EXCURSION 2009

It is <u>your</u> job to fill out the details in the table below.

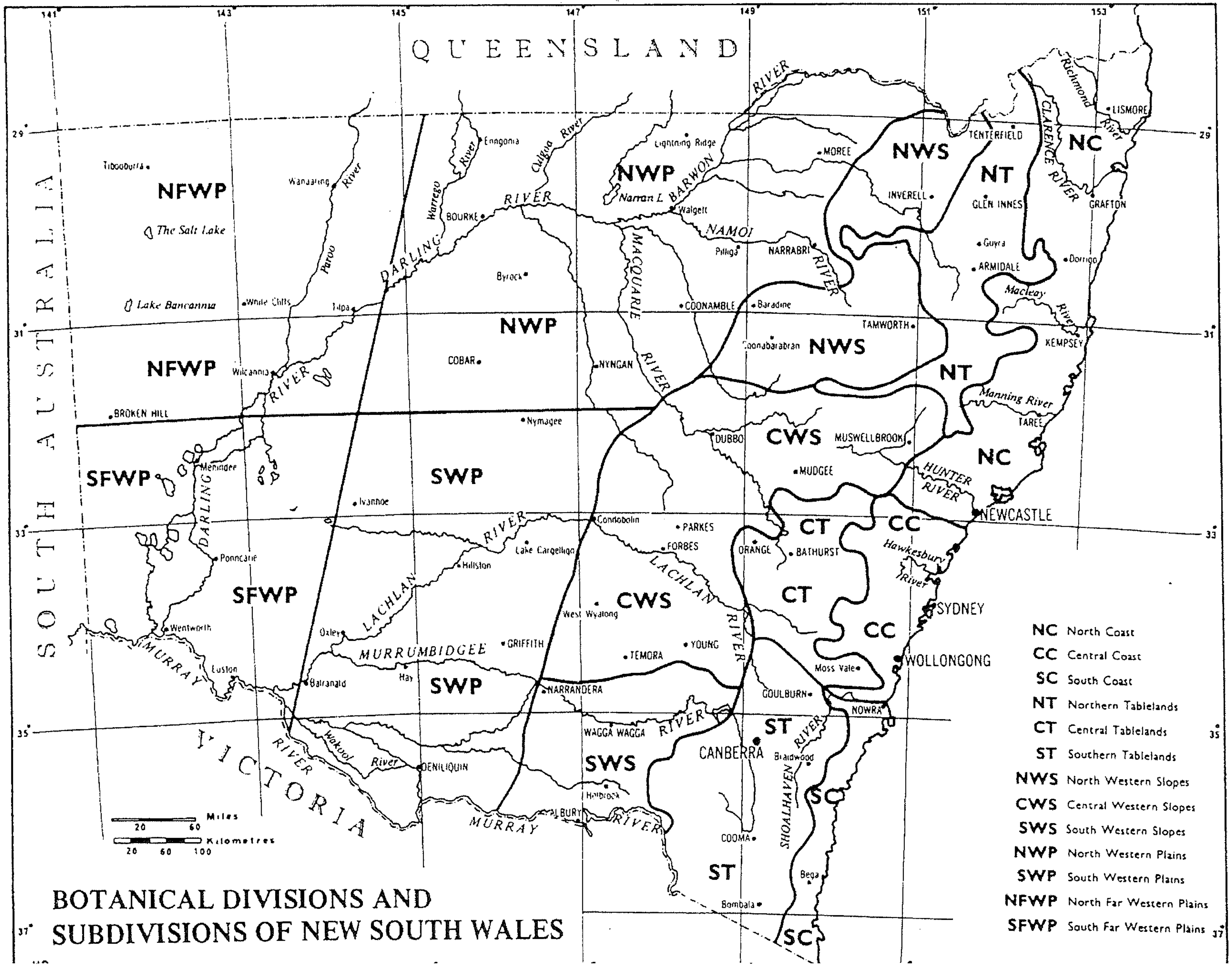
Scott Mooney (local organizer)	School of BEES UNSW, NSW, 2052, Australia s.mooney@unsw.edu.au Keywords: vegetation history (palynology), fire (charcoal analysis), climate, human impact
Val Attenbrow	Anthropology/Archaeology Australian Museum 6 College Street Sydney NSW 2010 Australia Val.Attenbrow@austmus.gov.au Keywords: archaeology, Aboriginal, backed artifacts
Geoff Hope	Research School of Pacific and Asian Studies Australian National University Canberra, ACT, 0200, Australia geoffrey.hope@anu.edu.au Keywords: vegetation history (palynology), climate change, management of upland swamps
Willy Tinner	willy.tinner@ips.unibe.ch
Elisa Vescovi	Elisa.vescovi@ips.unibe.ch

Jacqueline van Leeuwen	vanleeuwen@ips.unibe.ch
Pim van der Knaap	Knaap@ips.unibe.ch
Stephanie Samartin	Stephanie.samartin@ips.unibe.ch
Camila Calò	camilla.calo@ips.unibe.ch
Paul Henne	Paul.henne@ips.unibe.ch
Orla Dermody	orla.dermody@pioneer.com

Tiiu Koff	tkoff@tlu.ee
Klaus (bus driver)	

SOME GENERAL INFORMATION ABOUT THE SYDNEY BASIN

For explanation and description of the Botanical Divisions and Subdivisions of New South Wales see Anderson, R. H. (1961). Introduction. *Contr. New South Wales Natl. Herb. Fl. New South Wales* Nos 1–18, pp. 1–15.



BOTANICAL DIVISIONS AND SUBDIVISIONS OF NEW SOUTH WALES

REGION 5 — SYDNEY

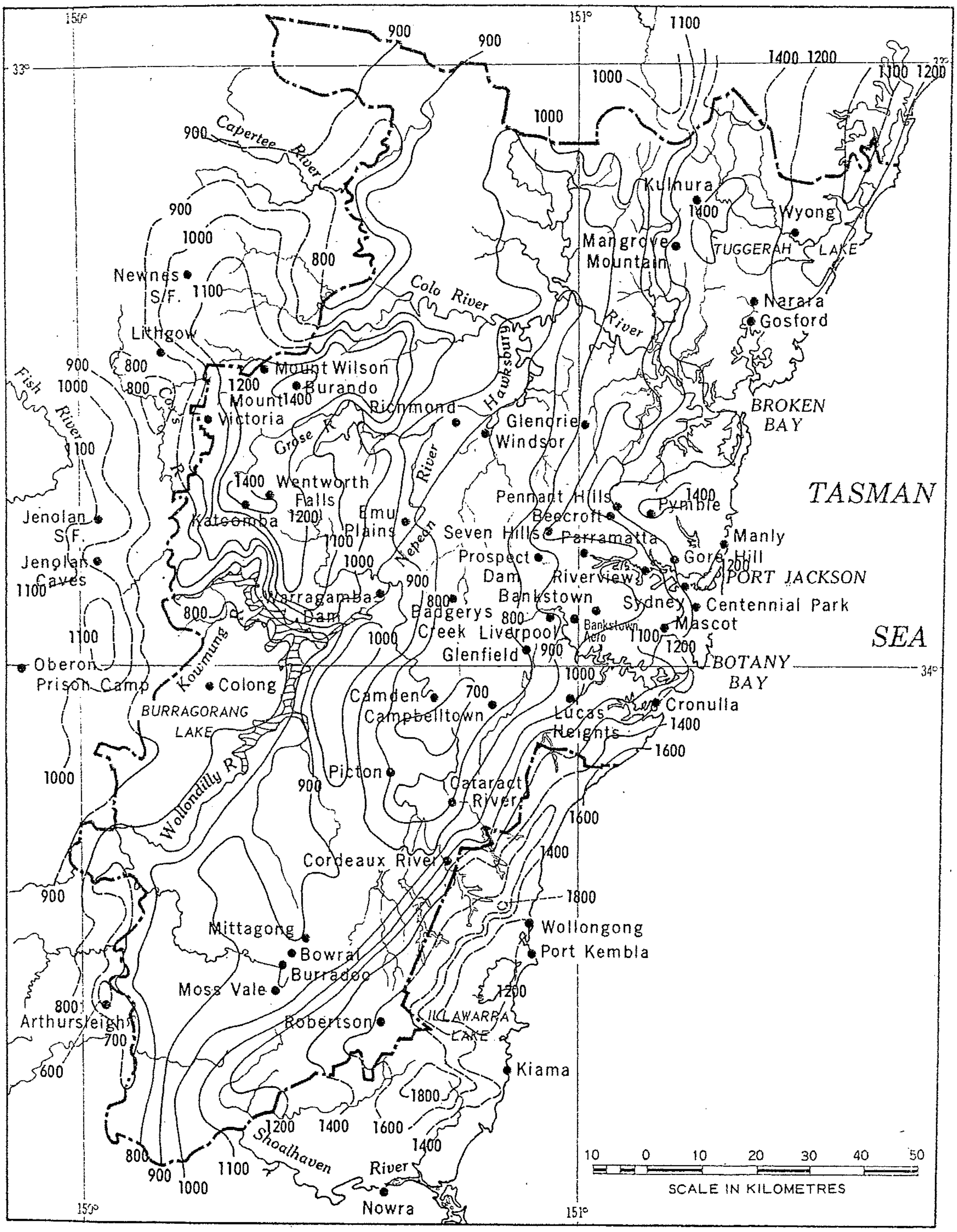
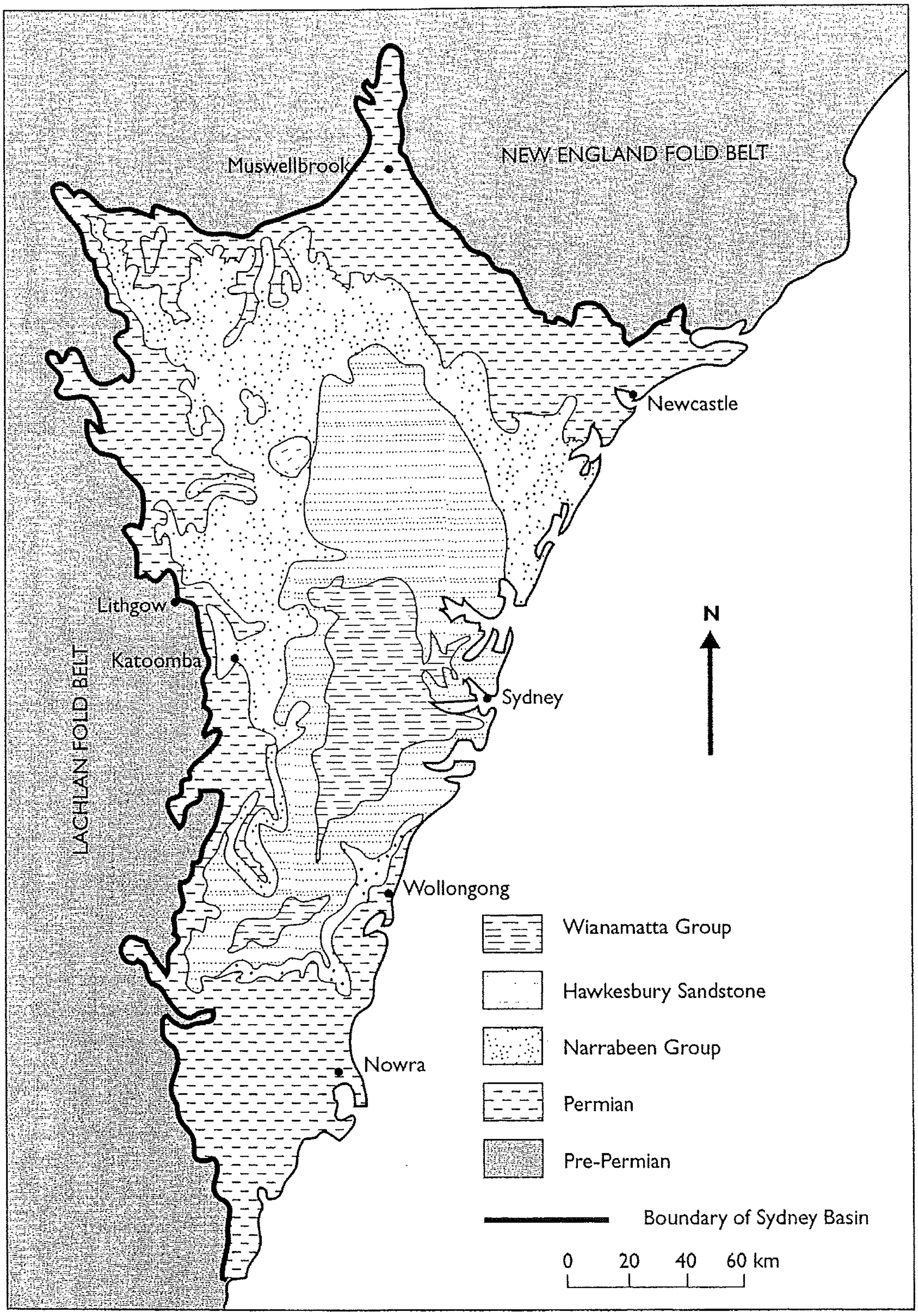


Fig 1 Average annual rainfall (mm).



NEW ENGLAND FOLD BELT
LACHLAN FOLD BELT
Muswellbrook
Newcastle
Lithgow
Katoomba
Sydney
Wollongong
Nowra
N
Wianamatta Group
Hawkesbury Sandstone
Narrabeen Group
Permian
Pre-Permian
Boundary of Sydney Basin
0 20 40 60 km

We all Live in a Catchment

A catchment is an area of land with natural features such as hills or mountains forming its boundaries. The water that falls on the catchment drains to a creek, river, lake or the ocean.

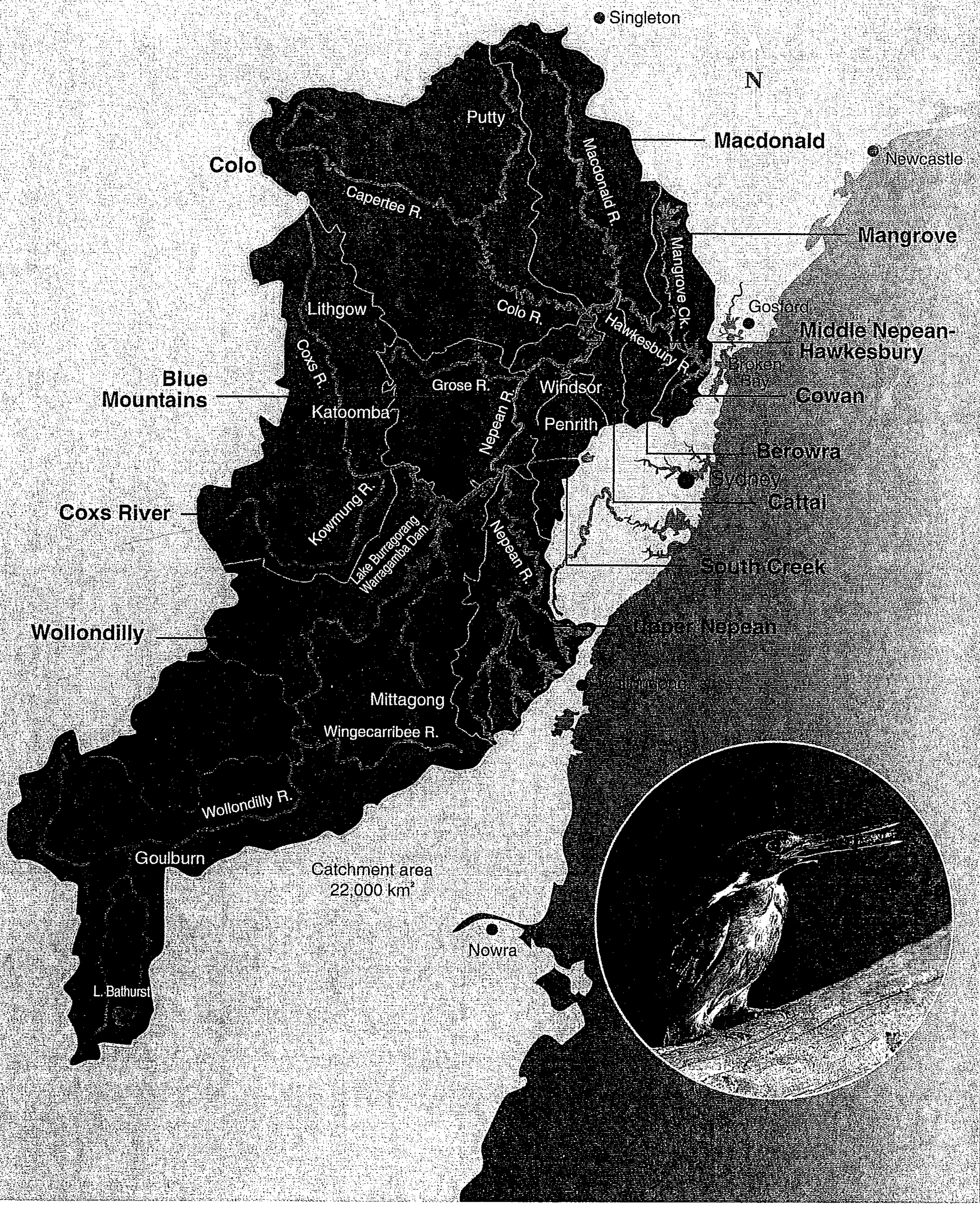
The Hawkesbury-Nepean catchment is large but within it are twelve smaller catchments that collect water for the tributaries of the Hawkesbury-Nepean River. These smaller catchments are identified on the map.

Sydney and surrounding regions rely on the catchment to supply nearly all of their water needs.

Total Catchment Management

Total Catchment Management (TCM) is the coordinated and sustainable use and management of land, water, vegetation and other natural resources on a catchment basis so as to balance resource utilisation and conservation.

A catchment provides a natural planning unit for resource management in which to optimise economic developments and the social well-being of the community.



'ALTOGETHER BARREN, PECULIARLY ROMANTIC': THE SANDSTONE LANDS AROUND SYDNEY

R. W. and A. R. M. YOUNG*

SUMMARY: The poor and rugged sandstone plateaux around Sydney were long seen as little more than a barrier to the fertile inland. Yet this wilderness has had a fascination for artists and sightseers alike. Economic impacts came slowly, while action to preserve the landscape met with considerable success, but over the last decade there has been increasing conflict between developers and conservationists. A geomorphological account of the sandstones is presented here, both as a contribution to the rational resolution of that conflict, and as a guide to the look of the land. Emphasis is given to the interaction of surface processes and bedrock characteristics.

To the first European settlers of the Sydney region (Figure 1) the sandstone plateaux which surrounded the settlement were noteworthy mainly for their uselessness for food production and for the forbidding nature of their rugged terrain. It may be that the Aborigines viewed them in a somewhat similar, if less inauspicious light, for although occupance of the lowlands dates as far back as 45,000 BP (Nanson *et al.* 1987), the main occupance of the plateaux seems to date from later than 7,000 BP (Hughes and Sullivan 1981). Yet colonial painters were fascinated by the great cliffs, waterfalls and sweeping vistas of the Blue Mountains — so much so that many of the paintings of Martens, Piguenet and von Guerard celebrate a wilderness in which man seems out of place. Joseph Lycett, describing his 'View of the Wingecarribee' (c. 1824), saw 'the principal objects' as 'the extraordinary rocks which, in stupendous masses, overhang the River' (quoted in Bonyhady 1985). Those responsible for conquering the wilderness saw it with a less sympathetic eye. Surveyor Govett described the Blue Mountains as having an 'awful solemnity', an appearance 'altogether barren, peculiarly romantic . . . awfully desolate'; one not atypical gully he described as an 'infernal Hole' (quoted in Speirs 1981). As the wilderness of the plateaux was celebrated in art, so too was its conquest, especially the building of transport lines across it (e.g. Earle's *'King's Tableland'* c. 1826, Martens' *'Zig Zag Railway'* 1876 and Streeton's *'Fire's On'* 1891).

The inevitable tension between the desires to exult in the wilderness and to tame it, a tension often present within individual minds, not only remains, but in recent decades, has been markedly intensified. These plateaux still are, as Griffith Taylor (1958) described them thirty years ago, an 'almost empty land'. And, as Taylor never tired of emphasising, they were 'empty' because, except where shales or basalt overlie the sandstone, their soils were unsuitable for agriculture, and because their rugged terrain confined transport and settlement to narrow corridors.

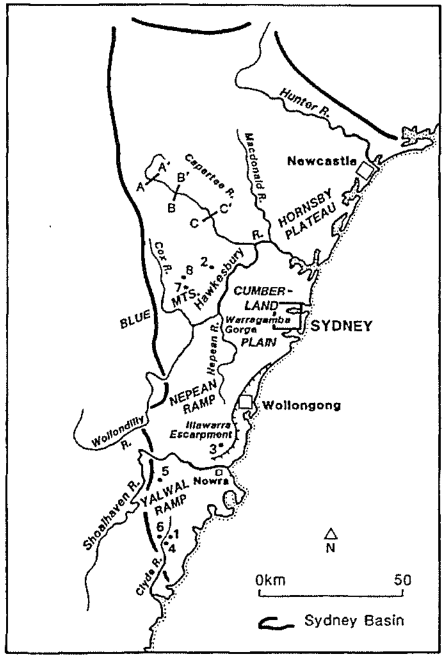


Figure 1: Location of major topographic features in the Sydney Basin. Location of Plates (1-8), and of sections in Figure 4 (A-A', B-B', C-C') are also shown.

Action to preserve the sandstone landscape began quite early here. In 1879, just seven years after the dedication of the first national park in the USA, the Royal National Park was set aside for public recreation on the southern outskirts of Sydney. In deference to Taylor, it must be admitted that this park and its successors are on land for which there was little competing demand. Indeed

* Department of Geography, University of Wollongong, PO Box 1144, Wollongong, NSW 2500, Australia.

much of the opposition to the second large park, Ku-ring-gai Chase, which opened in 1894, was prompted by the apparent waste of public money on land in which 'thirty acres would hardly feed a goat' (quoted by Taylor 1958). Moreover, the great bulk of the land dedicated to national parks has been set aside in the last two decades. Today major parks and reserves occupy some 963,430 ha, or about one-third of the sandstone plateaux of the region (Figure 2). To this area can be added approximately another 130,000 ha set aside as catchment for the region's water supply. About 8 per cent of this catchment area, some of it valley-bottom land already cleared for agriculture, has been flooded, but disruption in the remainder has been limited mainly to the cutting of fire trails and corridors for power lines and to periodic burning designed to reduce the hazard of bushfires.

Nonetheless, major changes have occurred, and are doing so at an increasing rate. Suburban Sydney has sprawled onto the low sandstone plateaux to the north and south and along the corridor across the Blue Mountains. Major expressways and a railway for the export of coal have been carved through almost pristine bushland. An increasing reliance on mineral exports has led to a great expansion of the traditional mining areas on the flanks of the region; most of the Nepean Ramp in the south-east, for instance, is either designated as active coal leases or as a reserve for future mining (Figure 3). Many of these leases lie in the catchment area, and attempts to extend them under the water storages (Reynolds 1977) and also into the national parks have resulted in heightened controversy over future land use in the region.

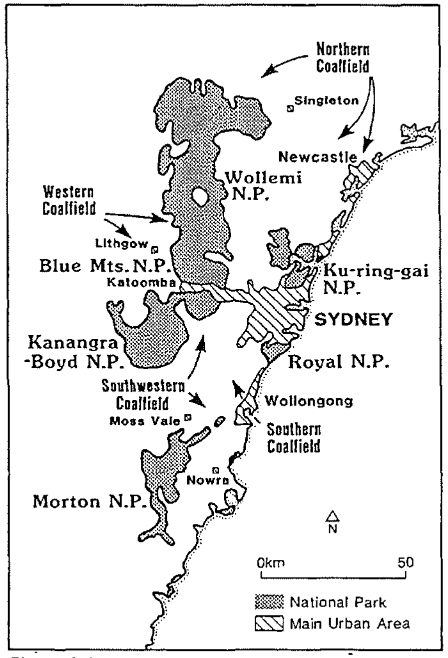


Figure 2: Location of the coalfields and major national parks around Sydney.

Whether one's interest lies primarily in the rational resolution of these controversies or simply in understanding the look of this land which has fascinated countless thousands, an appreciation of the forces which have shaped the plateaux is essential. Much has been written on the long-term geomorphological evolution of the region, although the traditional cyclical interpretations (see the fine Davisian synthesis written by Taylor 1958) have been challenged (e.g. R. Young 1977, 1978a). Only recently, however, has much attention been given to the interaction of contemporary denudational processes and lithological constraints, and to their modification by man (e.g. Branagan 1985; Pells *et al.* 1987; see also Young and Nanson 1983). This is our concern here.

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

From Carboniferous to Triassic times, and perhaps as late as the Jurassic, sediments were swept from the folded and crystalline rocks of Palaeozoic ranges in northern and central New South Wales into the Sydney Basin, and were then uplifted by epeirogenic movements (Herbert and Helby 1980; Branagan *et al.* 1976). During the first major phase of deposition which was dominantly marine, alternating sandstones and siltstones were laid down as the basin's margins expanded and contracted. Early in this phase some coal was deposited, and late in it there was extensive vulcanism in the southern part of the basin. When marine sedimentation gave way to freshwater deposition in the late Permian, extensive coal-bearing beds and thick sequences of sandstones and shales were deposited. The basin's margins contracted, so that the uppermost beds were confined mainly to the centre. Uplift may have occurred in several phases but strata had reached essentially their present elevation by Early to Middle Tertiary times (Wellman and McDougall 1974; R. Young 1978a; Bishop *et al.* 1982). This broad warping, with some faulting, produced an asymmetric, elongated, saucer-like regional structure which rises steeply in the west and more gently to the north and south.

Thus, the centre of the basin is today a rolling lowland, known as the Cumberland Plain (Figure 1),

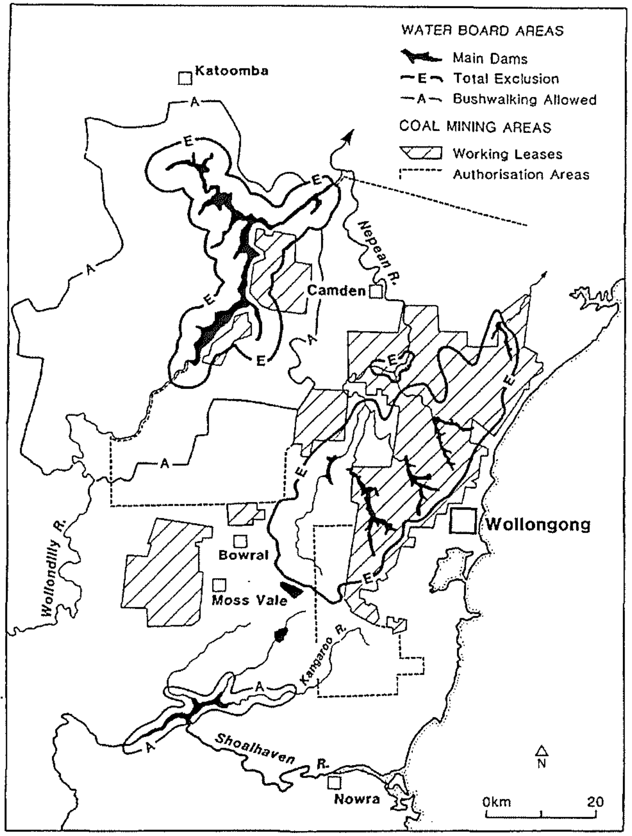


Figure 3: Overlapping of coal mining leases and Water Board catchment areas in the southern part of the Sydney region.

developed mainly on the Wianamatta Shale, which is the uppermost of the Triassic sequence. Except for an extensive outlier in the south-west near Moss Vale, these shales have been almost completely stripped from the surrounding plateaux. The dissected surfaces of the plateaux are carved from the Triassic Hawkesbury Sandstone in the north and south, whereas in the west the Hawkesbury Sandstone and the underlying Narrabeen Group form the surface of the Blue Mountains. In the far south, the Permian Nowra Sandstone and Snapper Point Formation form rugged plateaux. The coal resources of the basin crop out beneath Triassic sediments along the Illawarra Escarpment in the south-east and in the deep and broad valleys on the western side of the Blue Mountains. On the northern flank of the basin, the Hunter River and its tributaries have dissected the lower Permain sequence into rolling valleys. These valleys which have long been used for agriculture and underground coal mining, are now the site of extensive open-cut extraction of coal.

The landforms of the plateaux can be most simply described in terms of the repetition of three sub-types: plateau summits and upland valleys; cliffs; and valley sides and floors. There are, however, marked variations in each of these types across the region.

PLATEAU SUMMITS AND UPLAND VALLEYS

Where the plateau is cut mainly from a single sandstone formation, as is the case with Hawkesbury Sandstone on the Hornsby and Woronora plateaux, the summits are relatively narrow, though sometimes flanked by benches. However,

where there is substantial capping by basalt or shale, the ridges tend to be much broader. Benches on the summits are linked to bedding of the rock, and, according to some authors, are particularly prominent where minor claystone lenses are interbedded with sandstone (e.g. Pickard and Jacobs 1983). However, the occurrence of claystone must be demonstrated rather than assumed, for, as Mainguet (1972) noted, flow patterns within sandstones are complex, and seepage often emerges from two-dimensional, non-point sources close to summits. The benches seem due to the enhanced weathering of sandstone at such seepage outlets. Benches are broad where bedding is thick; where bedding is very thin, multiple minor benches can impart a striking convexity to the general form of the slope.

Of great importance to the management of the summit areas are recently revealed close linkages between biological and physical processes of denudation. Results obtained by Humphreys and Mitchell (1983) indicate rates of surface mounding of soil by termites and ants up to 570-840 $g/m^2/yr$, by worms of up to 134 $g/m^2/yr$ and by lyrebirds of up to 4,470 $g/m^2/yr$ (see also Adamson *et al.* 1983). The fall of trees in the sclerophyll woodland that generally covers the summits can also cause surface mounding of up to 134 $g/m^2/yr$ (Humphreys and Mitchell 1983). Mounded material is shifted downslope mainly by surface wash, though the rates of movement range from 4 to 900 $g/m^2/yr$, depending on local surface conditions (Humphreys and Mitchell 1983). However, this same monitoring program indicates that soil creep on these slopes is negligible. The high frequency of fire in the sclerophyll woodland seems to play an important role in the breakdown of sandstone surfaces (Adamson *et al.* 1983), though the rates at which this breakdown occurs have still to be determined. Adamson and his colleagues have also demonstrated that fire and the subsequent patterns of regeneration have a significant effect on the transport of sandstone debris by overland flow over slopes on the summits of the plateaux.

On parts of the plateaux, and especially in the Blue Mountains, there is considerable local relief. The tops of the clifflines are frequently deeply notched. Holland (1974, 1977) has shown clearly how the headward migration of small knickpoints along the claystones in the Narrabeen Group leads to incision of the lower reaches of the upland valleys. In many instances, such as the Grand Canyon at Blackheath, these lower reaches form extremely narrow slot valleys which may descend almost through the entire cliff-forming stratum. Even where creeks tumble over high waterfalls, there is substantial incision above the falls, as can be seen at Govett's Leap or Wentworth Falls.

As claystone beds in the Hawkesbury Sandstone, Nowra Sandstone and Snapper Point Formation are fewer and less continuous than in the Narrabeen Group sandstones, slot valleys are rarely found on the other plateaux. Streams on the plateaux are generally incised only to shallow depth, and flow through broad, gently sloping depressions (Holland 1974; Buchanan 1980; A. Young 1986a), which are often sediment-choked and swampy. The dells are characterised by almost treeless vegetations — sedgelands and heathlands — which contrast sharply with eucalypt woodland/open forest that dominates the plateau summits and valley sides. The change from woodland to sedgeland/heath is usually abrupt and is due to the wetness of the shallow upland valleys.

The dells are supplied with a coarse sandy load as a result of weathering and erosion of the plateau summits, yet they are small headwater streams with low discharges and gentle gradients. They often are unable to flush their load from the headwaters into the gorges which dissect the plateaux. Because they become sediment-choked, they lack continuous open channels so that seepage and also runoff from low magnitude storms do not flow away rapidly. Thus, a perched water table is held within the sediments; breakdown of organic debris is slow and incomplete because of the resultant poor aeration; colloidal organic matter accumulates, enhancing the moisture-retaining capacity of the sediments. The importance of such hydrological factors can be further demonstrated by considering the distributions of sedgelands across the plateaux, looking firstly at the hanging swamps of the Blue Mountains and secondly at the dells of the Woronora Plateau.

While dells on most plateaux occur mainly on gentle slopes (all of those in Cataract and Cordeaux catchments on the Woronora Plateau have average gradients lower than 8°), in the Blue Mountains curtains of sedgeland hang down near-vertical slopes in many places. These hanging swamps develop below the contact of the horizontally extensive Wentworth Falls Claystone with the overlying and well-jointed Grose Sandstone of the Narrabeen Group. Seepage from the ridges moves through the joints in the sandstone but emerges when it strikes the far less permeable claystone. Even where this contact intersects very steep slopes and cliff-lines, the persistent emergence of seepage maintains hanging swamps with their root mats binding a few centimetres of organic-rich soil. Where the claystone crops out on gentler valley sides, dells occur with a well-defined upslope margin following the contact along the contour (Holland 1974).

Hanging swamps do not characterise the other plateaux because the other major sandstone formations, apart from the Narrabeen Group, lack extensive continuous claystone beds. On the Woronora Plateau, the Hawkesbury Sandstone has only discontinuous and restricted claystone facies and the presence of swampy dells results from the impermeability of the Sandstone itself. Subsurface flow is largely horizontal, with only limited flow down vertical joints (Reynolds 1977). Sedgelands are extensive on undissected parts of the plateau along the eastern side where average precipitation (1,500 mm/year) exceeds average evaporation (900 mm/year) annually and in each month of the year (A. Young 1986a). Valleyside swamps are common here, occurring where seepage emerges along bedding planes. Further west across the plateau, where climatic conditions are drier, valleyside swamps are rare and the valley floor swamps are heathlands or even open woodlands of scribbly gums. Here annual average rainfall is only 900-1,100 mm/year and exceeds annual average evaporation probably by less than 100 mm/year. The drier environment is reflected also in the soils which change from very dark grey to black peaty podsols under sedgelands in the eastern part to shallow yellow earthy sands with a very dark brown A horizon under open woodland further west. On a much smaller scale, similar changes from relatively wet to relatively dry conditions across benches in the Tianjara area on the Shoalhaven Ramp have created patterning of alternating sedgelands and mallee eucalypt woodland (Pickard and Jacobs 1983).

The impermeability of the Hawkesbury Sandstone and its role in preserving high water tables in the dells were shown dramatically as a result of human interference at one site in Avon catchment (A. Young 1986b). The site suffered a maximum of 2.4 m of subsidence between 1965 and 1975 due to underground extraction of two coal seams (Kapp 1980). There was extensive cracking of the sandstone at the surface, as well as opening of joints in tensional areas and generation of 'A-tent' structures in compressional zones. This allowed vertical seepage into the bedrock from the swampy sediments and lowered the water table from the ground surface to more than 8 m below bedrock. A secondary consequence was severe gullying in the dell (A. Young 1986b).

The broad-scale dependence of the dells on hydrological conditions is echoed on a smaller scale within them. Melville and Fitzpatrick (1983) described three hydrological zones within those of the Budderoo area at the southern end of the Woronora Plateau. In the valley axes there is a zone of permanent saturation where actual evapotranspiration equals the potential rate at all times. Runoff begins from this zone immediately after rainfall. On the sideslopes, still under sedgeland/heathland, there is an intermediate area where soils have a water storage capacity which varies with antecedent rainfall. On the ridges occupied by eucalypt woodland, the soils are saturated only for brief periods after rainfall. Potential evapotranspiration exceeds the actual rate in this zone. These hydrological zones are matched by changes in soil type and sediment transport processes (A. Young 1986a). Comparisons of two catchments at Budderoo showed that the catchment with most extensive swamps (46 per cent of total area under sedgeland/heathland) generated only 54 per cent of rainfall as runoff, whereas the drier catchment (36 per cent of area under swamp) generated 64 per cent of rainfall as runoff (Melville and Fitzpatrick 1983). Hence, the dells retain rainfall more efficiently than the eucalypt woodlands, and can supply flow during prolonged drought conditions. This role is well-recognised (see for example Forster *et al.* 1977) and even popular works on the Blue Mountains (Speirs 1981; Liddle and Baker 1987) make eloquent pleas for preservation of the swamps for this reason. We may note also that the large pools which lie in the valley axes of the larger swamps provide continuous water supplies for fauna during long dry spells.

It is obvious that the high natural quality of the water in the storage reservoirs around Sydney is due primarily to the large undisturbed catchment areas from which it is gathered. Very little treatment is required before the water is supplied for domestic purposes. The quality is maintained partly by the presence of the dells which are very effective traps for sediment eroded from the ridges and which release water with typically low ionic concentrations. Thus, protection of the dells is important for preservation of water quality within the catchment areas, for the maintenance of flow during long droughts and for ecological reasons.

It is not only water and sediment which accumulate in the dells. Recent work on the soils of Avon catchment on the Woronora Plateau (Young and Sim 1987) has shown that the dells are areas of iron accumulation also. Soils developed on Hawkesbury Sandstone in the catchment are generally skeletal lithosols on ridgetops, yellow earths of variable depth up to 1.5 m on valley sides and organic sands in the dells. In the lithosols and yellow earths, concentrations of total free iron and of mobile/amorphous iron were less than 5g/kg close to bedrock and even lower near the soil surface. However in the dells, concentrations were much higher and were greatest close to the surface (Table 1). These data show clearly that the swamps are zones of accumulation of iron which has been leached from the ridges and washed with sediment or transported in solution into the swamps. Oxidation and immobilisation of iron in the surface horizons is due to localised aeration around plant roots. Indeed sheaths of orange iron oxide can be found along the fine roots of many sedges.

Table 1: AVERAGE CONCENTRATIONS OF IRON IN SOILS ON HAWKESBURY SANDSTONE, AVON CATCHMENT

Soil type	Total free iron (g/kg)		Mobile/amorphous iron (g/kg)	
	at 0.1 m	at 0.5 m	at 0.1 m	at 0.5 m
Lithosol	2.60	n.a.	0.66	n.a.
Yellow earth	0.82	4.06	0.56	0.86
Organic sand	12.02	8.91	4.83	1.83

Source: Young and Sim (1987) Total free iron as citrate-dithionite extractable; mobile/amorphous iron as oxalate extractable.

Clearly, within the organic-rich and acidic soils of the dells, iron is mobile in the soil water. Iron levels on filtered samples of water from streams flowing over the Hawkesbury Sandstone are low, ranging from 0-0.15 mg/l generally but reaching 0.5 mg/l (Halford *et al.* 1985; Johnson 1986). For drinking water, 0.3 mg/l is acceptable but <0.1 mg/l is desirable, so that the movement of iron within the catchment is of great importance to the water supply authority, the Metropolitan Water Sewerage and Drainage Board (MWSDB). High iron levels are encountered in the water from Avon and Cordeaux storages, particularly when the water is turbid after heavy rainfall (MWSDB 1986). Thus, much of the iron entering the storages does so in association with suspended sediment. When this sediment settles to the floor of the reservoirs, iron can be re-mobilised into the water in the anoxic conditions that prevail as the lake waters are stratified during summer. There is already a substantial store of iron in the stored waters and its re-mobilisation into the supply has become a significant problem in the Wollongong area. Hence, it is important to minimise further inputs of iron into the stored waters, and again this emphasises the need to protect the dells from erosion. They are excellent sediment and iron traps and their erosion would lead to substantial increases in iron inputs to the stored waters.

Not all of the iron leached from the sandstone moves in soil water or runoff. Particularly near cliffs or knickpoints on streams, water moves down joint planes and along subsurface bedding planes. As it emerges at the surface, iron in solution in the ferrous state is rapidly oxidised and gelatinous orange amorphous iron oxides are precipitated. Precipitate from the Nepean catchment yielded 172.8 g/kg amorphous iron and a similar dry deposit from O'Hares Creek catchment showed some poorly crystallised goethite; others from near Yerranderie were high in siderite (Blong, *personal communication* 1987). The precipitates may form banded porous tufas along bedding planes or minor joints, or stalactites below overhangs. Excellent examples of such stalactites are found particularly in the Blue Mountains, for example in the Valley of the Waters at Wentworth Falls and Magdala Creek at Springwood. Thus, water movement from the upland summits and valleys into the gorges and valleys that dissect the plateau is not confined to surface flow. Subsurface movement is also of major importance, particularly in the development of waterfalls and as an influence on the stability of the clifflines.

CLIFFS

The most visually striking landforms of the region are undoubtedly the long lines of cliffs, especially those of the Blue Mountains and the Clyde-Shoalhaven area (Plates 1, 2 and 4). They are the prime tourist attractions, they have dominated the vistas painted by many artists (Speirs 1981), and the scattering over them of romantic names, such as the Donjon or Shrouded Gods Mountain, attest to their place in the popular perception of these landscapes. Yet the very general resume written by Taylor (1958) is the only readily available treatment of their form and origins. In extending Taylor's account we turn first to a consideration of a particularly impressive example — the western wall of the Castle in the Clyde River valley (Plate 4).

The Nowra Sandstone, of which the upper cliffline of the Castle is formed, can be rated as a rock of medium strength. Although no triaxial tests have been made on this sandstone, Schmidt-Hammer tests indicate uniaxial comprehensive strengths of 55 to 70 Megapascals (Mpa), values somewhat higher than the range of about 20 to 60 Mpa recorded for the majority of tests on the Hawkesbury Sandstone (Pells 1977, 1985) which form the main cliffs further north in the region. The resistance of the Hawkesbury Sandstone to shearing stress (that is, when the stress is translated obliquely rather than applied solely in the vertical plane) is less than half its compressive strength (Johnson 1960; Pells 1977, 1985), and this is probably true of the Nowra Sandstone also. Nonetheless, the stresses generated even by the 150 m high cliffs of the Castle fall well below these critical levels of rock strength.

The stability of the west wall of the Castle is greatly enhanced by the geometry of the fractures through the sandstone. As is the case in most parts of the region, except for sites of localised steep folding like the Lapstone Monocline, the bedding of the sandstone is inclined at only a few degrees (Plates 2 and 4). Most joints dip steeply (70-90°) and, in conjunction with the almost horizontal bedding, form assemblages of rectangular

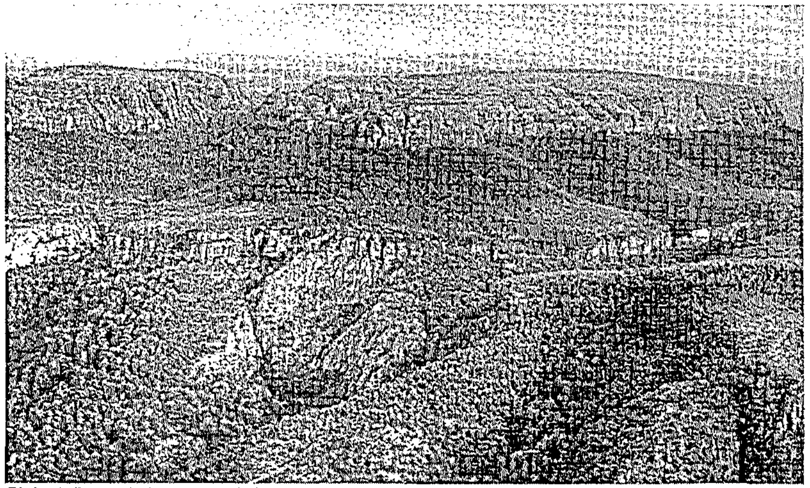


Plate 1: *Rugged plateau terrain in the upper Clyde valley at the southern extremity of the Sydney Basin. The plateau summits and upper cliffs are carved from Nowra Sandstone, the upland valleys are cut mainly in Wandrawandian Siltstone, the second cliffline is in the Snapper Point Formation, and the sides of the gorge are cut in folded Devonian rocks. Just out of view to the right Eocene basalts that flowed down the upland valleys demonstrate the great antiquity of the landscape.*

blocks that are very stable. Yet, as can be seen clearly in Plate 4, some joints which dip outwards from the cliff face provide failure planes down which blocks can slip and then fall. The complexity arising from the intersection of differentially inclined joints is well illustrated by the wedge-shaped block (marked A) shown on Plate 4. Despite the precarious appearance of this block, estimates of its geometric and frictional parameters indicate that it is stable (see wedge-failure analysis tables given by Hoek and Bray 1974). In short, where their foundations are sound, cliffs like this one are very stable.

The importance of failure in claystones or shales at the base of the cliffs has long been recognised here, but the usual dismissal of it as a weathering of 'soft rock from beneath hard rock' is misleading. At some sites in the Clyde and Shoalhaven catchments the contact between the Nowra Sandstone and the underlying Wandrawandian Siltsone is buttressed, not undercut. Moreover, the main undercutting often is not in the clayey rock, but in conglomeratic beds at the base of the sandstone; water seeping through the conglomerate weakens the contact on the surface of the smooth pebbles which then simply fall out of the

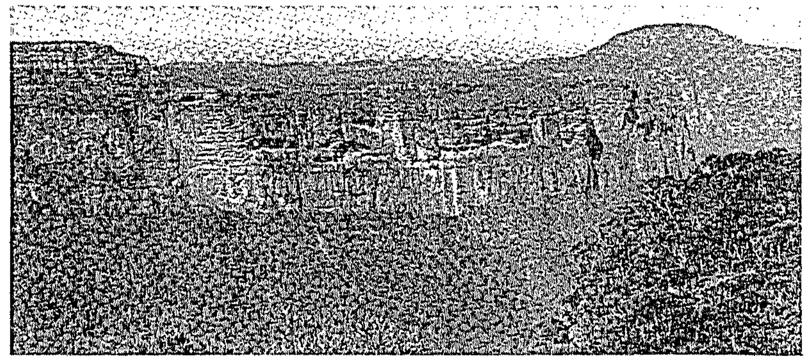


Plate 2: *Cliffs lining the gorge of the Grose River, in the Blue Mountains, are carved from sandstones of the Narrabeen Group. The lower slopes of the gorge are cut mainly from Coal Measure sediments.*

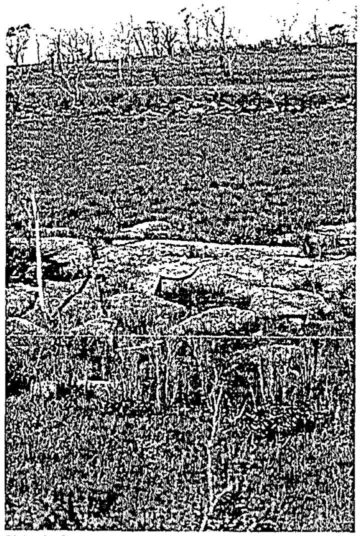


Plate 3: *Stepped sedgeland on the plateau surface at the Barron Grounds in the upper Kangaroo River catchment, south of Wollongong. This scene highlights the importance of beds of low permeability in the Hawkesbury Sandstone in the development of sedgelands in the southern part of the region.*

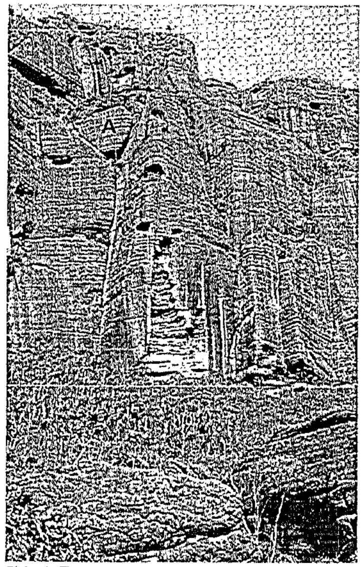


Plate 4: *The western wall of the Castle in the upper Clyde valley. This 150 m cliffline is cut in the Nowra Sandstone and the slopes beneath it are cut in the Wandrawandian Siltstone. The almost horizontal bedding and steep jointing is typical of most outcrops in the region. Note the effect of intersecting joints on the block at the upper left (A) of the plate. The vertical extension of the prominent caverns points to the importance of percolating groundwater in their development.*

matrix. When undercutting does occur in the claystones and shales, the breakdown of these rocks is not just a matter of increasing plasticity due to weathering as is often assumed (e.g. Evans 1981). Except where seepage concentrates along major fractures, the really intense weathering of the clayey rocks is located not in the undercut, but beyond the drip line of water coming over the cliff, which leads to the mass failure of saturated clays on the slopes *below* the undercut. The majority of undercuts seen by us are extending by brittle fracture in clayey rocks that have not been intensely weathered.

In accounting for undercutting, the physical character of the clayey rocks and also the concentration of stresses acting on them must be considered. Hebblewhite (1978) comments in a geotechnical study of the Appin Colliery that, although the shales are quite strong in compression (averaging 75 Mpa when confining pressure is 10 Mpa), they are quite brittle when unconfined. Furthermore, at the base of cliffs these rocks are subjected not just to the average stress generated by the overlying sandstone, but to the much greater local concentration of stress that occurs at the foot of rock walls (Stacey 1970). An even greater concentration of stresses occurs as the undercut deepens, and to these stresses must be added any horizontal tectonic stress which, in the mines near Wollongong, is known to be up to three times greater than the vertical stress generated by the overburden (Hebblewhite 1978). First approximations by us indicate that stresses at the foot of many cliffs in the region may be close to the measured shearing strengths of unweathered claystones (Johnson 1960; Hebblewhite 1978) and that only minor hydration of clay is probably needed for these rocks to fracture and for undercutting to develop.

The failure of sandstone above an undercut can occur in several ways. A joint-bounded block will become unstable, owing to the shift in its centre of gravity, once undercut beyond one-third of its width and will topple as undercutting proceeds. If the joints are widely spaced, the rock may fail by brittle fracture before the block topples because the strength of these sandstones in tension is only about 5 to 10 per cent of their strength in compression (Pells 1977, 1985; Jaggar 1978). This is why large plates of sandstone projecting more than a few metres from the cliff face are rarely seen in this region. As many failures are triggered by high stress concentrations in partly weathered claystones beneath the sandstone, the displacement of blocks may involve a backward rotation rather than a forward toppling motion (Pells *et al.* 1987; Cunningham *forthcoming).*

Not all large failures on the cliffs are triggered by undercutting, for, especially in the southern part of the region, gliding of very large blocks away from clifflines is quite common. Probably the most convincing evidence of the displacement of blocks extending the full height of the cliffs can be seen along the Shoalhaven River just west of Nowra, where crevasses zig-zag from one set of joints to another (R. Young 1983a). Many of these crevasses have no tributary streams that could have cut them, have no outlet on the cliff face, and have projecting plates on the outer block that match recesses on the inner wall. A spectacular instance of block gliding is at Chimney Stack Rock, near Yalwal, where blocks 15 to 27 m high have apparently moved as far as 100 m from the adjacent cliffs (Plate 5). Another notable example is at Burra Moko Head near Blackheath, in the Blue Mountains, where a pinnacle 40 to 60 m high has moved from the cliffline (Pells *et al.* 1987). The mechanics of gliding hereabouts are poorly understood, for the plasticity of the shales seems too low for them to transport the huge sandstone blocks. The answer may lie in rheological deformation over time spans of thousands or even millions of years. Of this we know little, but, to cite one instance, a great detached pinnacle at the head of Yarrunga Creek seems not to have shifted since 1836 when it was depicted in Conrad Martens' painting 'Fitzroy Falls'.

Of course, not all pinnacles are the result of block gliding; many have been carved by the concentration of erosion along joint planes. Fine examples can be seen in Monolith Valley (Plate 6), in the southern extremity of the region, but undoubtedly the best known is the Three Sisters at Katoomba (Plate 7).

Thus far we have considered the cliffs as though they were dry stone walls, but the effects of water must also be taken into account. When saturated, the Hawkesbury Sandstone has only about 50 per cent of the compressive strength it has when dry (Pells 1977). Furthermore, it is well known that locally high porewater pressures reduce the stability of joint-bounded blocks. Consequently, at sites like Caloola Pass and Johnson's Spur near Wollongong, continuous flow from large swamps on the plateau surface can degrade the cliff line.

The interplay of water and of the strength of rock masses is most readily seen at numerous spectacular waterfalls that plunge over the cliffs. They are usually attributed to erosion, by the falling water, of claystones under the sandstone, but this is too simple an explanation (R. Young 1985). Many of these falls are buttressed at the base, rather than undercut. Where undercutting is present, it often is located to the side of, rather than behind the falls, indicating that it is probably the result of the saturation of rock by seepage or by spray, and not the result of direct stream erosion. In some cases, like Fitzroy Falls, there is neither undercutting nor a plunge pool. Especially

Plate 5: Chimney Stack Rock near Yalwal, west of Nowra. Despite its slender form, this tower of Nowra Sandstone has apparently moved outwards, gliding over the Wandrawandian Siltstone for a distance of 100 m, from the adjacent cliffline.

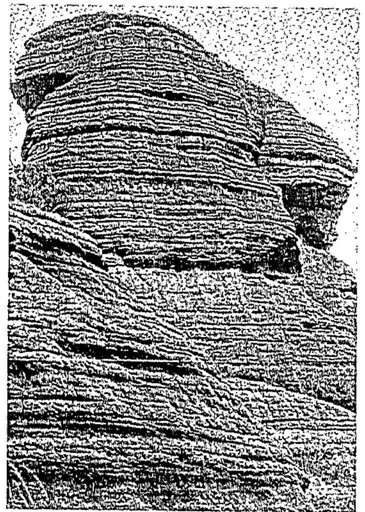


Plate 6: Pinnacle carved from Nowra Sandstone in Monolith Valley at the southern extremity of the region. The pronounced convexity is typical of slopes developed on the closely bedded but very strongly cemented sandstones in this locality. The growth of a small cavern has resulted in the collapse of a block on the right hand side of the pinnacle.

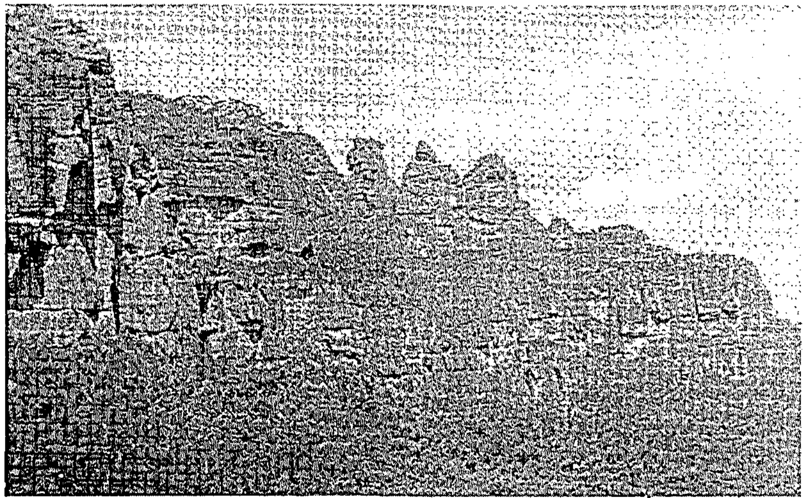


Plate 7: The effects of vertical jointing and of erosion along prominent claystone beds are well illustrated at the Three Sisters near Katoomba in the Blue Mountains.

in cases like this one, the effect of the water seems to be only a speeding up of the mechanisms of failure operating along the adjacent cliffs (R. Young 1985).

Although the quartzose sandstones of this region are relatively resistant to weathering, at many sites chemical alteration extends to considerable depths. Drilling during geotechnical investigations for the Warragamba Dam (Johnson 1960) revealed two zones of weathering under broad interfluves on the Hawkesbury Sandstone. To depths of about 15 m the sandstone had been converted to corestones of hard rock surrounded by a 'sugary mass of decomposed material' (Johnson 1960). Beneath this zone, and extending to the watertable, the conversion of siderite cement to limonite, together with secondary silicification between grains, had actually increased the hardness of the rock. Clearly, changes such as these can have considerable effects on the mass strength of cliffs.

The most striking manifestation of weathering on the cliff faces are the very extensive caves (Plates 4 and 8). As a first attempt to assess their incidence, we analysed 14 panoramic photos of cliffs in the Blue Mountains and the Clyde and Shoalhaven valleys. This analysis, which revealed that the eye greatly exaggerates the proportion of cliffs occupied by caves, gave a range of 3 per cent to 28 per cent and an average of 11 per cent. The caves rarely extend more than a few metres into the cliffs. Contrary to popular belief, they are not formed by wind erosion, as can be readily demonstrated by their occurrence in very sheltered sites. While hydration of clay in the matrix of sandstone may be a contributing factor, the mobilisation of iron and silica by water moving through the rock is of far greater importance (Johnson 1974). Schmidt-Hammer tests show about a 50 per cent decrease in strength from case hardened rims to the weathered roofs and back walls of caves. The primary cause, even well away from the sea, seems to be salt weathering, though the process is not a disruption of grains by the growth of salt crystals but rather a chemical etching of quartz grains promoted by the presence of chloride (A. Young 1987). Hughes and Sullivan (1983) suggest that the natural rate of cavern growth is generally less than 0.5 to 0.2 mm/100 years, but that Aboriginal occupance increased this rate to a maximum of about 6 mm/100 years.

Evidence pointing to slow rates of contemporary denudation in the landscape is supported by investigations of long-term evolution using radiometric dating of basalts. These studies (e.g. Wellman and McDougall 1974; R. Young 1983b; Young and years. Even where much siltstone outcrops beneath the sandstone, the rate of retreat is apparently less than 200 m/million years (Young and McDougall 1985).

These average long-term rates have been greatly exceeded since the advent of mining in the region 100 years ago. Probably the first large-scale impact of mining on the stability of the cliffs is vividly recorded in photos of the shale oil plant at Newnes (c. 1915) which show five major and several minor collapses that contrast starkly to the stability of adjacent cliffs. Since then, major collapses triggered by mining have occurred at

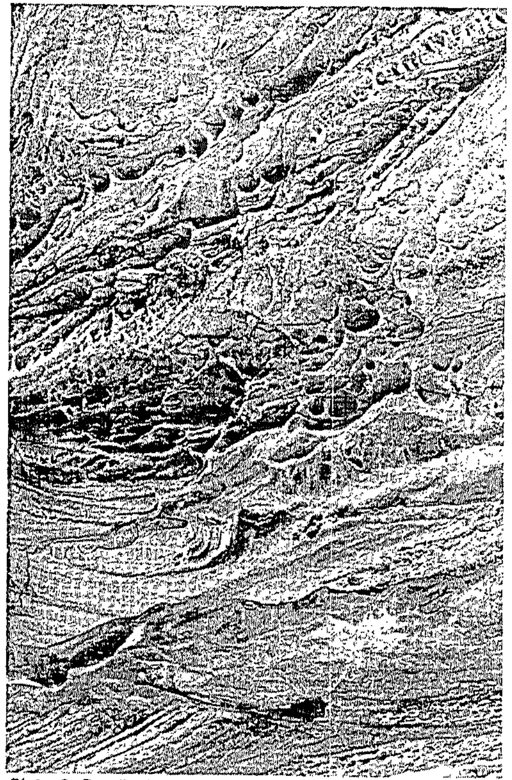


Plate 8: Detail of the disintegration of sandstone caused by percolating water at the wrongly named 'Wind Eroded Cave' at Blackheath in the Blue Mountains. Note the control of minor structural features on the growth of the cave.

Hassan's Walls and Angus Place, near Lithgow, Dog Face Rock at Katoomba, Dapto and Huntley near Wollongong and, especially, at North Nattai in the Burragorang Valley (Pells *et al.* 1987). A detailed study of the North Nattai site (Cunningham *forthcoming*) has shown that an 800 m section of cliff, from which about 30 million tonnes have fallen since 1965, coincides with an area from which the coal seam was completely extracted. Cunningham's observation that the collapse involves an initial vertical displacement of enormous sandstone towers demonstrates the importance of the cliff-foot conditions emphasised in our discussion of the natural stability of the region's cliffs. Indeed, Pells *et al.* (1987) argue that all major cliffline failures caused by mining in the Sydney region occurred where full extraction (pillar or longwall) methods had been carried out, and that no major failures have been caused by mining where pillars remain.

SIDE SLOPES AND VALLEY FLOORS

The morphology of slopes below the main cliffs is controlled largely by lithological variation. In the Blue Mountains cliffs cut in the Narrabeen sandstones stand above long ridges on the Coal Measures and Permian shales, below which are cliffs cut in Permian sandstones and, in the western valleys, hilly terrain on granite (Branagan *et al.* 1976). Along the Illawarra Escarpment cliffs in the Hawkesbury Sandstone cap a sequence of minor cliffs and benches in Narrabeen sediments at the base of which are ridges eroded from the Coal Measures. The pattern of benching changes southward as volcanic sandstones and extrusives become increasingly prominent on the escarpment. Even more striking lithological constraints on slope morphology (Plate 1) can be seen in the Permian and folded basement rocks at the southern extremity of the region (R. Young 1977).

Many of the bedrock slopes on the Illawarra escarpment and in most of the gorges further west are mantled by taluvial deposits of boulders in a sandy-clay matrix (Walker 1963; Bowman 1972; A. Young 1978). Deep and strongly differentiated weathering profiles show that the largest of these deposits are relict, and the size of the debris and the distance travelled show that the collapses which produced them were far greater than any contemporary failure on the Illawarra Escarpment (A. Young 1977). Bowman (1972) and A. Young (1978) have demonstrated that the strength of the taluvial deposits is low and that they will fail on slopes greater than 10-15° when monthly rainfall exceeds 200-300 mm. Instability of taluvium is locally increased by undercutting and concentration of seepage, and, together with the instability of slopes cut across claystones, poses the major geotechnical hazard to suburban expansion in Wollongong and northern Sydney (Bowman 1972; A. Young 1978; Branagan 1985; see also Walker and Fell 1987).

Erosion of the lower slopes of many valleys in the region is retarded by dense wet sclerophyll forest and by ribbons of rainforest along stream channels. When fire destroys the vegetative cover in these or the more widespread dry sclerophyll woodlands, rapid erosion may occur (Blong *et al.* 1982). Furthermore, even dense vegetation gives little protection from rainfalls of great intensity which have caused catastrophic erosion, especially on the Illawarra Escarpment (Nanson and Hean 1985).

Many of the valleys, especially those which run eastward across the Blue Mountains, decrease markedly in width in the downstream direction. This curious feature, seemingly at odds with the normal pattern of valley morphology, received special attention in accounts of the geomorphological evolution of the region. For instance, Charles Darwin thought it indicative of a marine rather than a fluvial origin of the valleys; for a review of Darwin's assertion and of subsequent criticism see R. Young (1978a). Griffith Taylor (1958) saw these 'bottleneck' valleys as evidence of a major reversal of the direction of drainage in which streams that once flowed westwards were captured by more 'vigorous' streams draining to the east. The downstream decrease in width can, however, be explained simply in terms of lithological variation. Where considerable thicknesses of shale are exposed beneath the sandstone, notably on the western margin of the Sydney Basin, valleys are broad, with very extensive pediment-like footslopes. Towards the centre of the basin, where the shales dip below the level of stream incision and where only sandstones are exposed, valleys are very narrow. This relationship between lithology and valley morphology is well illustrated by the downstream contraction from the very wide valley of the Capertree River to the narrow winding canyon of the Colo River (Figure 4). Another excellent example can be seen in the marked narrowing of the Cox and Wollondilly River valleys to the long cliff-lined slot at Warragamba (Figure 1), a situation which was ideal for the construction of the main water storage dam in the Sydney Region.

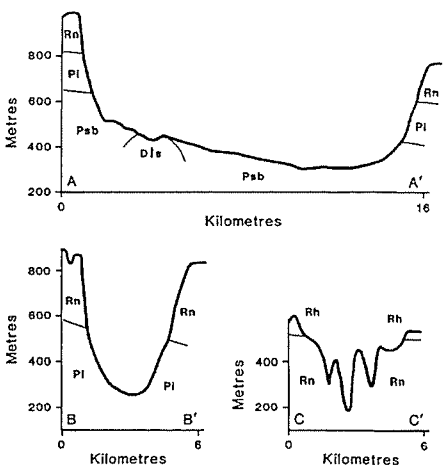


Figure 4: Changing lithology and downstream decrease of valley width in the Capertee-Colo catchment. See Figure 1 for the location of the sections. Geology: Rh — Hawkesbury Sandstone; Rn — Narrabeen Group; Pi — Illawarra Coal Measures; Psb — Berry Formation (siltstone); Dls — Lambie Group (siltstone).

In contrast to the very straight reaches like the slot at Warragamba, many valleys incised into the sandstones are highly sinuous. The Hawkesbury River and its major tributary the Colo River are cases in point. The form and dimensions of the incised meanders show varying degrees of hydrologic and geologic constraint (Dury 1966; R. Young 1978b). The irregular size and shape of many of these meanders are demonstrably linked to major fracture patterns in the sandstone, while the very regular downstream trends of others seems closely analogous to those of alluvial meanders. Nonetheless, the very great age of many of these incised meanders (R. Young 1978a, 1978b) precludes any simple correlation with pluvial phases in the Later Quaternary. The lower reaches of valleys such as that of the Hawkesbury River which were inundated by the Holocene rise of sea level now form superb winding rias.

The floors of most of the valleys have only narrow and often discontinuous alluvial deposits. Many of these deposits have been considered as indicative of climatic change (Walker 1962), but attention has been directed increasingly to the role of local erosional thresholds and to the reworking of older sediment (Young and Nanson 1982; Erskine and Melville 1983; Blong and Gillespie 1978). Varied land use also has caused considerable changes to valley-floor deposits. Hughes and Sullivan (1981) suggest that such changes began in prehistoric times, in response to increased burning by Aborigines of valley sides, but this contention is disputed (Perrin 1984). Clearing for farming after 1788 certainly increased sediment loads (Henry 1977; Warner 1984), but the magnitude of such changes has been obscured by fluctuations in erosion triggered by short-term changes in rainfall (Pickup 1976). Mining of sand and gravel has had considerable effects on both the channels and floodplains of George's and Nepean rivers (Warner 1984). The main alteration of valley floors has been the building of numerous dams and weirs (Warner 1984). As all of the major valleys in the southern part of the region have been partly flooded by dams, proposals for building additional dams in the northern part have raised considerable controversy about how the region should be used.

FUTURE USE OF THE PLATEAUX

The 'emptiness' of the plateaux was a consequence of their geomorphic characteristics — infertile soils, rugged terrain, absence of easily-traversed routes; as a further consequence, large areas were available to be set aside as national parks or were seen as most useful simply as water catchment areas. These roles are still highly valued by the community. Yet that same community is seeking to use the areas increasingly for recreation and to benefit from continued exploitation of coal resources that have now been worked out around the plateaux fringes. Former holiday resorts such as Katoomba and Gosford have been transformed by better transport at the demand of an expanded population into day-trip centres and commuter dormitory suburbs. The requirements for water for Sydney and its surrounds are so great that they are supplied from as far south as the Shoalhaven River. Pressures on the port facilities in Sydney itself led to diversion of coal, and in the future wheat, to the ports near Wollongong and Newcastle, with the consequent construction of new rail and improved road routes to those ports. These changes have led to many disputes between those concerned with development of the region and those seeking to preserve a vanishing wilderness.

Recent discussion about recreational use of Water Board catchment areas exemplifies the range of issues commonly involved in such disputes (Longworth and McKenzie 1986). The dams controlled by the Water Board have long been popular picnic sites, but the catchment areas other than parts of the Blue Mountains have been closed even to low pressure activities such as bushwalking. Only in parts of the Shoalhaven Scheme, which are remote from supply takeoff points, has some non-power boating been permitted. The demand for access to the stored waters for recreation purposes has increased with greater population pressure and with a general trend to multi-purpose management of natural resources. Surveys of public opinion showed considerable support for greater access for recreation, but allied with this, a strong support for policies which maintained high water quality. Thus, activities such as power boating were not favoured (Longworth and McKenzie 1986). Conservation groups argued for maintaining present policies to reduce the risk of ecological damage by increased fire risk, weed invasion and construction of facilities such as roads. It seemed that the desire for more recreational facilities was often counterbalanced by concern for maintenance of the environment and of water quality.

A clearer division of opinion within the community is evident in disputes over mining within national parks in the region. Since the early 1970s, mines in the Southern Coalfield have encroached into the catchment areas on the Woronora Plateau, as leases worked from along the Illawarra escarpment have neared exhaustion. Similar underground mining was proposed in various national parks within the Sydney Basin, with the issues of concern being outlined in a state government publication optimistically proposing the resolution of conflicts between underground extraction of coal and national parks (NSW. Department of Environment and Planning 1980). To many conservationists, the discussion in no way reached 'resolution' and the proposed 'no-development core' with a buffer zone and a periphery in which mine workings could be permitted was simplistic and irrelevant to the realities of the distributions of the natural resources of the parks. At present, the issue is in abeyance as the coal industry is contracting rather than expanding, but it seems inevitable that the matter will become controversial again in the future. Clearly, its resolution must be based on a sound understanding of the implications of mining for the geomorphology and hence the hydrology and ecology of these sandstone plateaux. We have discussed earlier some of these implications, with respect to the dells and the clifflines. Yet it is ironic that the collapse of cliffs triggered by mining has had strikingly disparate effects. At Hassan's Walls, near Lithgow, it resulted in the closing of tourist vantage points and unquestionably degraded the scenic qualities of this once popular tourist locality. However, when a long tension crack opened behind the Dog Face cliff at Katoomba in 1930 flood lights were installed and coaches brought tourists from Sydney to see the expected collapse (Pells *et al.* 1987). Half a century later, the scar of the Dog Face collapse is still a major tourist attraction at Katoomba.

Continued growth of population in the Sydney region will increase the demand for the opening of more of the surrounding plateaux to a variety of land uses. Moreover, as the examples discussed here show, decisions concerning those demands will not be easy. Nevertheless, given the considerable successes in the cause of conservation over the last decade or so, especially with the great increase in area dedicated as national parks, the survival of this wilderness in the foreseeable future seems reasonably secure.

ACKNOWLEDGEMENTS

Thanks are due to Hilde Shaw, Richard Miller and Robyn Johnston for technical assistance, and to Dr R. Blong and an anonymous referee for very helpful comments on an earlier draft.

REFERENCES

Adamson, D., Selkirk, P. M. and Mitchell, P. (1983) 'The role of fire and lyre birds in the sandstone landscape of the Sydney Basin', in Young, R. W. and Nanson, G. C. (eds) *Aspects of Australian sandstone landscapes*, Australian and New Zealand Geomorphology Group, Wollongong, pp. 81-93.

Bishop, P., Hunt, P. and Schmidt, P. (1982) 'Limits to the age of the Lapstone Monocline N.S.W. — a palaeomagnetic study', *Journal, Geological Society of Australia*, 29, 319-26.

Blong, R. J. and Gillespie, R. (1978) 'Fluvially transported charcoal gives erroneous ^{14}C ages for recent deposits', *Nature*, 271, 739-41.

Blong, R. J., Riley, S. J. and Crozier, R. J. (1982) 'Sediment yield from runoff following bushfire near Narrabeen Lagoon, N.S.W.', *Search*, 13, 36-8.

Bonhady, T. (1985) *Images in opposition; Australian landscape painting 1801-1890*, Oxford University Press, Melbourne.

Bowman, H. N. (1972) 'Natural slope stability in the City of Greater Wollongong', *Records, Geological Survey of New South Wales*, 14, 159-222.

Branagan, D. (1985) 'An overview of the geology of the Sydney Region', in Pells, P. J. (ed.) *Engineering geology of the Sydney region*, Balkema, Rotterdam, pp. 3-48.

Branagan, D., Herbert, C. and Langford-Smith, T. (1976) *An outline of the geology and geomorphology of the Sydney Basin*, Science Press, Sydney.

Buchanan, R. A. (1980) 'The Lambert Peninsula, Kur-ring-gai Chase National Park; physiography and the distribution of podsols, shrublands and swamps, with details of swamp vegetation', *Proceedings, Linnean Society of New South Wales*, 104, 13-94.

Cunningham, D. M. *(forthcoming)* 'The escarpment failure at North Nattai, N.S.W.', *Australian Geographer.*

Dury, G. H. (1966) 'Incised valley meanders on the lower Colo River, New South Wales', *Australian Geographer*, 10, 17-25.

Erskine, W. and Melville, M. D. (1983) 'Sedimentary properties and processes in a sandstone valley; Fernances Creek, Hunter Valley, N.S.W.', in Young, R. W. and Nanson, G. C. (eds) *Aspects of Australian sandstone landscapes*, Australian and New Zealand Geomorphology Group, Wollongong, pp. 94-105.

Evans, R. S. (1981) 'An analysis of secondary toppling rock failures — the stress distribution method', *Quarterly Journal of Engineering Geology*, 14, 77-86.

Forster, G. R., Campbell, D., Benson, D. and Moore, R. M. (1977) *Vegetation and soils of the Western region of Sydney*, Technical Memorandum, CSIRO Division of Landuse Research, Canberra.

Halford, W., Johnson, M. and Karavokyros, P. (1985) *Analyses of creek and seepage waters from the Illawarra region, South Coast, N.S.W.*, Report 85/8, Mineral Resources Development Laboratory, NSW Department of Mineral Resources.

Hebblewhite, B. K. (1978) *Rock mechanics investigation of structural stability in the Bulli Seam at Appin Colliery*, Australian Coal Research Laboratories, Wollongong.

Henry, H. (1977) 'Catastrophic channel changes in the MacDonald Valley, New South Wales', *Journal, Royal Society of New South Wales*, 110, 1-16.

Herbert, C. and Helby, C. (1980) *Guide to the Sydney Basin*, Geological Survey of New South Wales, Sydney.

Hoek, E. and Bray, J. (1974) *Rock slope engineering*, Institute of Mining and Metallurgy, London.

Holland, W. N. (1974) *Origin and development of hanging valleys in the Blue Mountains, N.S.W.*, unpublished PhD thesis, University of Sydney.

Holland, W. N. (1977) 'Slot valleys', *Australian Geographer*, 13, 338-9.

Hughes, P. J. and Sullivan, M. E. (1981) 'Aboriginal burning and late Holocene geomorphic events in eastern N.S.W.', *Search*, 12, 277-8.

Hughes, P. J. and Sullivan, M. E. (1983) 'The geoarchaeology of the Sydney Basin sandstones', in Young, R. W. and Nanson, G. C. (eds) *Aspects of Australian sandstone landscapes*, Australian and New Zealand Geomorphology Group, Wollongong, pp. 120-6.

Humphreys, G. S. and Mitchell, P. (1983) 'A preliminary assessment of the role of bioturbation and rainwash on sandstone hillslopes in the Sydney Basin', in Young, R. W. and Nanson, G. C. (eds) *Aspects of Australian sandstone landscapes*, Australian and New Zealand Geomorphology Group, Wollongong, pp. 66-80.

Jaggar, F. (1978) *Rock mechanics investigations of structural stability in the Bulli Seam at Westcliff Colliery*, Australian Coal Research Laboratories, Wollongong.

Johnson, A. R. M. (1974) 'Cavernous weathering at Berowra, New South Wales', *Australian Geographer*, 12, 531-5.

Johnson, M. (1986) *Analyses of surface waters from the Woronora-Stanwell Park area of the Sydney Basin*, Report 86/6, Mineral Resources Development Laboratory, NSW Department of Mineral Resources.

Johnson, W. (1960) 'Geological investigations at Warragamba Dam, N.S.W., to the end of 1955', *Journal, Institute of Engineers Australia*, 32, 85-97.

Kapp, W. A. (1980) 'A study of mine subsidence at two collieries in the Southern Coalfield, N.S.W.', *Proceedings, Australasian Institute of Mining and Metallurgy*, 276, 1-11.

Liddle, D. and Baker, M. (1987) *Blue Mountains wilderness*, Second Back Row Press, Leura.

Longworth and McKenzie Pty Ltd (1986) *Survey of existing and potential recreational uses of the Water Board's catchments and storages*, Report from Metropolitan Water Sewerage and Drainage Board, Sydney.

Mainguet, M. (1972) *Le modele des gres. Problemes generaux*, Institut Geographique National, Paris.

Melville, M. D. and Fitzpatrick, E. A. (1983) 'Some hydrological characteristics of the sandstone plateau near Barren Grounds, N.S.W.', in Young, R. W. and Nanson, G. C. (eds) *Aspects of Australian sandstone landscapes*, Australian and New Zealand Geomorphology Group, Wollongong, pp. 39-47.

MSWDB [Metropolitan Water Sewerage and Drainage Board] (1986) *South Coast water quality investigation. Pt 1, Raw water sources*, Scientific Services Sub-branch, MWSDB.

Nanson, G. C. and Hean, D. (1985) 'The West Dapto flood of February 1984; rainfall characteristics and channel changes', *Australian Geographer*, 16, 249-59.

Nanson, G. C., Young, R. W. and Stockton, E. D. (1987) 'The chronology and palaeoenvironment of the Cranebrook Terrace (near Sydney) containing artefacts more than 40,000 years old', *Archaeology in Oceania*, 22, 72-8.

NSW. Department of Environment and Planning (1980) *Resolution of conflicts between underground extraction of coal resources and dedication and management of areas as national parks and nature reserves: statement of policy*, Report 80/35, Department of Environment and Planning, Sydney.

Pells, P. J. (1977) 'Measurement of engineering properties of Hawkesbury Sandstone', *Australian Geomechanics Journal*, 1, 10-20.

Pells, P. J. (1985) 'Engineering properties of the Hawkesbury Sandstone', in Pells, P. J. (ed.) *Engineering geology of the Sydney Region*, Balkema, Rotterdam, pp. 179-97.

Pells, P. J., Braybrooke, J. C., Mong, J. and Kotze, G. P. (1987) 'Cliff line collapse associated with mining activities', in Walker, B. F. and Fell, R. (eds) *Soil slope instability and stabilisation*, Balkema, Rotterdam, pp. 359-85.

Perrin, K. (1984) *Transformations of the South Coast of New South Wales*, unpublished BSc honours thesis, University of Sydney.

Pickard, J. and Jacobs, S. W. (1983) 'Vegetation patterns on the Sassafras Plateau', in Young, R. W. and Nanson, G. C. (eds) *Aspects of Australian sandstone landscapes*, Australian and New Zealand Geomorphology Group, Wollongong, pp. 54-65.

Pickup, G. (1976) 'Geomorphic effects of changes in river runoff, Cumberland Basin N.S.W.', *Australian Geographer*, 13, 188-93.

Reynolds, R. G. (1977) *Coal mining under stored water*, Report of Public Enquiry, NSW Government Printer, Sydney.

Speirs, H. (1981) *Landscape art and the Blue Mountains*, Alternative Publishing Co-operative, Sydney.

Stacey, T. R. (1970) 'The stresses surrounding open-pit mine slopes', in van Rensburg, P. W. (ed.) *Planning open pit mines*, Balkema, Capetown, pp. 199-207.

Taylor, G. (1958) *Sydneyside scenery*, Angus & Robertson, Sydney.

Walker, B. F. and Fell, R. (1987) *Soil slope instability and stabilisation*, Balkema, Rotterdam.

Walker, P. H. (1962) 'Terrace chronology and soil formation on the South Coast of New South Wales', *Journal of Soil Science*, 13, 178-86.

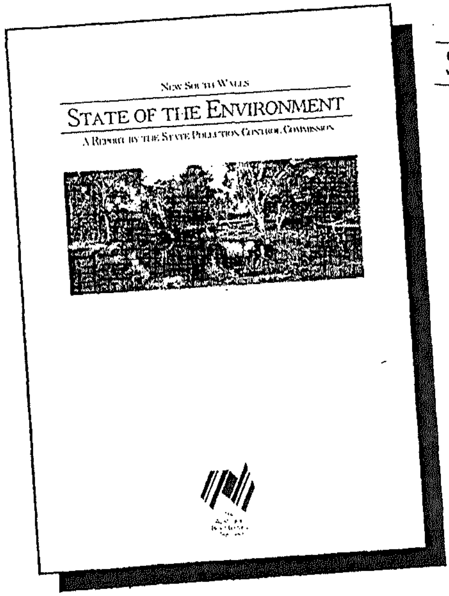
Walker, P. H. (1963) 'Soil history and debris-avalanche deposits along the Illawarra scarpland', *Australian Journal of Soil Research*, 1, 223-30.

Warner, R. F. (1984) 'Man's impact on Australian drainage systems', *Australian Geographer*, 16, 133-41.

Wellman, P. and McDougall, I. (1974) 'Potassium-argon ages on the Cainozoic volcanic rocks of New South Wales', *Journal, Geological Society of Australia*, 21, 247-72.

Young, A. R. M. (1977) 'The characteristics and origin of coarse debris deposits near Wollongong, Australia', *Catena*, 4, 289-307.

Young, A. R. M. (1978) 'The influence of debris mantles and local climatic variations on slope stability near Wollongong, Australia', *Catena*, 5, 95-107.
Young, A. R. M. (1986a) 'The geomorphic development of dells (upland swamps) on the Woronora Plateau, N.S.W., Australia', *Zeitschrift fur Geomorphologie NF*, 30, 317-27.
Young, A. R. M. (1986b) 'Quaternary sedimentation on the Woronora Plateau and its implications for climatic change', *Australian Geographer*, 17, 1-5.
Young, A. R. M. (1987) 'Salt as an agent in cavernous weathering', *Geology*, 15, 962-66.
Young, A. R. M. and Sim, R. (1987) *Soils of Avon catchment area with special reference to their iron content*, Report to the Illawarra office of the Metropolitan Water Sewerage and Drainage Board.
Young, R. W. (1977) 'Landscape evolution in the Shoalhaven River catchment of southeastern New South Wales', *Zeitschrift fur Geomorphologie NF*, 21, 262-83.
Young, R. W. (1978a) 'The study of landform evolution in the Sydney region: a review', *Australian Geographer*, 14, 71-93.
Young, R. W. (1978b) 'Geological and hydrological influences on the development of meandering valleys in the Shoalhaven River catchment, southeast Australia', *Erdkunde*, 32, 171-82.
Young, R. W. (1983a) 'Block gliding in sandstones of the southern Sydney Basin, in Young, R. W. and Nanson, G. C. (eds) *Aspects of Australian sandstone landscapes*, Australian and New Zealand Geomorphology Group, Wollongong, pp. 31-8.
Young, R. W. (1983b) 'The tempo of geomorphological change: evidence from southeastern Australia', *Journal of Geology*, 91, 221-30.
Young, R. W. (1985) 'Waterfalls: form and process', *Zeitschrift fur Geomorphologie NF, Supplementband*, 55, 81-95.
Young, R. W. and MacDougall, I. (1985) 'The age, extent and geomorphological significance of the Sassafras basalt, south-eastern New South Wales', *Australian Journal of Earth Science*, 32, 323-31.
Young, R. W. and Nanson, G. C. (1982) 'Terrace formation in the Illawarra region of New South Wales', *Australian Geographer*, 15, 212-19.
Young, R. W. and Nanson, G. C. (1983) *Aspects of Australian sandstone landscapes*, Australian and New Zealand Geomorphology Group, Wollongong.



NEW SOUTH WALES

STATE OF THE ENVIRONMENT

An important report about environmental protection in NSW and the current state of the environment in each region of the state.

For a FREE copy of the report and information on other publications available from the Commission write to:

Publications Officer
State Pollution Control Commission
GPO Box 4036
Sydney NSW 2001

Phone (02) 265 8888

FREE!

State Pollution Control Commission

The natural vegetation of the Sydney 1:100 000 map sheet

Doug Benson and Jocelyn Howell

Benson, Doug & Howell, Jocelyn (National Herbarium of New South Wales, Royal Botanic Gardens Sydney, New South Wales, Australia 2000) 1994. The natural vegetation of the Sydney 1:100 000 map sheet. Cunninghamia *3(4): 677–787.* The composition and extent of the present natural vegetation on the Sydney 1:100 000 map sheet 9130 (bounded by latitudes 33° 30' and 34° 00' S and longitudes 151° 00' and 151° 30' E) are mapped and described in terms of structure and characteristic species. Sixteen map units covering 42 plant communities are recognised and related to geology and physiography. The most extensive unit is the well-known Hawkesbury Sandstone vegetation, which has been broadly subdivided into Sydney Sandstone Gully Forest (Map unit 10ag), Sydney Sandstone Ridgetop Woodland (Map unit 10ar) and Coastal Sandstone Heath (Map unit 21g). Along the coast north of Long Reef more clayey soils, developed on the Narrabeen Formation, carry tall open-forest, open-forest and coastal heath vegetation. There are patches of scrub on Pleistocene sand deposits at Bouddi and La Perouse, and remnants of open-forest on Wianamatta Shale further west. A map of the vegetation of Ku-ring-gai Chase National Park and Muogamarra Nature Reserve (1:40 000 scale) showing 21 plant communities is provided on the back of the Sydney map.

Twenty-three major conservation reserves for the Sydney map area are briefly described, with species lists for most. Seventy-eight significant plant species are listed for the area, 41 of which are listed as nationally rare or endangered species (Briggs & Leigh 1988 with current ROTAP updatings); others are of regional significance. Species listed are either rare, threatened or of botanical significance in terms of geographic distribution. Regional affinities, historical changes, Aboriginal and European impacts, and conservation of vegetation are discussed.

Introduction

In January 1788 the ships of the First Fleet, sent from England with convicts to found a penal colony in New South Wales, entered Birra Birra, the land of the Aboriginal people. They had sailed into the lower reaches of what we now know as Sydney Harbour. As the colonists proceeded westwards towards Sydney Cove, Captain Watkin Tench of the Marines was amongst those 'enjoying the luxuriant prospect of its shores, covered with trees to the water's edge, among which many of the Indians were frequently seen'. George Worgan, surgeon of the *Sirius*, observed 'Here, a romantic rocky, craggy Precipice over which, a little purling stream makes a Cascade There a soft vivid-green, shady Lawn attracts your Eye.' Having found Botany Bay unsuitable for settlement, the fleet's captain, Captain Arthur Phillip, was now searching for a better site further north, at the inlet named Port Jackson by

Captain Cook in 1770. He found this an ideal harbour for the ships, and noted glowingly that: 'The necks of land that form the different coves, and near the water for some distance, are in general so rocky that it is surprizing such large trees should find sufficient nourishment, but the soil between the rocks is good, and the summits of the rocks, as well as the whole country round us, with few exceptions, are covered with trees' (Tench 1979, Worgan 1978, Phillip 1789).

In no time, trees were cut down, the ground cleared, and huts constructed. 'The abode of silence and tranquillity was now changed to that of noise, clamour, and confusion', observed David Collins, legal officer of the new settlement (Collins 1798).

Using historical and contemporary sources, Benson and Howell (1990a), in *Taken for granted: the bushland of Sydney and its suburbs*, described the original vegetation patterns in the County of Cumberland in terms of eight major vegetation types, and discussed the changes that followed the European-style agricultural and urban development of the area over the next two centuries. Particular emphasis was given to each of the 40 local government areas. The present paper, part of the Sydney Region Vegetation Map Series, describes the current condition and extent of the natural vegetation of the north-eastern half of the County of Cumberland, on the Sydney 1:100 000 map sheet, just over 200 years after the beginning of European settlement. As far as practicable, this work does not repeat *Taken for granted*, and only a small amount of historical material is included. Instead, the emphasis is on describing the present-day vegetation in terms of 16 map units, identifying significant areas and species, and includes floristic lists, brief descriptions and references to the major National Parks.

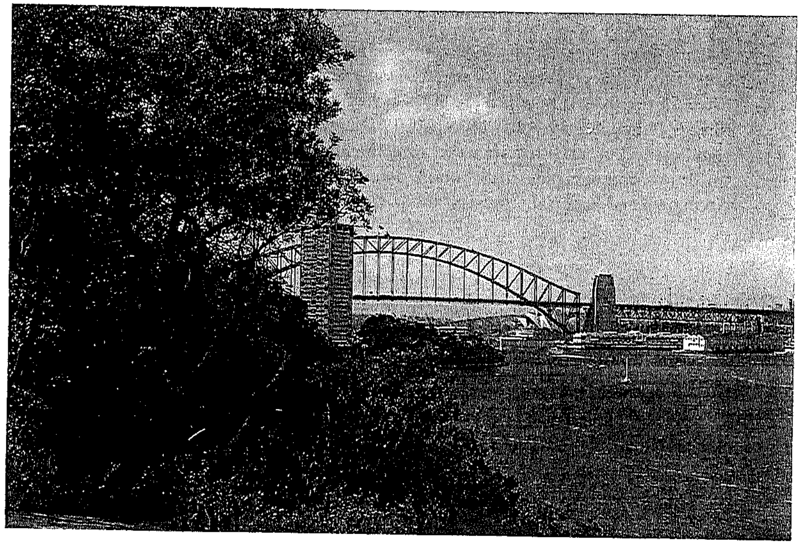


Figure 1. Sydney is probably one of the few great cities of the world where natural vegetation still survives so close to the heart of the city. Here *Banksia integrifolia* grows on the rocky Harbour foreshore at Balls Head.

Figure 2. Exposures of Hawkesbury Sandstone such as this at North Head form the prominent headlands around Sydney Harbour. These 'craggy precipices' delighted the first settlers until they found that this country was so difficult to farm.

The current work updates and enlarges a previous draft report (Benson 1980a) and provisional map (1980). The Sydney 1:100 000 vegetation map sheet is located inside the back cover. A vegetation map of Ku-ring-gai Chase National Park and Muogamarra Nature Reserve at 1:40 000 scale (originally prepared at 1:25 000 scale) is also provided. This map, taken from the vegetation surveys of Thomas and Benson (1985a,b), has not been readily available before, and provides a detailed picture of an important conservation and recreation area.

Location, physiography and climate

The Sydney 1:100 000 Vegetation Map Sheet (based on the Sydney 1:100 000 Topographic Sheet 9130, AUSLIG, Canberra) is bounded by latitudes, 33° 30' and 34° 00' S, and longitudes, 151° 00' and 151° 30' E. It includes the city of Sydney and suburban areas as far west as Parramatta, and the coastline from the Bouddi Peninsula and Broken Bay in the north to Botany Bay and the Georges River in the south. Natural vegetation is almost all confined to the northern half of the sheet, which includes Ku-ring-gai Chase National Park, Marramarra National Park, Muogamarra Nature Reserve, and parts of Brisbane Water and Bouddi National Parks.

Topographically, the northern half of the Sydney map sheet area is a dissected plateau of Hawkesbury Sandstone, the south-eastern corner of the Hornsby Plateau (Herbert 1983), generally 20–50 m elevation near Sydney and rising to 200 m high around

Glenorie in the north-west corner of the map. The major inlets, Broken Bay, Port Jackson and Georges River/Botany Bay are drowned river valleys. Most of the National Parks and remaining natural vegetation are on this Hawkesbury Sandstone landscape, as its thin sandy soils have made it useless for agriculture in comparison with the more fertile Wianamatta Shale soils of the southern half of the map sheet (Chapman & Murphy 1989). The Wianamatta Shale landscapes are gently undulating, covering the higher ridgelines of the Hornsby Plateau in the settled areas of northern Sydney. South of the harbour they are low-lying and extend from the city of Sydney westward to Parramatta, and from there across the Cumberland Plain to the Hawkesbury River and the foot of the Blue Mountains. Being topographically less rugged and having more fertile soils than those on the Hawkesbury Sandstone, these areas were settled and cultivated early in the nineteenth century. In the twentieth century extensive suburban development has followed.

The Narrabeen Group (Newport and Garie Formation, and Terrigal Formation) underlies the Hawkesbury Sandstone and outcrops north of Sydney along the Warringah Peninsula (now part of Pittwater Council area) and north of Broken Bay (Herbert 1983). This has interbedded laminites, shales and sandstones, and forms higher-nutrient soils than the adjacent Hawkesbury Sandstone landscapes. In contrast, in the Eastern Suburbs between Botany Bay and Bondi, the extensive sand deposits of Holocene and Pleistocene age overlying the Hawkesbury Sandstone have extremely low nutrient status, but the original vegetation here has been almost completely destroyed by suburban development.

A few volcanic outcrops occur in the area as diatremes or dykes. Soils have been mapped and discussed by Walker (1960) and Corbett (1972), and most recently a Soil Landscapes Map at 1:100 000 scale has been produced (Chapman & Murphy 1989). This describes 25 soil landscapes and relates closely to the vegetation map units.

Rainfall is related to elevation and coastal influence and occurs throughout the year, but is heaviest in June. It is highest (above 1400 mm p.a.) along the crest of the upper North Shore (e.g. Pymble 1444 mm p.a.) and on the coast (generally 1200–1400 mm p.a.) (e.g. Sydney — Observatory Hill 1209 mm p.a., Narrabeen 1278 mm p.a.). On the lower-lying country around Botany Bay it is about 1100 mm and decreases westward with increasing distance from the coast (Ashfield–Burwood about 1000 mm, Parramatta about 900 mm p.a.). Similar decreases in rainfall occur on the higher sandstone country further north (e.g. Hornsby about 1200 mm, Glenorie 900 mm p.a.) (Bureau of Meteorology 1979).

Mean monthly maximum temperatures for January are 25.9° C at Sydney and 28.1° C at Parramatta, while mean monthly minimum temperatures for July are 7.8° at Sydney and 4.6° C at Parramatta. The lowest (screen) minimum temperatures recorded are 2.1° C for Sydney, -2.9° C for Parramatta, and -4.6° C for Pennant Hills. The lowest terrestrial (i.e. ground level) minimum temperature recorded is -4.4° C for Sydney (the screen minimum was 3.7° C at this time). Frosts very rarely occur near the coast, the frost period increasing with distance from the coast and with elevation. The average severe frost period (i.e. screen minimum temperature less than 0° C), for example, is 85 days at Pennant Hills, 38 days at Parramatta and 46 days at Bankstown.

Average soil temperatures at Sydney, at 25 mm depth, range from 11.3° C in July to 21.4° C in February (data from Bureau of Meteorology 1979).

Methods

Areas of vegetation with similar structure (Specht 1970) and floristics (dominant species) were grouped to form the map units on the basis of aerial photopatterns and recognisable geological and landscape characteristics. Aerial photography from the New South Wales Department of Lands (Sydney 1982 1:16 000 colour) was used. Geology was based on geological maps (NSW Dept of Mines 1966, NSW Dept of Mineral Resources 1983). Compilation maps were prepared at 1:25 000 scale and subsequently reduced to 1:100 000 scale with little loss of detail.

Present-day (i.e. 1982) naturally-occurring vegetation is mapped; presumed vegetation formerly covering cleared agricultural and suburban areas is shown in Figure 1 and as an inset on the map sheet. An alphanumeric code is used to distinguish individual plant communities. The numeric code represents the structural form of the plant community and the alphabetic code represents the characteristic species. The codes used are consistent throughout the Sydney Region 1:100 000 Vegetation Map Series, allowing map units to be cross-referenced (Benson 1986a, Keith & Benson 1988, Benson & Keith 1990, Benson 1992a).

There are a number of constraints in reducing the complex pattern of natural vegetation to a map format. The map units recognised are not all of equivalent rank. Some are essentially land-units made up of several groupings of plant species, termed plant communities associated with a particular geological or physiographic type (e.g. map units 4a, 10ag, 10ar), whereas others are more early plant associations (*sensu* Beadle & Costin 1952) (map units 6b, 9o). Generally the term 'plant community' is used for the basic vegetation unit. For ease of reference, map units have also been provided with common names based loosely on habitat and composition.

The vegetation map is a diagrammatic attempt to simplify, over an extensive region, the distributional patterns of an often rich and varied flora. It is scale-dependent and map units will almost invariably include unmapped areas of other map units too small to be shown separately. Similarly, most plant communities do not have clear-cut boundaries, but grade into each other, often over a broad ecotone. For mapping purposes such boundaries have to be approximated to a line.

Field checking has been carried out intermittently between 1975 and 1990 and has included recording notes on structure, characteristic species of major strata and associated environmental factors. As major patterns necessary for mapping purposes are generally well known, broadscale computer analyses of floristic data have not been necessary. Floristic analyses of a number of local areas have been carried out and are referred to in the descriptions e.g. coastal vegetation (Adam, Stricker et al. 1989), Ku-ring-gai Chase National Park (Outhred et al. 1985), Lane Cove River National Park (Clarke & Benson 1987), and Garigal National Park (Sheringham & Sanders 1993). Extensive species lists have been compiled for some areas, generally during the course of specific local vegetation studies.

Species recorded for major conservation areas are provided (see Table 3). Species lists for other sites have not been presented, though some may be listed in the bibliographies of floristic lists (Pickard 1972; Bryant & Benson 1981; Keith 1988; Benson & Melrose 1993). Botanical names used are those currently recognised at the National Herbarium of New South Wales. For authorities see Harden (1990–93).

Review of vegetation studies

Aboriginal people left no written records of the vegetation that supported them for thousands of years, though some of their names for plants and their uses were recorded by nineteenth century botanists such as Joseph Maiden (1889). Surprisingly, only a handful of Aboriginal names for Sydney plants have survived in current usage. Examples include Waratah, Geebung, Gymea, Mugga, Burrawang and Bangalay.

The scientific study of plants in the Sydney region began at Botany Bay in April 1770 when Joseph Banks and Daniel Solander landed from Captain Cook's *Endeavour* and described the 'rich and diverse flora'. The influence of the botanist Joseph Banks was crucial in the selection of Sydney as the site for a settlement. His ongoing interest ensured continuing concern for accurate botanical study and plant collection in the colony. Other professional botanists and botanical collectors were often based with colonial governors and included in exploring parties. Among these were George Caley, who was employed in the colony from 1800–1810 by Joseph Banks, and Allan Cunningham, collector for the Royal Botanic Gardens at Kew from 1817 and Colonial Botanist and Superintendent of the Sydney Botanic Gardens in 1837. As botanical collector Cunningham accompanied John Oxley and Philip King on early expeditions (1817–1822), and later himself explored parts of northern New South Wales and the Darling Downs of Queensland. Being primarily botanical collectors for overseas herbaria, such workers published very little themselves, but some of the diaries they kept have been subsequently published e.g. see Lee (1925) for Cunningham, and Andrews (1984) and Currey (1966) for Caley.

The European explorers and settlers were concerned with the agricultural value of the new country and used the vegetation as an indicator of its potential. They were also concerned with any likely vegetable products such as timber or food plants that could be of use to them. Most of the published accounts of explorers and visitors to the colony contain some references to the vegetation, though these accounts are of variable quality. Botanical names are used infrequently and identification of plant species is often difficult or impossible.

Baron Ferdinand von Mueller was the outstanding colonial botanist of the second half of the nineteenth century, and collectors sent many specimens to him in Melbourne. Among local Sydney collectors were the Reverend William Woolls, who published a number of lists of local Parramatta species, and Louisa Atkinson, who made collections at Berrima and Kurrajong, though most of their collections went either to Europe or Melbourne. Most of the collections now readily available to researchers in New South Wales date from the establishment of the National Herbarium of New South Wales in the 1880s by the Director of the Sydney Botanic Gardens, Charles

Moore. Moore's successor, Joseph Henry Maiden, was a very active botanist and enthusiastically developed the National Herbarium of New South Wales as a national collection. He concentrated on taxonomic work, and in particular the eucalypts, but also published papers on aspects of ecology. Sydney botanists published mainly through the journals of the Linnean Society of New South Wales and the Royal Society of New South Wales.

A.A. Hamilton's *Topographical, ecological and taxonomic notes of the ocean shoreline vegetation of Port Jackson* (1918) and *Ecological study of the saltmarsh vegetation in the Port Jackson district* (1919) are probably the first major descriptive ecological papers for the Sydney area. These were followed by papers on the ecology of the vegetation at Mount Wilson (Brough, McLuckie & Petrie 1924; Petrie 1925; McLuckie & Petrie 1926), Bulli (Davis 1936, 1941a, 1941b) and on the New South Wales Central Coast (Pidgeon 1937, 1938, 1940, 1941). In a series of major papers, Ilma Pidgeon described the general differences in vegetation on Wianamatta Shale and Hawkesbury Sandstone in terms of a series of plant communities in various stages of succession, the

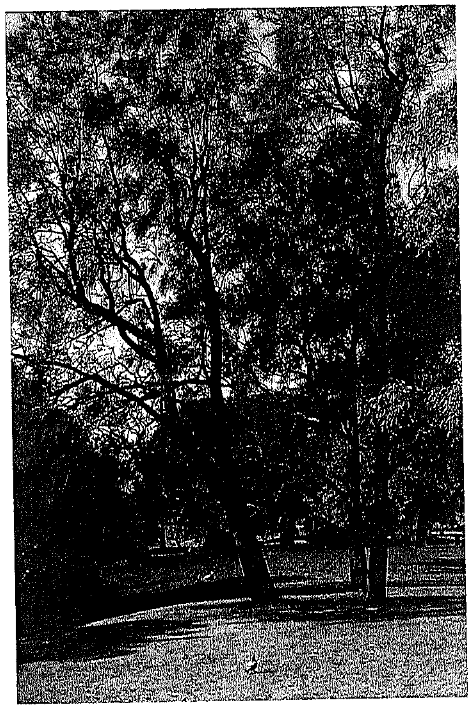


Figure 3. J. H. Maiden, an early Director of the Royal Botanic Gardens Sydney, saw the value of conserving native vegetation, and it is largely due to his foresight that these remnant *Casuarina glauca* trees still survive in the Sydney Gardens today. This species rootsuckers vigorously, and these trees are probably genetically identical with the pre-1788 trees here.

stages being related to physiographic and moisture conditions. She did not include maps, but provided detailed descriptions of the plant communities, in particular of the Hawkesbury Sandstone of the Hornsby Plateau. Phillips (1947) complemented this work with descriptions of the main plant communities of the Wianamatta Shale.

Interest then turned towards the role of soil nutrients. Nola Hannon (1956, 1958) examined the role of soil nitrogen. N.C.W. Beadle (1953, 1962, 1966) demonstrated that the distribution of major vegetation types around Sydney relates largely to the differing levels of soil nutrients, particularly phosphorus, essentially derived from the parent material. Smaller-scale variation was related to physiographic factors. Rainforest vegetation is generally confined to soils with higher phosphorus levels while the sclerophyll vegetation occurs on soils with very low phosphorus levels. Increased soil nutrients in run-off from disturbed areas may promote exotic weed invasion in naturally low-nutrient sites (Clements 1983).

Recent interest in Sydney vegetation, as a result of the general awareness of conservation issues, has led to many local vegetation surveys and inventories (see Pickard 1972, Bryant & Benson 1981, Keith 1988, National Trust 1991, Benson & Melrose 1993), and to the vegetation surveys in the Sydney Region Vegetation Map Series. Accounts of the vegetation with particular reference to changes over the past 200 years include Benson and Howell (1990b) and in particular *Taken for granted* (Benson & Howell 1990a). As the present map sheet deals with about half of the area covered by Benson and Howell (1990a), the relationship between the eight general vegetation types described there and the map units described here is given in Table 1. A modified section of their map showing the extent of natural vegetation in 1788 for the Sydney map area is given in Figure 1.

As well as survey and descriptive studies, there has also been increasing and much-needed work on problems associated with conservation biology and natural area management. In particular, aspects such as fire (e.g. Bradstock & Myerscough 1981), soil nutrients and the spread of exotic weeds, and studies on the ecology of individual species (e.g. Auld & Myerscough 1986, Auld 1986) are now receiving due attention. We also hope to make ecological data on individual plant species more accessible through the Ecology of Sydney Plant Species project (Benson & McDougall 1993).

Table 1. Vegetation types in *Taken for granted*, Benson and Howell (1990a) (in bold type) with corresponding Sydney map sheet map units and codes.

Blue Gum High Forest
Blue Gum High Forest 6b

Turpentine–Ironbark Forest
Turpentine–Ironbark Forest 9o

Cumberland Plain Woodlands
Transition Forest 9d

Sandstone heaths, woodlands and forests
Sydney Sandstone Gully Forest 10ag
Sydney Sandstone Ridgetop Woodland 10ar
Duffys Forest 9sf
Coastal Clay Heath 21a
Coastal Sandstone Heath 21g

Eastern Suburbs Banksia Scrub
Coastal Dune Forest 9t
Coastal Dune Heath 21b

Freshwater and Estuarine wetlands
Estuarine Complex 4a
Coastal Swamp Forest Complex 27a
Freshwater Reed Swamps 28a

Glen Forest 6c, Spotted Gum–Blackbutt Forest 9g and Narrabeen Slopes Forest 9h were not treated separately in *Taken For Granted.*

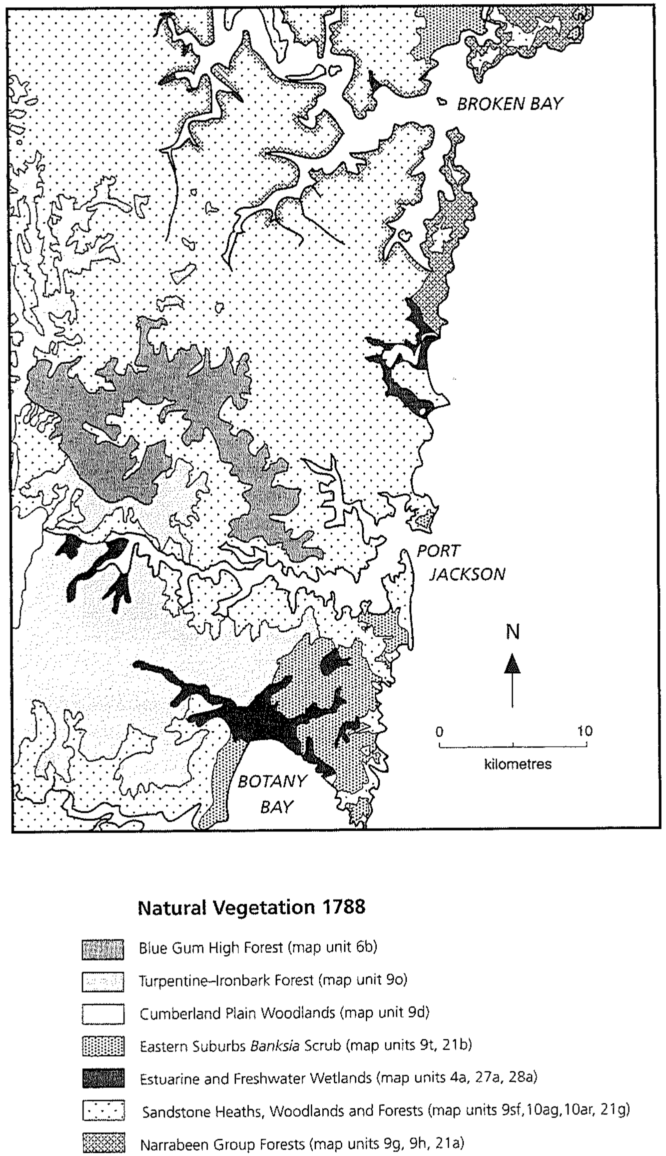


Figure 4. Presumed 1788 or pre-European pattern of natural vegetation of the Sydney map sheet area.

Table 2. Map unit, common name, structure, main canopy species, geology and occurrence for plant communities in the area covered by the Sydney 1:100 000 map sheet

Map unit description

Map unit	Structure	Main canopy species	Geology	Occurrence
4a	**Estuarine Complex**			
	Open-scrub	*Avicennia marina* *Aegiceras corniculatum*	Holocene alluvium	Estuarine mudflats, regular tidal inundation
	Herbland	*Sarcocornia quinqueflora* *Suaeda australis*	"	Occasional tidal inundation
	Rushland	*Juncus kraussii* *Phragmites australis*	"	Infrequent tidal inundation; brackish water
	Low open-forest	*Casuarina glauca* *Baumea juncea*	"	Poorly-drained, some saline influence
6b	**Blue Gum High Forest**			
	Tall open-forest/ Open-forest	*Eucalyptus pilularis* *Eucalyptus saligna*	Wianamatta Shale	Broad ridges with residual shale soils North Shore to Hornsby
6c	**Glen Forest**			
	Tall open-forest	*Eucalyptus saligna*	Diatremes	Isolated valleys
	Tall open-forest	*Eucalyptus agglomerata* *Angophora floribunda*	"	"
9d	**Transition Forest**			
	Open-forest	*Eucalyptus fibrosa* *Eucalyptus moluccana* *Melaleuca decora*	Wianamatta Shale	Auburn
9g	**Spotted Gum–Blackbutt Forest**			
	Open-forest	*Eucalyptus gummifera* *Eucalyptus maculata* *Eucalyptus pilularis*	Narrabeen Group	Bouddi Peninsula
	Open-forest	*Eucalyptus maculata* *Eucalyptus paniculata*	"	Lower hillslopes, Warringah Peninsula
	Woodland	*Eucalyptus umbra* *Eucalyptus paniculata*	"	Exposed slopes, Bouddi Peninsula
	Open-forest	*Archontophoenix cunninghamiana*	"	Deep gullies, Bouddi Peninsula
9h	**Narrabeen Slopes Forest**			
	Open-forest	*Eucalyptus deanei* *Angophora floribunda*	Narrabeen Group	Lower hillslopes, Broken Bay–Hawkesbury River
	Open-forest	*Angophora floribunda* *Allocasuarina torulosa*	"	"

Map unit	Structure	Main canopy species	Geology	Occurrence
9o	**Turpentine–Ironbark Forest**			
	Open-forest	*Syncarpia glomulifera* *Eucalyptus paniculata*	Wianamatta Shale soils	Inner western Sydney, lower rainfall between Glenorie and Ryde; often near junction with sandstone
9sf	**Duffys Forest**			
	Open-forest	*Eucalyptus sieberi* *Eucalyptus capitellata* *Eucalyptus gummifera* *Angophora costata*	Wianamatta Shale–Hawkesbury Sandstone	Residual plateau remnants with ironstone gravels
9t	**Coastal Dune Forest**			
	Open-forest	*Eucalyptus botryoides* *Eucalyptus pilularis* *Angophora costata*	Holocene Sand	Ramsgate La Perouse
	Sydney Sandstone Complex			
10ag	**Sydney Sandstone Gully Forest**			
	Open-forest/ woodland	*Eucalyptus piperita* *Angophora costata* *Eucalyptus gummifera*	Hawkesbury Sandstone	Sheltered hillsides, gullies
	Tall open-forest	*Eucalyptus pilularis* *Syncarpia glomulifera*	"	Gullies sheltered aspects
	Closed-forest	*Ceratopetalum apetalum* *Tristaniopsis laurina*	"	Sheltered gullies
	Sydney Sandstone Complex			
10ar	**Sydney Sandstone Ridgetop Woodland**			
	Woodland/ Low woodland	*Eucalyptus gummifera* *Eucalyptus haemastoma* *Eucalyptus sparsifolia* *Eucalyptus racemosa*	Hawkesbury Sandstone	Ridges, plateaus and dry, exposed hillsides
	Woodland/ Low woodland	*Eucalyptus eximia* *Eucalyptus gummifera* *Angophora bakeri*	"	Ridges, plateaus, northwest of area
	Open-scrub	*Banksia ericifolia* *Hakea teretifolia*	"	Poorly-drained sites
21a	**Coastal Clay Heath**			
	Open-heath	*Allocasuarina distyla*	Narrabeen Group	Long Reef to Bouddi
	Grassland	*Themeda australis*	"	"
21b	**Coastal Dune Heath**			
	Open-heath	*Banksia aemula*	Pleistocene Sand	Coastal dunes, Bouddi, North Head, La Perouse
	Open-scrub	*Monotoca elliptica*	"	"

Map unit	Structure	Main canopy species	Geology	Occurrence
	Open-scrub	*Banksia integrifolia* *Leptospermum laevigatum*		
21g	**Coastal Sandstone Heath**			
	Shrubland	*Baeckea imbricata*	Hawkesbury Sandstone	Shoreline heath
	Open-heath/ Closed-scrub	*Banksia ericifolia* *Darwinia fascicularis*	"	Coastal heath, sandy shallow, soils
	Open-heath/ closed-scrub	*Allocasuarina distyla* *Banksia ericifolia*	"	Widespread, shallow sandy, often poorly-drained soils
	Open-heath	*Baeckea diosmifolia* *Baeckea brevifolia*	"	Rocky outcrop heath
	Open-heath	*Hakea teretifolia* *Banksia oblongifolia*	"	Wet heath, poorly-drained
	Sedgeland/ shrubland	*Banksia robur* *Viminaria juncea* *Gymnoschoenus sphaerocephalus*	"	Swamps, impeded drainage
	Open-scrub	*Angophora hispida*	"	Drier areas
	Shrubland (mallee)	*Eucalyptus luehmanniana*	"	Shallow soils, permanent seepage
27a	**Coastal Swamp Forest Complex**			
	Open-forest	*Eucalyptus botryoides* *Eucalyptus robusta*	Holocene stream alluvium & estuarine sediment	Creekflats or impeded drainage, Warringah Peninsula
	Open-forest	*Livistona australis*	"	"
	Scrub	*Melaleuca linariifolia* *Melaleuca styphelioides*	"	"
	Reedland	*Phragmites australis* *Typha orientalis*	"	"
	Herbland	*Persicaria strigosa* *Blechnum camfieldii* *Triglochin procera* *Baumea juncea*	"	Impeded drainage
28c	**Coastal Freshwater Swamp**			
	Open-sedgeland	*Eleocharis sphacelata* *Baumea juncea* *Persicaria decipiens*	Holocene marine sand & sandy peat	Botany Swamps, Centennial Park
	Low open-forest	*Melaleuca quinquenervia*	"	"

C Cleared

These areas are mostly suburban development. Small remnants of vegetation too small to map may occur here.

Description of map units

A summary of the plant communities recognised in the Sydney 1:100 000 sheet area, their structural formation, main canopy species and geological substrate and occurrence is given in Table 2. The map unit numbering system applies to all maps in the Sydney Region Vegetation Map Series, missing numbers being communities which do not occur in the Sydney map area.

Map unit 4a
Estuarine Complex

Small patches of estuarine vegetation are found on alluvial mudflats (Holocene sand, silt and clay deposits) subject to varying degrees of tidal inundation. 'For it is strikingly singular that three such noble harbours as Botany Bay, Port Jackson, and Broken Bay, alike end in shallows and swamps, filled with mangroves' wrote Watkin Tench in 1788 (Tench 1979). Today such vegetation still occurs in Broken Bay and the lower Hawkesbury River, Port Jackson and the Parramatta and Lane Cove Rivers and Botany Bay and the Georges River. It generally consists of a sequence of zones of different structure and floristics related to duration of tidal inundation and salinity. The following zones may be recognised, though not all will necessarily occur at any one site.

i) Open-scrub of *Avicennia marina–Aegiceras corniculatum*, confined to the seaward edge of the mudflat and made up of mangroves (1–5 m high) of the Grey Mangrove, *Avicennia marina* and the smaller, River Mangrove, *Aegiceras corniculatum*. Mangroves generally receive daily tidal inundation.

ii) Herbland of *Sarcocornia quinqueflora–Suaeda australis*, a zone of saltmarsh, a herbland dominated by the succulent stemmed members of the Chenopodiaceae, *Sarcocornia quinqueflora* and *Suaeda australis*.

iii) Rushland of *Juncus kraussii* and *Phragmites australis*. These areas have brackish water and receive infrequent tidal inundation.

iv) Low open-forest of *Casuarina glauca* and *Baumea juncea*. Areas with saline soils and periodic flooding. Swamp forest with *Eucalyptus robusta* may occur on alluvium at the landward end of the zonation (see Map Unit 27a Coastal Swamp Forest Complex).

The nature of the surrounding country may influence the floristic composition. Estuarine areas on the southern side of the Parramatta River drain from low-relief country with clay soils from Wianamatta Shale. The clayey alluvium originally supported saltmarsh interspersed with broad bare mudflat areas, only infrequently flooded and described at Homebush Bay as the dry salt plain by Hamilton (1919). The senior author remembers these sites from his schoolday explorations in the early 1960s. These clay rich mudflats, remnants of which still survive at Homebush Bay, included species such as *Lampranthus tegens*, *Wilsonia backhousei* and *Halosarcia pergranulata* subsp. *pergranulata*, not generally found in other saltmarsh areas (Clarke & Benson 1988). For example the major saltmarsh reserves at Towra point are on more sandy alluvium and do not include these dry salt-plain species. Extensive areas of these estuarine mudflats in the upper Parramatta River in Concord and Auburn municipalities and along the Cooks River in Marrickville, were destroyed by landfill between 1920 and 1970. A potential longterm threat to saltmarsh vegetation comes from the spread of the weed *Juncus acutus*, now established at Homebush Bay and Saltpan Creek.

Along the Lane Cove River and the northern side of the Parramatta River, as well as Broken Bay and the Hawkesbury River, including the lower reaches of its tributary creeks downstream from Wisemans Ferry, much of the alluvial material is sandy, being derived from the nearby Hawkesbury Sandstone. The adjacent hillslopes are generally much steeper, and estuarine areas are much more limited; mangroves predominate, saltmarsh areas are of only limited extent. Where sandstone hillsides drop sharply into the water with no build-up of alluvium, the zonation may be truncated to a line of mangroves and a few trees of *Casuarina glauca*. In the Lane Cove River agricultural and particularly urban development in the catchment has increased sedimentation and allowed mangroves, particularly *Avicennia marina* populations to expand seawards (McLoughlin 1985, Thorogood 1985), though similar expansion of saltmarsh has not been recorded. Saltmarsh and landward vegetation such as *Juncus kraussii* and *Casuarina glauca* has generally declined as a result of landfilling.

Coastal lagoons at Narrabeen and Dee Why (Coveny g), have some small remaining areas, principally of rushland, while limited stands of estuarine low open-forest persist at Warriewood.

Within the Sydney map area, descriptions of estuarine vegetation have been compiled for Brisbane Water National Park (Benson & Fallding 1981); Muogamarra Nature Reserve (Thomas & Benson 1985b); Ku-ring-gai Chase National Park (Thomas & Benson 1985a) Calna and Berowra Creeks (Pickard 1974), Smiths Creek, Terrey Hills (Kratochvil et al. 1973), Port Jackson and the Cooks River (Hamilton 1919), Bantry Bay (Upper Middle Harbour Conservation Committee 1974), Homebush Bay (Centre for Environmental Studies, 1978; Clarke & Benson 1988, Adam 1991, Kachka 1993), the Lane Cove River (McLoughlin 1985), Wolli Creek (Allaway & Clarke 1987, Brown et al. 1988).

A wealth of observations on the behaviour of saltmarsh species, together with descriptions of vegetation in areas where it has long since been removed, such as Cooks River, are given in Hamilton (1919). Detailed studies of mangrove and saltmarsh communities and individual species at Towra Point, an important estuarine area on the southern shore of Botany Bay but outside the Sydney map area, have been carried out by Clarke and Hannon (1967, 1969, 1970, 1971).

Map Unit 6b
Blue Gum High Forest

Tall open-forest–open-forest: *Eucalyptus pilularis–Eucalyptus saligna*

This was the original vegetation of the higher rainfall (above 1100 mm p.a.) Wianamatta Shale soils of Sydney's north shore suburbs (Benson & Howell 1990a). The original forest was composed of big trees, probably over 40 m in height, and it was obviously a valuable source of timber last century. For example Raymond (1832) describes land near Pennant Hills let on lease for the purpose of cutting timber: 'Their leases are nearly expired. Much fine timber still remains, the trees along this range being in general of an uncommonly large size, perhaps more so than in any other part of Cumberland, and therefore very advantageously situated so near a rapidly increasing town.'

Eucalyptus pilularis and *Eucalyptus saligna* are the main trees, originally probably in excess of 30 m tall. Other tree species include *Angophora costata*, *Eucalyptus paniculata*, *Eucalyptus globoidea* and *Syncarpia glomulifera*. An open, small-tree layer of saplings of canopy tree species and mature individuals of *Allocasuarina torulosa* is often present on drier sites, or *Pittosporum undulatum* on moister ones.

Shrubs are common, and often form a dense cover. Common species on drier sites are *Platylobium formosum*, *Leucopogon juniperinus*, *Dodonaea triquetra* and *Hibbertia aspera*. On moister sites and in depressions these shrubs are replaced by ferns, particularly *Calochlaena (Culcita) dubia*, *Adiantum aethiopicum* and *Doodia aspera*, and shrubs with softer leaves, such as *Breynia oblongifolia* and *Polyscias sambucifolius*.

Mesic shrubs may line shallow water courses but 'rainforest-type' understorey rarely occurs on the shale soils, as the deep, sheltered gullies required for the best development of these species cut through the thin shale capping to the low nutrient Hawkesbury Sandstone soils below. 'Rainforest-type' gully vegetation in the area is therefore generally on sandstone though this may be enriched by shale material washed down from the ridges. On the shale soils there were patches of wetter understorey on sheltered hillsides, but localised rainforest understorey patches only occur at Brush Farm at Eastwood where an unusual combination of rich soils, unusually deep, sheltered gullies, and a high rainfall allowed rainforest species to survive. Species here include *Acmena smithii*, *Cryptocarya glaucescens*, *Guioa semiglauca*, *Schizomeria ovata*, *Rhodamnia rubescens* and *Euodia micrococca* (Coveny a, Broadbent & Buchanan 1984, Benson 1986b).

Blue Gum High Forest was an important resource to the timber-getters who cut out much of the valuable Blackbutt and Blue Gum in the nineteenth century (Hawkins 1994). Clearing and agricultural development led to dairy farms and orchards and then suburban development. Most of Sydney's Blue Gum High Forest has now been destroyed; Benson and Howell (1990b) estimated that only 0.9% of the original 11 000 ha found in the County of Cumberland remained in 1980). There are still some small remnants. In particular, in two reserves, Dalrymple Hay Nature Reserve at St Ives (Benson & Keith 1984a) and Ludovic Blackwood Memorial Sanctuary at Beecroft (Buchanan 1977, 1978), and in a number of smaller areas, such as Sheldon Forest, Turramurra; Darvall Park, Denistone (Coveny e); Brush Farm Park, Eastwood where there is an important remnant of rainforest (Coveny a, Broadbent & Buchanan 1984, Benson 1986b); Observatory Park, Beecroft; and Edna May Hunt Reserve, Eastwood (Benson 1979b). In addition, patches too small to map at the present scale [may] persist on roadsides or creek edges; it is important to protect these as they add to the areas of scarce habitat available for perpetuation of the forest's species.

Along creeks and drainage lines where remnants of this community still persist, there is often dense exotic weed growth invading and crowding out the native species. *Ligustrum sinense* and *L. lucidum* (Privet species) are the main culprits, while *Tradescantia albiflora* (Wandering Jew) is another major problem species. This ground-cover plant smothers native ground species, prevents seedling recruitment and is very difficult to eradicate. The most effective control in bushland areas appears to be hand-weeding and careful herbicide use. Many native understorey species can persist as propagules in the soil, able to re-establish when conditions for germination and regrowth are favourable.

Figure 5. Remnant Blue Gum High Forest, map unit 6b, with *Eucalyptus saligna* at Dalrymple–Hay Nature Reserve, St Ives.

Map Unit 6c
Glen Forest

Small volcanic necks or diatremes are scattered throughout the Sydney region, about 25 being shown on the Sydney 1:100 000 geology map (Herbert 1983). These sites have higher-nutrient soils than surrounding areas (Chapman & Murphy 1989) and their vegetation generally contrasts markedly with that on the adjacent sandstone or shale soils. Where the surrounding rock is low-nutrient sandstone these differences are particularly distinctive because of the differences in soil nutrients, and because many such diatremes often occur in sheltered valley positions. Unfortunately most natural vegetation on diatremes in the immediate Sydney area has been destroyed, either because their fertile soils were cleared for agriculture, or because the basaltic rocks, a convenient source of blue metal aggregate, have been extensively quarried. Remnant diatreme vegetation indicates that considerable local differences in vegetation composition occurred between sites, mainly as a result of variations in soil type and exposure conditions; two sub-units are recognised below.

i) Tall open-forest: *Eucalyptus saligna*

Eucalyptus saligna dominated vegetation, very similar to the Blue Gum High Forest of the North Shore (map unit 6b), grew on high-nutrient volcanic soils under similar high rainfall conditions (1200–1400 mm p.a.). Old Mans Valley at Hornsby, probably the largest diatreme in the area, has been extensively quarried for blue metal aggregate, but remnant vegetation on nearby Joes Mountain in Berowra Valley Bushland Park (too small to map at 1:100 000 scale) has *Eucalyptus saligna* as the dominant tree species with less frequent trees of *Eucalyptus pilularis* and *Angophora floribunda*. Native understorey species include *Calochlaena dubia*, *Blechnum cartilagineum*, *Adiantum aethiopicum*, *Pteridium esculentum*, *Smilax australis*, *Pandorea pandorana* and *Poa affinis* (Smith & Smith 1990). Weeds constituted 14% of the species recorded in the survey plot including *Lonicera japonica*, which was codominant with *Calochlaena* in the dense fern layer, and *Ligustrum lucidum*, *Ligustum sinense* and *Cinnamomum camphora* that were codominant in the shrub and low tree layers.

Similar high rainfall vegetation probably occurred on other diatremes such as at Browns Field (South Turramurra Environment Protection 1980), Dundas, Burwood and Lugarno. Volcanic necks in the Blue Mountains with similar vegetation are known as Glens e.g. Murphys Glen, Tobys Glen (Keith & Benson 1988).

ii) Tall open-forest: *Eucalyptus agglomerata–Angophora floribunda*

In Ku-ring-gai Chase, the amphitheatre-shaped valley of Campbells Crater contains tall open-forest to open-forest with trees 15–35 m tall with a mid-dense canopy cover. On the slopes of the crater the understorey is shrubby but the floor supports small trees, palms and tree ferns with a ground cover of monocotyledons and ferns. Vines are common (Thomas & Benson 1985a). Main tree species are *Eucalyptus agglomerata, Angophora floribunda, Allocasuarina torulosa,* also with *Angophora costata* and *Eucalyptus umbra*. Small trees include *Acacia floribunda*, *Synoum glandulosum* and the palm *Livistona australis*. Understorey species include shrubs; *Pultenaea flexilis*, *Prostanthera denticulata*, *Astrotricha floccosa*, and ground species; *Dianella caerulea*, *Oplismenus imbecillis*, *Calochlaena dubia*, *Hypolepis muelleri*, *Cyathea australis*, *Pteridium esculentum*, *Pseuderanthemum variabile*, *Hydrocotyle acutiloba*, *Goodenia ovata*, *Helichrysum elatum*, *Cissus hypoglauca*, *Smilax australis*, *Pandorea pandorana* and *Cayratia clematidea*.

At Campbells Crater variation relates to slope, soil and aspect. The understorey changes between the sides and the floor of the crater. On the sides a sandy topsoil lies over a clay sub-soil and this tends to support a denser shrub layer than the hard clay soil on the crater floor. The lower south-facing slope of the crater has a dense fern understorey, while the east- and north-facing slopes have a more open understorey. Weed infestation is heavy on the crater floor where the soil is more fertile. Species that are absent or uncommon elsewhere in Ku-ring-gai Chase National Park are *Eucalyptus agglomerata*, *Toona ciliata*, *Seringia arborescens*, *Asterolasia correifolia*, *Rulingia dasyphylla* and *Rubus rosifolius*.

Remnants of similar vegetation occur at Dillons Crater in Brisbane Water National Park (Benson & Fallding 1981) and Peats Crater in Muogamarra Nature Reserve, though much of the volcanic areas have been cleared. Blanch and Marramarra Craters in Marramarra National Park, and one north of Fiddletown (Smith & Smith 1990), probably still have similar vegetation.

Volcanic dykes also occur, but are generally too narrow to support a distinct plant community, though understorey species may show local variations indicative of the more clayey, higher-nutrient soils. Sanders (1983) found that wide variation occurred within the vegetation associated with dykes and that soil and topographic position were important factors for species distribution; soil movement downslope from the dyke accounts for 'dyke' vegetation growing on sandstone. On soils associated with a dyke at West Head is open-forest with trees of *Eucalyptus paniculata, Eucalyptus umbra, Angophora floribunda, Eucalyptus scias* subsp. *scias, Syncarpia glomulifera* and *Allocasuarina torulosa*. Six species were found to characterise the vegetation on the ridge: *Macrozamia spiralis, Xylomelum pyriforme, Lomatia silaifolia, Pultenaea daphnoides, Notelaea ovata* and *Breynia oblongifolia;* and three to characterise the basalt soil in the creek; *Cissus hypoglauca, Doodia aspera* and *Livistona australis*.

Map Unit 9d
Transition Forest

Open-forest: *Eucalyptus fibrosa–Eucalyptus moluccana–Melaleuca decora*

Found in the Bankstown–Regents Park area, small patches of this vegetation still exist around Duck River, Auburn and Rookwood Cemetery, occurring on lower rainfall Wianamatta Shale (rainfall at Lidcombe is about 800 mm p.a.) on soils often associated with ironstone gravels, generally red podzolics or relict red podzolics. These are of low fertility and support vegetation with a shrubby understorey rather than the grasses that are characteristic of the more fertile soils of the Cumberland Plain with a similar rainfall. Floristically this vegetation is similar to the open-forest on transitions from Wianamatta Shale to the Tertiary alluvium in the Castlereagh–Penrith area and mapped (map unit 9d) on the Penrith Sheet (Benson 1992a), although here it is on Wianamatta Shale. It is likely that similar soil and drainage conditions here support this vegetation.

Structure is open-forest with an understorey ranging from a dense shrub layer about 3 m high to open and grassy with scattered shrubs. In the Bankstown–Regents Park area the main canopy tree species are *Eucalyptus fibrosa* and *Eucalyptus moluccana*. *Eucalyptus longifolia* and *Eucalyptus globoidea* occur sporadically and do not appear to be in any particular habitat. *Eucalyptus tereticornis* is found in the lower rainfall areas generally on lower hill slopes and depressions. *Syncarpia glomulifera* is usually found in higher-rainfall areas. *Angophora bakeri* was recorded only from near Duck River at Auburn, and *Eucalyptus parramattensis* from Bass Hill.

Dense shrubs are found along watercourses. *Melaleuca decora* is common in depressions and on poorly-drained flats. *Melaleuca styphelioides* is less common and found along creek channels. Other shrub species along creeks include *Rapanea variabilis* and *Breynia oblongifolia*. Shrubs also predominate on dry gravelly rises. Of the larger shrubs *Bursaria spinosa*, *Melaleuca nodosa* and *Acacia decurrens* are most common. Smaller shrubs include *Lissanthe strigosa*, *Daviesia ulicifolia*, *Dillwynia juniperina*, *Callistemon pinifolius*, *Acacia pubescens* and *Dodonaea triquetra*. Ground plants, grasses such as *Themeda australis* and *Aristida vagans*, sedges such as *Lepidosperma laterale* and *Lomandra longifolia* and herbs such as *Vernonia cinerea*, *Pratia purpurascens* and *Hardenbergia violacea* are interspersed with the shrubs or are more conspicuous on the sides of gravelly ridges.

Price (1979) studied the remnants of native vegetation in the Auburn area. He found that the original forest structure at Duck River and Rookwood Cemetery has been largely modified by fire, since european settlement, into grasslands, *Melaleuca* and eucalypt scrub, and low woodland. Grasslands dominated by *Themeda australis* occur in areas cleared long ago and little interfered with other than by regular burning. Other species associated with them include *Patersonia longifolia*, *Hypoxis hygrometrica*, *Xanthorrhoea* and *Lomandra* species and ground orchid species of *Diuris*, *Microtis* and *Thelymitra*.

Melaleuca and eucalypt scrub is common on land that has been partly cleared or left to recolonise naturally. *Melaleuca decora, Melaleuca nodosa* and *Melaleuca styphelioides* are the most abundant shrub species here and may be accompanied by small trees of *Eucalyptus fibrosa*, *Eucalyptus moluccana*, *Eucalyptus resinifera*, *Angophora bakeri*, *Syncarpia glomulifera* and *Eucalyptus longifolia*. Depending on the density of the *Melaleuca* canopy, there may be scattered herbs or open grassy places in between. Herb species include *Stylidium graminifolium*, *Lomandra* species, *Dianella* species, *Calotis cuneifolia* and *Vernonia cinerea*. Shrubs of open places such as *Daviesia ulicifolia*, *Dillwynia juniperina*, *Indigofera australis*, *Pimelea linifolia*, *Olearia microphylla*, *Ozothamnus diosmifolius*, *Bursaria spinosa*, *Callistemon linearis*, *C. pinifolius*, and the low-growing *Melaleuca* species, *Melaleuca erubescens* and *Melaleuca thymifolia*, are usually more common than species found in more shady habitats, such as *Polyscias sambucifolius*, *Pittosporum undulatum* and *Breynia oblongifolia*. Fire modifies the structure and floristics of these *Melaleuca* scrubs. When the canopy is opened to light, short-lived herbs such as *Pelargonium inodorum*, *Polymeria calycina*, *Senecio hispidulus* and shrub species *Cassinia arcuata*, *Ozothamnus diosmifolius*, *Olearia microphylla*, *Pimelea linifolia*, *Pultenaea villosa*, *Acacia falcata* and *Acacia longifolia*, establish.

The understorey of shrubs and tall herbs in the low woodland remnants include shade-tolerant or moisture-requiring species, many of them having seeds that are probably spread by birds. Species able to survive fires by suckering, such as *Breynia oblongifolia*, *Phyllanthus gasstroemii*, *Rapanea variabilis*, *Notelaea longifolia* and the exotic weed species *Asparagus officinalis* and *Myrsiphyllum asparagoides* are most abundant; other species include *Glochidion ferdinandi*, *Pittosporum undulatum*, *P. revolutum* and *Omalanthus populifolius*. For the Auburn area Price recorded 292 native species, a considerable number in view of the degree of disturbance the area has suffered.

This vegetation occurs on very poor agricultural soils. It remained largely undisturbed until the expansion of suburban development in the Bankstown–Liverpool district following the Second World War. Remnants still survive on State, Commonwealth and local council land. Probably the best example in the map area is along Duck River at Auburn. There are also remnants at Rookwood Cemetery, Carysfield Park at Bass Hill, Norfolk Reserve, Greenacre, and Airport and Ashford Reserves, Milperra. A nationally listed rare species, *Acacia pubescens*, is almost completely restricted to this community and has been recorded at a number of sites in the area including Carysfield Park and Rookwood Cemetery and along the railway line near Punchbowl and Yagoona. Trees of *Eucalyptus longifolia* with *Melaleuca decora* still survive beside Parramatta Road at its intersection with Hill Road, Granville. These are significant because they are the last naturally occurring native trees along Parramatta Road between Sydney and Parramatta.

Figure 6. *Eucalyptus maculata* open-forest, map unit 9g(ii), on the lower slopes at Elvina Bay, western Pittwater.

Map unit 9g
Spotted Gum–Blackbutt Forest

Spotted Gum–Blackbutt Forest is a very extensive and varied community on the Gosford map sheet area (Benson 1986a). It is an important component of the forestry activities of the Wyong district and extends south along the coast into the Bouddi and Warringah Peninsulas on the Sydney map sheet, where *Eucalyptus maculata*, Spotted Gum, is particularly conspicuous. Here, spotted Gum–Blackbutt Forest is found along the entrance to Brisbane Water between Wagstaff and The Rip (McRae 1990), along the Warringah Peninsula, on Scotland Island, and on the foreshores of Pittwater (Pidgeon 1937; Thomas & Benson 1985a). It is found on lower hillslopes on the Narrabeen Group–Terrigal Formation and coastal occurrences of the Newport Formations (interbedded laminite, shale and sandstones), on shallow to deep lithosols and podzolics of the Watagan Soil Landscape (Chapman & Murphy 1989). Annual rainfall here is up to 1500 mm with no winter frosts or seasonal drought (Kartzoff 1969). A number of sub-units can be recognised.

i) Open-forest: *Eucalyptus gummifera–Eucalyptus maculata–Eucalyptus pilularis*

Occurs mainly in the Wyong area on the Gosford map sheet (Benson 1986a).

ii) Open-forest: *Eucalyptus maculata–Eucalyptus paniculata*

Eucalyptus maculata, Spotted Gum, is the most characteristic tree, e.g. making up 46% of a sample of 150 trees in Hudson Park, Avalon (Smith & Smith 1993), forming an open-forest 15–30 m high with a mid-dense canopy cover. Associated trees at Hudson Park are *Angophora costata* (16%), *Eucalyptus gummifera* (13%), *Eucalyptus umbra* (9%), *Eucalyptus punctata* (6%), *Eucalyptus paniculata* (4%), *Syncarpia glomulifera* (3%), *Eucalyptus botryoides* (2%) and *Angophora floribunda* (1%). Small trees include *Allocasuarina torulosa*, *Glochidion ferdinandi* and *Livistona australis*. The understorey varies according to aspect. On dry sites there is a very sparse small tree and shrub layer with *Allocasuarina littoralis*, *Dodonaea triquetra*, *Platylobium formosum*, *Macrozamia communis* and *Pultenaea flexilis*, a mid-dense low shrub layer and an open ground cover of herbs and graminoids. In sheltered aspects the small tree layer is denser, including *Elaeocarpus reticulatus* and *Pittosporum undulatum*, there are few low shrubs, and ferns such as *Adiantum aethiopicum* and *Doodia caudata*, and vines such as *Cissus hypoglauca*, *Pandorea pandorana*, *Cayratia clematidea*, *Geitonoplesium cymosum* and *Eustrephus latifolius* may form a 'rainforest type' understorey. Small rainforest trees may occur, particularly on the Warringah Peninsula, including *Diospyros australis*, *Synoum glandulosum*, *Cassine australis* var. *australis*, *Euodia micrococca*, *Commersonia fraseri* and *Alphitonia excelsa*. *Livistona australis* is locally abundant around Bilgola.

Floristic lists have been compiled for Angophora Reserve and Hudson Park, Avalon (Table 3, Smith & Smith 1993), the National Trust's Burley Griffin Lodge at Avalon (Buchanan 1979b), western Pittwater (Thomas & Benson 1985a), and Loquat Valley, Bayview (Costin 1986).

iii) Woodland: *Eucalyptus umbra–Eucalyptus paniculata*

Related vegetation is found on the south-eastern side of the Bouddi Peninsula on slopes running from the main ridge to the coast (McRae 1990). Here the slopes are steep, from 10° to 35°, the aspect varies around south-east and there is always some degree of exposure to coastal winds and saltspray. Where the coastal exposure is greatest, the structure is reduced to a tall shrubland in which the canopy merges with the shrub layer. Elsewhere it is woodland structure.

The main tree species, *Eucalyptus umbra*, *Eucalyptus paniculata*, *Angophora costata* and *Syncarpia glomulifera* form a layer that varies from a height of 25 m and a cover of 25% to a height of 3 m with 10% cover, with increasing exposure. The shrub layer (3 m high with 20% cover) has a variable composition with common species including *Macrozamia communis*, *Dodonaea triquetra* and *Pultenaea flexilis*. The tall ground layer (1.5 m high with 30% ground cover) is dominated by *Lomandra longifolia*, *Imperata cylindrica*, *Gahnia melanocarpa* and *Pteridium esculentum*. The variablility in all strata is due to aspect and soil, the latter arising from the variable nature of the parent rocks (McRae 1990).

iv) Open-forest: *Archontophoenix cunninghamiana*

On slopes below Mt Bouddi are deep gullies with marginal rainforest dominated by Bangalow Palm, *Archontophoenix cunninghamiana*, with scattered *Eucalyptus deanei* and *Allocasuarina torulosa* (McRae 1990). Structurally this is open-forest with the trees up to 30 m high and reaching 60% canopy cover. There is a small tree layer, 10 m high, with Cabbage Palm, *Livistona australis, Duboisia myoporoides, Glochidion ferdinandii, Ficus coronata, Pittosporum undulatum, Schizomeria ovata*, and *Acmena smithii*, scattered shrubs including *Notelaea venosa, Wilkiea huegliana, Eupomatia laurina* and *Citriobatus pauciflorus*, and ground cover species including *Cissus antarctica, Rubus moorei, Morinda jasminoides, Gymnostachys anceps* and *Blechnum cartilagineum*. *Lantana camara* is usually abundant in the surrounding eucalypt woodland and in time could increase from its currently isolated thickets within the palm-forests.

Map unit 9h
Narrabeen Slopes Forest

Narrabeen Slopes Forest is particularly characteristic of the foreshores of Broken Bay and Pittwater (communities 6 and 7 of Thomas & Benson 1985a) and along the Hawkesbury River and its tributaries, Mangrove and Mooney Mooney Creeks (Benson & Fallding 1981; Benson 1986a). Similar vegetation is found on lower slopes of the islands of Broken Bay — Spectacle Island (Webb 1981), Bar Island (Benson 1984), Milson Island (Cleland 1914) Lion Island (Benson 1981a), Long Island (Coveny & McDougall 1990) and Dangar Island, and Scotland Island in Pittwater. All of these islands, with the exception of Bar Island, have Hawkesbury Sandstone vegetation (map unit 10ar) on their crests.

Narrabeen Slopes Forest is found on strata of the Narrabeen Group–Newport Formation (interbedded shale, laminite and medium-grained quartz sandstone) that outcrop on lower slopes and hillsides below cliffs and ridges of Hawkesbury Sandstone. Vegetation structure and floristic composition are particularly influenced by aspect. South-facing slopes are steeper, cooler and moister than north-facing slopes, which are less steep, but drier and more sunny. Two sub-units are recognised.

i) Open-forest: *Eucalyptus deanei–Angophora floribunda*

Sheltered south-facing aspects generally have open-forest with trees of *Eucalyptus deanei* and *Angophora floribunda* and may be associated with pockets of rainforest. This is found mainly on the northern side of Broken Bay in Mooney Mooney and Mullet Creeks on the Gosford map sheet (Benson 1986a), with one small occurrence at the southern end of Brisbane Water National Park and near Patonga (community 2B of Benson & Fallding 1981). There is generally a mesic understorey with climbers — *Hibbertia scandens, Hibbertia dentata, Cissus hypoglauca*; ferns — *Calochlaena dubia, Doodia aspera, Pteridium esculentum*; and other ground species — *Themeda australis, Imperata cyclindrica, Hydrocotyle* and *Lomandra* species.

ii) Open-forest: *Angophora floribunda–Allocasuarina torulosa*

On dry north- to west-facing slopes and on slopes open to sea breezes, open-forest is characterised by *Angophora floribunda, Eucalyptus punctata* and *Allocasuarina torulosa*. This occurs on the eastern sides of Mooney Mooney and Mullet Creeks in Brisbane Water National Park (community 2A of Benson & Fallding 1981), but is most common on the southern shore of Broken Bay on the foreshores of Cowan Creek, Coal and Candle Creek, Smiths Creek and the Hawkesbury River (Thomas & Benson 1985a, Community 7). Here it is from 15–25 m high with a mid-dense to open canopy cover. The main tree species are *Angophora floribunda, Eucalyptus punctata* and *Allocasuarina torulosa*, with *Eucalyptus botryoides, Eucalyptus umbra* and *Eucalyptus paniculata*. The understorey is usually dry with an open shrub layer and a ground cover dominated by grasses and herbs. Shrubs include *Pultenaea flexilis, Acacia ulicifolia, Astrotricha floccosa, Cassinia denticulata, Playsace linearifolia, Prostanthera denticulata* and *Persoonia linearis*. Grasses include *Entolasia* species and *Themeda australis*, and may predominate in frequently burned sites. On very sheltered aspects there may be moister species such as *Synoum glandulosum* and *Calochlaena dubia*.

Thomas and Benson (1985a) indicate that *Eucalyptus botryoides* and *Eucalyptus paniculata* occur with *Angophora floribunda* along the foreshores of Western Pittwater from McCarrs Creek to West Head on deeper, heavier soils in sheltered sites (described as their community 6). This variant commonly has an understorey of *Calochlaena dubia* and vines, particularly *Smilax australis* and *Geitonoplesium cymosum*, and has been included within this map unit. *Eucalyptus botryoides* may extend beyond the Narrabeen Group soils and is commonly found with *Angophora costata* on coastal sandstone headlands but rarely occurs away from the coast. *Eucalyptus maculata* rarely occurs in this unit. However, it is found around Pittwater where Narrabeen Slopes Forest is similar to and intergrades with Spotted Gum–Blackbutt Forest (map unit 9g).

Map unit 9o
Turpentine–Ironbark Forest

Open-forest: *Syncarpia glomulifera–Eucalyptus paniculata*

Turpentine–Ironbark Forest was the characteristic forest vegetation of the inner western part of Sydney from St Peters west to Peakhurst and sporadically as far as Lansdowne. It occurred on Wianamatta Shale, on shallow to deep podzolic soils of the Blacktown Soil Landscape (Chapman & Murphy 1989). It was also found north of the Parramatta River, from Ryde to Castle Hill and along shale-capped ridges around Glenorie and Arcadia, and on the transition zone between the Wianamatta Shale and the underlying Hawkesbury Sandstone, particularly on soils formerly known as the Hammondville Association (Walker 1960).

Turpentine–Ironbark Forest was first described by Phillips (1947) as a sub-association (*Eucalyptus pilularis–Eucalyptus resinifera*) of her *Eucalyptus pilularis–Eucalyptus saligna* Association, but is distinctive enough to map and discuss as a separate unit. With a moderate rainfall of between 900 mm and 1100 mm per annum, the vegetation, an intermediate, is part of the shale-vegetation gradient from the higher-rainfall Blue Gum High Forest (*Eucalyptus pilularis–Eucalyptus saligna* tall open-forest, map unit 6b), to the low rainfall Grey Box Woodland (*Eucalyptus moluccana–Eucalyptus tereticornis* woodland, map unit 10c, Benson 1992) further west on the Cumberland Plain.

Most of the Turpentine–Ironbark Forest has now gone, having been replaced by suburbs in the nineteenth and early twentieth centuries (Benson & Howell 1990a). Part of the Inner Western area, north of the Cooks River, in the Ashfield–Canterbury area was designated the *Kangaroo Ground* by Watkin Tench (Tench 1979), and was sought for early settlement. Collins (1798) wrote: 'The lieutenant-governor [Grose] proposing to open and cultivate the ground commonly known by the name of the Kangaroo Ground, situate to the westward of the town of Sydney between that

Figure 7. There are only a few surviving remnants of Turpentine–Ironbark Forest, map unit 9o, such as here at Fagan Park, Galston.

settlement and Parramatta, a gang of convicts was sent from the latter place for that purpose. The soil here was much better for agriculture than that immediately adjoining to the town of Sydney, and the ground lay well for cultivation; but it had hitherto been neglected, from its being deficient in the very essential requisite of water; on which account Parramatta had been preferred to it.'

This area would appear to have been eucalypt open-forest or woodland with an open understorey suitable for kangaroo habitat (Pratten 1993). There would, however, have been local variation in vegetation composition, and other early writers mention 'heavy timber and brush' (i.e. a dense understorey of shrubs). Peter Cunningham (1827) described Parramatta Road between Annandale and Ashfield bordered by land '... thickly covered with heavy timber and brush, the soil being usually a poor shallow reddish or ironstone clay, the contemplation whereof presents but little pleasure to the agriculturalist'.

Characteristic tree species were probably *Syncarpia glomulifera*, the Turpentine, and *Eucalyptus paniculata*, the Grey Ironbark. These would have been accompanied by a range of other species including *Eucalyptus globoidea*, *Eucalyptus punctata*, *Eucalyptus resinifera*, *Eucalyptus pilularis* and *Angophora floribunda*. Remnant trees of *Syncarpia glomulifera*, *Eucalyptus pilularis*, *Eucalyptus resinifera* and *Eucalyptus globoidea* still survive in Ashfield (Pratten 1993) and there are old herbarium collections of *Eucalyptus siderophloia* from Burwood and Belmore. A notice in the Sydney Morning Herald in December 1834, advertising allotments of the Burwood estate mentions 'timber: Shingle Oak, Iron and Stringy Bark, Mahogany, Blue Gum' etc. 'Blue Gum' here may refer to *Eucalyptus saligna*, which may have occurred locally in gullies or depressions, or *Eucalyptus tereticornis*, which may also have occurred.

Estimated canopy heights in remnant stands north of the Harbour, surveyed in the 1970s, ranged from 10 to 20 m with canopy cover from 30 to 67%, all figures characteristic of open-forest formation (D. Benson unpub. data). Most of these remnants are on the least favourable agricultural sites and have generally been logged, grazed and burnt at varying intensities. Plant densities for these stands, (mean = 719 ± 383 plants/ha), indicate a considerable amount of sapling and small tree regeneration. *Syncarpia glomulifera* was the most important species, accounting for 16% of total basal area and 35% of total plant density, probably because of its ability to withstand disturbance by resprouting, and its slow growth. Seven other tree species each accounted for between 4 and 14% of total basal area and between 2 and 10% of total plant density. A further eight species were recorded contributing to total site basal area.

The understorey was variously shrubby or grassy. Common shrub species in remnants now are *Dodonaea triquetra*, *Polyscias sambucifolia* and *Acacia falcata*, and grass and herb species include *Themeda australis*, *Echinopogon caespitosus*, *Pseuderanthemum variable* and *Pratia purpurascens*. In the early 1840s Mrs Charles Meredith described the forest at Homebush and mentions native species including *Hardenbergia violacea*, *Kennedia rubicunda*, *Pandorea pandorana* and other species likely to be *Oxylobium scandens*, *Dillwynia juniperina*, *Daviesia ulicifolia*, *Platylobium formosum*, *Viola hederacea*, *Wahlenbergia* species, *Lissanthe strigosa* and *Leucopogon juniperinus* (Meredith 1844, quoted in Benson & Howell 1990a). Most of these species can still be found near Homebush Bay, where an important remnant of this vegetation survives in land used for storage of naval munitions (Clarke & Benson 1988; Kachka 1993), or in the Yaralla Bushland in nearby Concord Municipality (Benson 1983).

There is also a small yet important remnant of native vegetation on the banks of the Cooks River at the end of Third Avenue, Campsie (Benson 1992b). The vegetation has patches of scrub, grassland and some trees. Most of the vegetation is of plants native to the site, many of which are growing very vigorously. In particular, in some of the more open areas there is a rich flora of ground cover species in particular grasses and prostrate small shrubs, such as *Astroloma humifusum*, *Calotis cuneifolia* and *Goodenia hederacea*. There was a patch of the orchid *Microtis unifolia* and some very impressive clumps of *Xanthorrhoea media*. Populations of *Calotis cuneifolia*, *Hibbertia serpyllifolia* and *Oxylobium ilicifolium* are probably the only natural occurrences surviving in inner western Sydney. Patches of shrubs include *Kunzea ambigua*, *Leptospermum trinervium* and shrubby trees of *Syncarpia glomulifera*. One of the reasons for the vigorous native plant growth is that the natural soils are essentially unmodified and have

not received nutrients in run-off from other areas. In comparison, adjacent areas with dumped soil have a significant number of weeds. This vegetation is the only remnant of Turpentine–Ironbark Forest vegetation for many kilometres, and is virtually the only remnant of native vegetation on the banks of the Cooks River. The only other native vegetation in the Cooks River valley is along Wolli Creek, in Girrahween Park, associated with outcropping sandstone and having a different species composition from this remnant on shale at Campsie.

On the northern side of the Harbour remnants occur at Ryde in Wallumatta Nature Reserve (Benson 1984, see below) and Fagan Park at Galston (Benson & Keith 1984b) including a good local stand of *Eucalyptus acmenoides*, a species which reaches its southern distributional limit at the Parramatta River — a few trees survive in Maze Park, West Ryde.

Turpentine–Ironbark Forest vegetation extended onto the transition zone between the shale and the underlying Hawkesbury Sandstone, on soils formerly known as the Hammondville Association (Walker 1960). Some of this transitional vegetation still survives as narrow edgers to cleared land on private property and on the margins of sandstone bushland reserves in northern Sydney, where there are remnants of shale overlying sandstone, e.g. Pennant Hills Park, Lane Cove National Park (formerly State Recreation Area) (Clarke & Benson 1987) and Garigal National Park (formerly Davidson State Recreation Area), Ku-ring-gai Chase National Park (Thomas & Benson 1985a), Marramarra National Park, and a number of Council parks. These patches are generally too small to map at the present scale. The vegetation of these areas differs from that on the deeper shale by including sandstone species. Structure is generally open-forest and tree species may be *Syncarpia glomulifera*, *Eucalyptus punctata*, *Eucalyptus paniculata* and *Eucalyptus globoidea*.

Protection of all small remnants of this shale-based flora is important since many of the smaller-growing species in particular are becoming rare, and many of the sites are in very vulnerable positions close to urban development and susceptible to weed invasion and nutrient-enriched run-off. Because shale areas are small and frequently on the margins of reserves, they may need particular and careful management.

Map unit 9sf
Duffys Forest

Open-forest: *Eucalyptus sieberi–Eucalyptus capitellata–Eucalyptus gummifera–Angophora costata*

On sandstone ridgetops in the Duffys Forest–Terrey Hills area are shale remnants from lenses within the Hawkesbury Sandstone (Herbert 1983), often with characteristic ironstone gravels, referred to as 'laterite' cappings. Soils are part of the Somersby Soil Landscape (Chapman & Murphy 1989), moderately deep yellow earths and deep red earths overlying laterite gravels and clays. A distinctive open-forest vegetation occurs on these.

At Duffys Forest, open-forest is 7–18 m high with a mid-dense canopy with trees of *Eucalyptus sieberi*, *Eucalyptus gummifera*, *Eucalyptus oblonga*, *Eucalyptus haemastoma* and *Angophora costata* (Benson 1974, 1979a; Thomas & Benson 1985a: community 10B). The understorey is of mid-dense shrubs often with emergent taller shrubs with a ground cover of low shrubs and monocots. Understorey species include *Telopea speciosissima*, *Xylomelum pyriforme*, *Ceratopetalum gummiferum*, *Banksia spinulosa*, *Persoonia levis*, *Micrantheum ericoides*, *Leptospermum trinervium*, *Pimelea linifolia*, *Acacia myrtifolia*, *Boronia pinnata* and *Cyathochaeta diandra*. Variation appears related to soil depth and type. Deeper soils carry more *Eucalyptus sieberi* with the occasional *Eucalyptus pilularis* and *Syncarpia glomulifera* and the understorey shrub *Bossiaea obcordata*, while thinner soils tend to support more sandstone woodland species. The central part of the original 'Duffys Forest' was cleared many years ago but Kartzoff (1969) reports that much blackbutt, *Eucalyptus pilularis*, was logged at Duffys Forest and that as a result of logging and burning, it is now extinct there, where it had been common 30 years before.

Thomas & Benson (1985a) also describe a slightly different community (community 10A) on low slope areas on shale-derived soils (possibly lateritic) and on deeper soils than the floristically similar *Eucalyptus sieberi* community. Structure is open-forest 0–17 m tall with a mid-dense canopy cover of trees of *Eucalyptus capitellata*, *Eucalyptus gummifera*, *Eucalyptus sieberi*, *Eucalyptus haemastoma*. The understorey has a sparse tall shrub layer, an open to mid-dense mid-height shrub

Figure 8. In the Leo Smith Reserve at Ramsgate there is an important remnant of Coastal Dune Forest, map unit 9t, with *Angophora costata* and a dense ground cover of Bracken and shrubs.

layer and an open to mid-dense ground cover of low shrubs, herbs and monocotyledons. Main species are *Ceratopetalum gummiferum*, *Persoonia levis*, *Acacia myrtifolia*, *Bossiaea obcordata*, *Banksia spinulosa*, *Lomatia silaifolia*, *Pultenaea elliptica*, *Micrantheum ericoides*, *Patersonia glabrata* and *Cyathochaeta diandra*. The shale influence on this community is distinctive and several species occur which are uncommon in the rest of the park (e.g. *Persoonia laurina*, *Pultenaea linophylla* form *b*. The threatened *Grevillea caleyi* occurs at the start of the Ryland Track. This community is very restricted in Ku-ring-gai Chase National Park. Similar vegetation also occurs at the junction of Forest Way and Mona Vale Rd, now part of Garigal National Park.

Also included in this map unit is open-forest with a very restricted distribution on remnant shale outcrops in the south of Brisbane Water National Park (mapped as community 4S, Benson & Fallding 1981). Trees here include *Eucalyptus gummifera*, *Angophora costata*, *Eucalyptus globoidea*, *Eucalyptus umbra*, *Eucalyptus punctata* and *Syncarpia glomulifera*. The shrub understorey is dominated by members of the Fabaceae family, and ground cover species include *Poa affinis*, *Entolasia stricta* and species of *Lomandra*.

Map unit 9t
Coastal Dune Forest

Open-forest: *Eucalyptus botryoides–Eucalyptus pilularis–Angophora costata*

Coastal Dune Forest occurred on the quartz sand of the Holocene beach ridges that extend along the western shore of Botany Bay, and on the northern side of Broken Bay between Pearl Beach, Umina and Woy Woy (New South Wales Department of Mineral Resouces 1983). It may also have occurred in sheltered sites on the 'marine' sands in Sydney's eastern suburbs, though most of this area appears to have had heath vegetation (Benson & Howell 1990a). Almost all has been destroyed by housing, with the exception of a small remnant on Botany Bay in the Leo Smith Reserve at Ramsgate, some low woodland with *Angophora costata* and *Eucalyptus botryoides* on the sheltered slopes of some dunes in Golf Courses at La Perouse, and a few remnants at Umina, too small to map.

Vegetation structure was originally open-forest to low woodland. *Eucalyptus botryoides*, *Eucalyptus pilularis* and *Angophora costata* appear to have been the main tree species, though *Angophora floribunda* is common in the Woy Woy occurrence.

Angophora floribunda, *Eucalyptus botryoides* and *Eucalyptus punctata* occur at Pearl Beach (Benson & Fallding (1981). The understorey was shrubby with such native species as *Banksia serrata*, *Elaeocarpus reticulatus*, *Hibbertia scandens*, *Leucopogon ericoides*, *Monotoca elliptica*, *Breynia oblongifolia*, *Glochidion ferdinandi* and *Pomax umbellata*. A species list for Leo Smith Reserve has been prepared by Benson & Keith (1985). This small area of open-forest at Ramsgate is the sole remnant of native sand vegetation of the beach ridge system (Outer Barrier) of western Botany Bay (nearby low-lying area has *Casuarina glauca* forest–Map unit 4a). It is different from the Eastern Suburbs *Banksia* Scrub of the transgressive dunes (map unit 21b), but has similarities to vegetation at Kurnell. Studies of intact vegetation on similar sand dune systems at Myall Lakes (Myerscough & Carólin 1986) demonstrate the complex nature of such vegetation systems.

Burges and Drover (1952) related vegetation patterns on the Holocene beach ridges between Umina and Woy Woy to increasing podzolisation and beachridge age (up to 4 000 years). Along the beach-front typical foredune colonisers were found, backed by a *Leptospermum laevigatum–Banksia integrifolia* thicket about 100 m wide. Isolated trees of *Eucalyptus botryoides* began to occur about 150 m from the beach and increased in number to form, with *Angophora floribunda*, a fairly open woodland on an area of iron podzol sands. Nearer to Woy Woy, on well-defined humus podzols, *Angophora floribunda* was replaced by *Angophora costata*. The swampy areas between the sand ridges had a range of vegetation from open water with *Typha*, to *Melaleuca quinquenervia* woodland. Remnant trees of *Angophora floribunda*, *Angophora costata*, *Eucalyptus pilularis*, *Glochidion ferdinandii* and a few conspicuous *Macrozamia communis* along the road verges around Ettalong and Umina are generally all that remains of this vegetation.

Figure 9. Some of the different habitats provided by the rugged sandstone topography are evident here in Ku-ring-gai Chase National Park — distant level ridgetops, exposed and sheltered hillsides and narrow valley floors each support different groupings of plant species.

Sydney Sandstone Complex (map units 10ag and 10ar)

This widespread vegetation complex occupies extensive areas of the Hawkesbury Sandstone plateaus and associated gullies. Depending on topographic position and aspect, there is considerable local variation in floristics and structure. Thomas and Benson (1985a), mapped 12 units for Hawkesbury Sandstone in Ku-ring-gai Chase National Park. Two broad sub-units have been recognised. These are a moist forest type, generally associated with sheltered hillsides and moist gullies (map unit 10ag), and a dry woodland type, generally associated with dry plateaus and ridges (map unit 10ar). These units have been used on the Katoomba, Wallerawang and Penrith sheets but not on the Gosford and Lake Macquarie map sheet (Benson 1986a), where a composite Hawkesbury Sandstone unit (map unit 10a) was used.

Sydney Sandstone Complex (map units 10ag and 10ar) ranges from tall open-forest to low woodland and open-scrub. It corresponds with part of the Mixed *Eucalyptus* Forest Association of Pidgeon (1937, 1938). In the map units described in this paper, Map Unit 10ag is essentially Pidgeon's High Forest, Map Unit 10ar includes scrub, tree-scrub, low scrub-forest and tall scrub-forest, and Map Unit 21g includes extensive areas

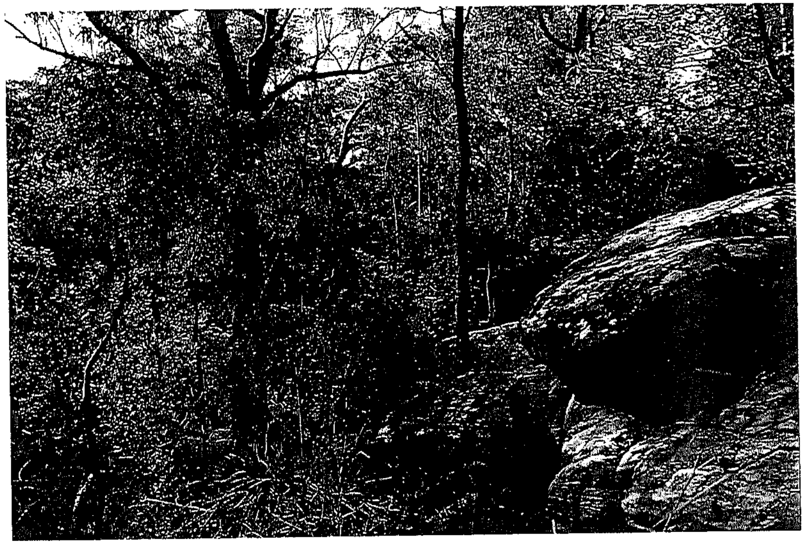


Figure 10. This open-forest in Pennant Hills Park, map unit 10ag(i), is typical of the vegetation on sheltered sandstone slopes in many of Sydney's bushland reserves.

of scrub, as well as sedge and shrub swamp. In terms of the floristic survey of Ku-ring-gai Chase by Outhred et al. (1985), Map Unit 10ag includes many of the M (particularly M4–M7), MT, and R series, while map unit 10ar covers the S, L and M (M1–M3) series.

Map unit 10ag
Sydney Sandstone Gully Forest

Sydney Sandstone Gully Forest has a widespread geographic distribution. It is found on the Hawkesbury Sandstone topography of the coast, Hornsby Plateau, lower Blue Mountains and Woronora Plateau. Map unit 10ag, open-forest to woodland, is generally confined to gullies and sheltered hillsides, particularly on southern to eastern aspects. Soils are shallow lithosols and siliceous sands, yellow earths and yellow podzolics (Hawkesbury Soil Landscape of Chapman & Murphy 1989), with deeper podzolic soils enriched by downwash material on lower slopes and in narrow valleys. Average height of the trees is 25 m, though varying from 18–30 m. Three sub-units are recognised.

i) Open-forest/woodland: *Eucalyptus piperita–Angophora costata–Eucalyptus pilularis*

The main trees are *Eucalyptus piperita*, *Angophora costata* and *Eucalyptus gummifera*. *Allocasuarina littoralis* is a common smaller tree. The understorey is dominated by a variety of shrubs, 0.5–2 m high, the main families being Proteaceae, Fabaceae and Myrtaceae. Pidgeon (1938) and Thomas and Benson (1985a) both list the following as frequent species: *Persoonia pinifolia*, *Acacia terminalis*, *Pultenaea daphnoides* and *Dodonaea triquetra*. There is considerable local variation in this community. For example localised occurrences of podzols on the Hornsby Plateau (Buchanan & Humphreys 1980), are characterised by the inclusion of a particular group of species, *Ceratopetalum gummiferum*, *Xylomelum pyriforme*, *Xanthorrhoea arborea*, *Ricinocarpos pinifolius* and *Gompholobium latifolium*.

Woodland of the more exposed parts of hillsides grades into open-forest as conditions become more sheltered, forming the vegetation characteristic of extensive tracts of sheltered sandstone slopes and gullies.

ii) Tall open-forest: *Eucalyptus pilularis–Syncarpia glomulifera*

Tall open-forest with trees over 30 m tall is found on the lower slopes of sandstone gullies in the Berowra Creek area, and on lower slopes where there is a localised enrichment from downwashed shale soils such as in the Lane Cove Valley. The

main trees are *Eucalyptus pilularis* and *Syncarpia glomulifera* but also occurring are trees of *Eucalyptus piperita* and *Angophora costata* generally associated with adjacent open-forest. Allocasuarina torulosa is a common smaller tree in the understorey

iii) Closed-forest: *Ceratopetalum apetalum–Tristaniopsis laurina*

This is the distinctive riparian flora occurring in narrow bands along perennial creeks. It may be locally of closed-forest structure, but is most commonly scrub, spaced out amongst boulders of the sandstone banks. It is generally an understorey to open-forest of *Eucalyptus piperita* or *Angophora costata*. Characteristic species are *Tristaniopsis laurina*, *Callicoma serratifolia*, *Lomatia myricoides*, *Leptospermum polygalifolium*, and *Austromyrtus tenuifolia*, with *Ceratopetalum apetalum* occurring in more favourable sites. The rare *Leptospermum deanei* is found only along Middle Harbour Creek and the upper Lane Cove River. In sheltered gullies that receive downwash from ridges with Wianamatta Shale there may be tall open-forest with *Eucalyptus saligna*, and occasional rainforest species such as *Schizomeria ovata*, with ferns in the understorey.

Vegetation on soils on small volcanic intrusions are included in this map unit. For example, open-forest with *Eucalyptus agglomerata* and *Angophora floribunda* at Campbells Crater, and open-forest with *Eucalyptus paniculata* and *Eucalyptus umbra* on a dyke at West Head, both within Ku-ring-gai Chase National Park. Such sites have characteristic understorey species related to the generally more clayey and higher nutrient status of the volcanic soils (Thomas & Benson 1985a; Sanders 1983).

Map unit 10ar
Sydney Sandstone Ridgetop Woodland

Sandstone Ridgetop Woodland is found on the more exposed ridges and plateau tops with shallower soils interrupted by outcrops of rock. Soils are shallow lithosols and earthy sands, yellow earths and yellow podzolics (Faulconbridge, Lucas Heights, Hawkesbury and Lambert Soil Landscapes of Chapman & Murphy 1989). There may be an average depth of 5–10 cm in some habitats but tree roots penetrate the deeper pockets of soil amongst the underlying rocks (Pidgeon 1938).

Figure 11. Low open woodland, map unit 10ar(ii), with *Angophora bakeri* and *Eucalyptus haemastoma* in Muogamarra Nature Reserve.

i) Woodland/Low woodland: *Eucalyptus gummifera–Eucalyptus haemastoma–Eucalyptus sparsifolia–Eucalyptus racemosa*

This is structurally very variable and includes areas of woodland, open-woodland, low woodland and low open-woodland, depending on local aspect, soil and drainage conditions, as well as the time since the last fire. Characteristic tree species are *Eucalyptus gummifera*, *Eucalyptus sparsifolia*, *Eucalyptus haemastoma* and *Eucalyptus racemosa*, sometimes with some intergradation between the latter two scribbly gum species. *Eucalyptus piperita* and *Angophora costata* may also occur. Localised patches of mallee eucalypts, *Eucalyptus luehmanniana*, *Eucalyptus obtusiflora*, *Eucalyptus camfieldii* and *Eucalyptus multicaulis*, may be responding to locally moister sites, or shallow rock platforms. *Eucalyptus capitellata* occurs on some more clayey ridges in the Terrey Hills area.

These dry, exposed communities have a rich sclerophyllous shrubby understorey, particularly with species of Proteaceae, Fabaceae, Epacridaceae and Myrtaceae. Common shrubs in Ku-ring-gai Chase National Park include species of *Pultenaea*, *Isopogon*, *Hibbertia*, *Hakea*, *Banksia*, *Boronia*, *Leucopogon*, *Grevillea*, *Gompholobium* and *Tetratheca*, as well as *Dillwynia retorta*, *Phyllota phylicoides*, *Leptospermum trinervium*, *Petrophile pulchella* and *Platysace linearifolia* (Thomas & Benson 1985a).

ii) Woodland/low woodland: *Eucalyptus eximia–Eucalyptus gummifera–Angophora bakeri*

This vegetation is found on dry hillsides and ridges in the north-west of the map sheet area, west of Berowra Creek, and is particularly widespread in Marramarra National Park. Rainfall is generally less than 1000 mm p.a., in contrast to the higher-rainfall (1000–1200 mm) country of Ku-ring-gai Chase and Brisbane Water National Parks. Characteristic trees include *Eucalyptus eximia* and *Angophora bakeri*, as well as the more widespread *Eucalyptus gummifera* and *Angophora costata*. Similar vegetation extends west to the lower Blue Mountains (Benson 1992a) and north into the MacDonald (Sanders et al. 1988) and Colo River areas.

iii) Open-scrub: *Banksia ericifolia–Hakea teretifolia*

In sites with shallow poorly-drained soil, patches of open-scrub with tall shrubs of *Banksia ericifolia* and *Hakea teretifolia* occur. Within the ridgetop woodland small patches of Coastal Sandstone Heath (Map Unit 21g) may occur, in particular coastal heath with *Banksia ericifolia* and *Darwinia fascicularis*, Open-heath with *Allocasuarina* and *Banksia ericifolia*, Rocky outcrop heath with *Baeckea diosmifolia* and *Baeckea brevifolia*, Wet heath with *Hakea teretifolia* and *Banksia oblongifolia*, and Open-scrub with *Angophora hispida*.

As mentioned earlier, floristic differences between gully forest and ridge woodland can be distinguished in Outhred's floristic analysis of Ku-ring-gai Chase vegetation, though there is considerable overlapping of species distributions. However, differences between the scrub or shrub-dominated vegetation and the taller woodland/forest vegetation are perhaps more marked. In particular, many species are essentially confined to the scrub vegetation or very open low tree vegetation, e.g. *Allocasuarina distyla*, *Phebalium squamulosum*, *Banksia oblongifolia*, *Kunzea capitata*, *Mirbelia rubiifolia*, *Stylidium lineare*, *Epacris microphylla*, and *Grevillea speciosa*. In contrast, very few species (e.g. *Micrantheum ericoides*), are essentially confined to the woodland, which is mainly made up of species that occur in both woodland and scrub, or woodland and forest. The woodland appears to be an ecotone between the heath and the forest.

Vegetation surveys of major Sydney sandstone areas include Brisbane Water National Park (Benson & Fallding 1981), Bouddi National Park (McRae 1990), Muogamarra Nature Reserve (Thomas & Benson 1985b), Ku-ring-gai Chase National Park (Thomas & Benson 1985a, Outhred et al. 1985, Rose 1982), Berowra Valley Bushland Park (Smith & Smith 1990), Pennant Hills Park (Beecroft–Cheltenham Civic Trust 1976), Lane Cove River State Recreation Area (Clarke & Benson 1987), Garigal National Park (McDougall & Conroy 1988–90, Sheringham & Sanders 1993) and Angophora Reserve and Hudson Park (Smith & Smith 1993). Brief reports and species lists are available for some of the islands of Broken Bay — Lion Island (Benson 1981, McDougall 1989), Spectacle Island (Webb 1981), Milson Island (Cleland 1914), Bar Island (Benson 1984) and Big Bay Island (Benson et al. 1989). Many of these lists have been included in Table 3.

Vegetation descriptions and/or species lists have been compiled for many other areas including the following ('V' indicates vegetation description included, 'F' indicates floristic list, 'M' indicates map): Elouera Bushland Reserve, Coveny (h) F, Benson (1980b) V; Katandra Sanctuary, Mona Vale, Coveny (l) F; Cheltenham, Coveny (b) F; Deep Creek, Narrabeen, McKern (1962) F, Coveny (f) F, Benson (1979a) V; Dee Why Lagoon, Coveny (g) F; Cumberland State Forest, Coveny (d) F; Lake Parramatta Reserve, Workers' Education Association Plant Ecology Group (1959) F, Coveny (m) F; Mowbray Park, Buchanan (1979a) VFM; Bantry Bay, Upper Middle Harbour Conservation Committee (1974) VFM; Manly Reservoir, Coveny (o) F; Vineyard Creek, Telopea, Benson (1980c) VF; Rawson Park, Mosman, Bradley & Bradley (1966–74) F, Benson (1975) VF; Garden Island, Rodd & Benson (1977) F; Outer Domain, Maiden (1902) also in Wilson (1985); Vaucluse, Holland (1980); Wolli Creek–Undercliffe–Bexley North, Benson (1978b) VF; Robinson (1986, 1987); Long Bay, Benson 1978a VF; Glebe Gully, Randwick, Coveny (j) F; La Perouse, Armstrong et al. (1976) VF.

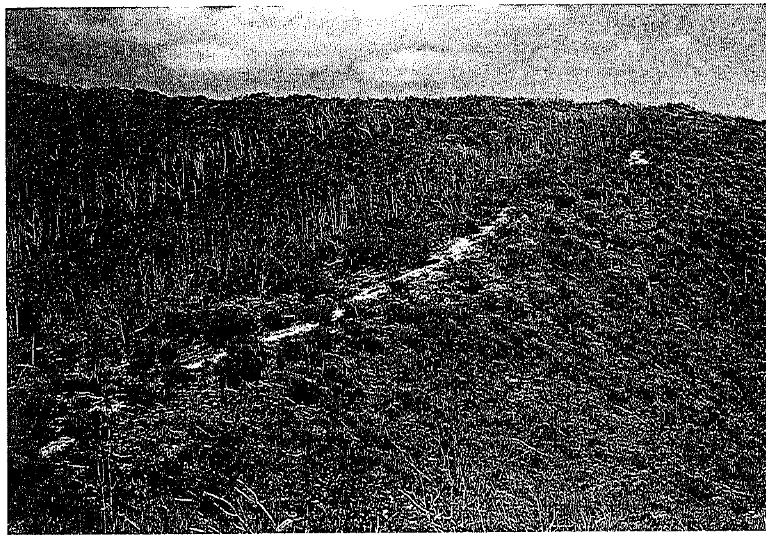


Figure 12. Coastal heath with *Allocasuarina distyla* at Bouddi National Park, map unit 21a(i), grades into woodland where there is shelter from onshore winds.

Map unit 21a

Coastal Clay Heath

Coastal Clay Heath vegetation occurs on coastal headlands on shales and sandstones of the Narrabeen Group, mostly interbedded laminite and shale with quartz to lithic quartz sandstone. These are found along the coastline in Bouddi National Park (McRae 1990) and along the Warringah Peninsula between Long Reef and Barrenjoey. Further north Coastal Clay Heath is found at Norah Head and from Munmorah State Recreation Area to Catherine Hill Bay (Benson 1986a, Adam, Stricker et al. 1989). Vegetation here is low and scrubby, both because of the low nutrient status of its soils, and because it is exposed to winds from the ocean which restrict tree growth. Soils are variable, with lithosols, siliceous sands and yellow podzolics on the sandstone, and brown and red podzolics on the shale strata (Chapman & Murphy 1989). Heath vegetation occurs on the more sandy soils, while those with more clay tend to support grassy vegetation.

i) Open-heath: *Allocasuarina distyla*

Heath vegetation at Bouddi may range from open-heath to closed-heath 1.5m high and with up to 95% canopy cover depending on time since fire (McRae 1990). Similar vegetation occurs on Barrenjoey Head. The most characteristic canopy species is *Allocasuarina distyla*; other heath species include *Hakea teretifolia*, *Banksia ericifolia*, *Lasiopetalum ferrugineum* and *Platysace linearifolia*. The ground stratum is poorly developed, including *Lomandra longifolia*, or absent. Fire kills the *Allocasuarina*, which relies on seed for reestablishment, and for a number of years its seedlings cannot attain dominance over those of other species or over species relying on lignotubers for regrowth. During this phase the local species richness is increased and abundant species include *Hakea teretifolia, Banksia ericifolia, Isopogon anemonifolius, Isopogon anethifolius, Woollsia pungens, Actinotus helianthi, Cyathochaeta diandra* and *Themeda australis* (McRae 1990).

Allocasuarina distyla open-heath appears to be part of the *Banksia serrata–Allocasuarina distyla* community of Adam, Stricker et al.(1989) who comment that in overall diversity and species composition, stands on Hawkesbury Sandstone in the Sydney region and on Permian sandstone around Jervis Bay are very similar. It is also similar to their *Banksia ericifolia–Westringia fruticosa* community.

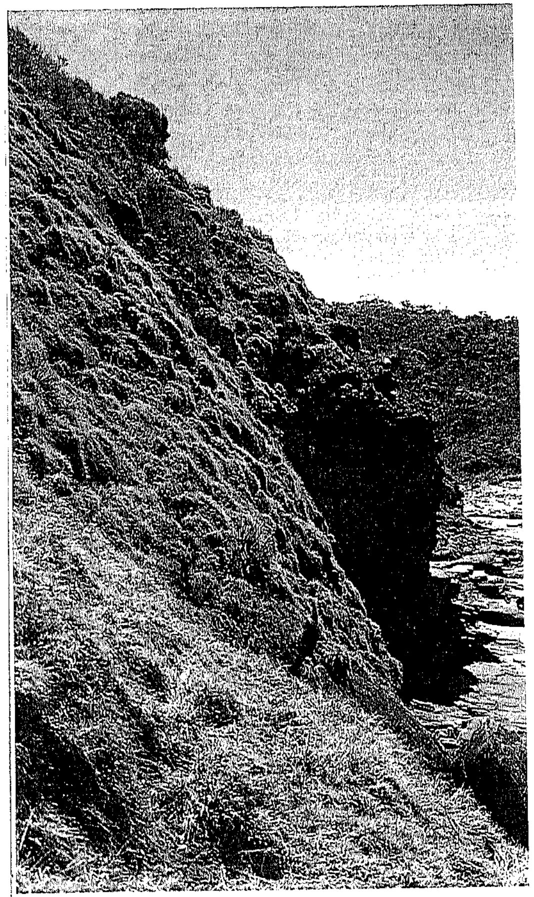


Figure 13. Grassland with *Themeda australis*, map unit 21a(ii), is characteristic of exposed coastal headlands of the Narrabeen Group shales and sandstone.

ii) Grassland: *Themeda australis*

Grassland dominated by *Themeda australis* occurs on exposed sites below coastal cliffs at Bouddi (McRae 1990) and on the Warringah Peninsula. It varies in height from 0.1 to 1 m with about 70% cover. *Themeda australis* is the main species, but there may also be a mixture of severely windswept shrubs such as *Westringia fruticosa, Banksia integrifolia* and *Baeckea imbricata*, smaller plants such as *Isolepis nodosus, Apium prostratum* and *Carpobrotus glaucescens* and the ferns, *Gleichenia rupestris* and the introduced *Cyrtomium falcatum*. *Themeda australis* grassland generally occurs on the most fertile headland soils possibly reflecting the long history of use and disturbance to which such sites have been subject (Adam, Stricker et al. 1989).

Map Unit 21b
Coastal Dune Heath

Coastal Dune Heath is found sporadically along the New South Wales coast. Major occurrences include Myall Lakes (Myerscough & Carolin 1986). On the Sydney map sheet Coastal Dune Heath is found on Mourawaring and Bombi Moors in Bouddi National Park (McRae 1990), at North Head, and in the Eastern Suburbs of Sydney. *Banksia aemula* open-heath is found on disjunct patches of highly leached, perched Pleistocene dune sand. The other community occurs on 'marine' sands of Holocene age. Coastal Dune Heath vegetation is often found associated with low woodland of *Angophora costata* and *Eucalyptus botryoides* on the sheltered slopes of steeper dunes (see Map unit 9t Coastal Dune Forest).

i. Open-heath: *Banksia aemula*

Banksia aemula open-heath is found on disjunct patches of highly leached, perched Pleistocene dune sand, on the Bombi and Mourawaring Moors in Bouddi National Park, on North Head and at La Perouse. Such sites are normally away from the immediate coastal environment and receive little salt-spray, but are on very low nutrient-status soils. This vegetation is discussed by Siddiqi et al. (1972) at Bouddi as dry *Banksia serratifolia* [=*aemula*] heath and by Adam, Stricker et al. (1989) as the *Banksia aemula–Hypolaena fastigiata* community.

At Bouddi, the shrub layer is up to 1.5 m high, with 20% canopy cover, and often merges with the low ground stratum, with 80% cover, dominated by graminoids (McRae 1990). The dominant shrub is *Banksia aemula* and common shrubs include *Allocasuarina distyla, Lambertia formosa, Platysace linearifolia, Isopogon anemonifolius, Persoonia lanceolata, Leptospermum polygalifolium* and low-growing *Eucalyptus umbra* and *Angophora costata*. Common understorey species include *Hypolaena fastigiata, Bossiaea ensata, Woollsia pungens* and *Lepidosperma* species. On the edges of the dunes a low open-woodland, 3 to 8 m high, dominated by *Angophora costata, Eucalyptus umbra* and *Allocasuarina distyla*, develops.

Pleistocene sand at North Head occupies the central part of the plateau but has been largely cleared of vegetation by the Army. A fringe of vegetation remains, some of which is in Sydney Harbour National Park. Most of this has been protected from fire for at least 30 years and now forms a dense scrub 8 m high dominated by the taller-growing *Leptospermum laevigatum* (Horton 1986). There are smaller shrubs of *Banksia aemula, Kunzea ambigua* and *Leptospermum*, many of which are now senescent or dying. Invasion of heathland by *Leptospermum laevigatum* in the absence of fire has been reported by Burrell (1981). An interesting aspect of the vegetation at North Head is the deterioration and death of individuals of the species *Eucalyptus camfieldii*, evidently in response to the lack of fire.

Small remnants of *Banksia aemula* open-heath, described as part of the Eastern Suburbs Banksia Scrub (Benson & Howell 1990a) occur at La Perouse, near Jennifer Street. This is the southern limit of distribution of *Banksia aemula* open-heath.

Figure 14. A small patch of the Eastern Suburbs Banksia Scrub, map unit 21b(i), survives at Jennifer St, La Perouse. The tall flowering spikes of *Xanthorrhoea resinosa* are conspicuous, particularly after fire.

Common shrub species here are *Banksia aemula, Monotoca elliptica, Eriostemon australasius, Ricinocarpos pinifolius* and *Xanthorrhoea resinosa*. There are many other species here and protection of the area is an important ongoing conservation issue. It has been burned frequently.

ii. Open-scrub: *Monotoca elliptica–Banksia integrifolia–Leptospermum laevigatum*

This occurs on 'marine' sands of Holocene age and occasionally on in situ weathering of Hawkesbury Sandstone. Floristically not very diverse, *Monotoca elliptica* is the only constant (Adam, Stricker et al. 1989), but *Banksia integrifolia, Leptospermum laevigatum, Melaleuca armillaris, Pimelea linifolia* and *Acacia sophorae* are widespread. The shrub layer is frequently wind-pruned, but in sheltered locations *Monotoca elliptica* and *Leptospermum laevigatum* may be 3–4 m tall.

Map Unit 21g
Coastal Sandstone Heath

James Atkinson provided this excellent description of coastal heath in 1826. 'The barren scrubs almost every where border the sea coast, and extend to various distances inland; in some places two or three miles; in others, lands of a better description approach close to the water's edge. The soil in these scrubs is either sandstone rock or sterile sand or gravel, covered, however, with a

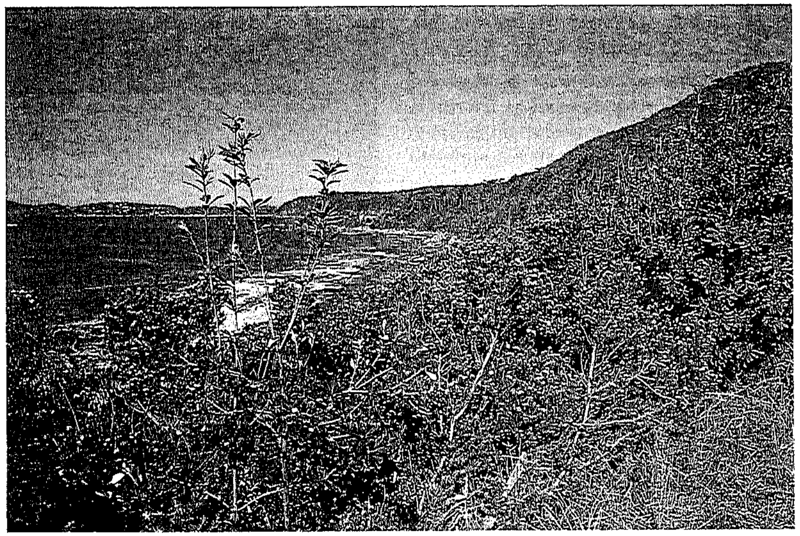


Figure 15. Coastal scrub with *Banksia integrifolia*, map unit 21b(ii), near Pearl Beach on the northern side of Broken Bay.

profusion of beautiful shrubs and bushes, producing the most elegant flowers, and affording a constant succession throughout the whole year, but most abundant in winter and spring; the shrubs and plants growing in these places furnish the Colonists with materials for brooms, but produce little else that can be converted to any useful purpose. – The grass tree, with its lofty flower stalk, is a conspicuous object in these wastes; of the hard and woody but light stalk of this plant the natives make the shaft of their spears, and shooting or fish gigs. Very few trees grow in these places, except a few stinted (sic) gum trees, in situations sheltered from the sea winds. Much honey might probably be collected from these scrubs, were bees plentiful in the Colony, and some small profit may possibly be thus made of them hereafter; but with this exception, they scarcely seem susceptible of any improvement'.

Coastal Sandstone Heath is found on Hawkesbury Sandstone headlands along the coast from Long Reef to La Perouse, and on nearby sandstone plateaus and ridges, particularly in the Deep Creek catchment and the Lambert Peninsula in Ku-ring-gai Chase National Park. Habitats include broad ridges, gently to moderately inclined slopes, wide rock benches with low broken scarps, small hanging valleys and areas of poor drainage. Soils are shallow, discontinuous earthy sands and yellow earths, siliceous sands, lithosols, leached sands, grey earths and gleyed podzolics (Lambert and Hawkesbury Soil Landscapes of Chapman & Murphy 1989).

Vegetation structure is variable, ranging through open-heath, shrubland, mallee, and sedgeland. Structure is influenced by fire frequency and the time since the last fire. Particularly important are the large, relatively quick-growing, but fire-sensitive (i.e. killed by fire) species (e.g. *Banksia ericifolia*, *Hakea teretifolia*, *Allocasuarina distyla*, *Petrophile pulchella*) that may readily predominate in a range of habitats under particular fire regimes. The interaction between these species and the generally slower-growing, more long-lived resprouter species (e.g. *Banksia oblongifolia*, *Angophora hispida*, *Lambertia formosa*) is an important consequence of the particular fire regimes in an area, with subsequent effects on vegetation structure and floristics. This is a potential area for future research. The other major factor in heath composition is soil moisture, and different communities are recognisable across the full range of drainage conditions.

Broad communities are recognised here, but there is considerable overlap and variation depending

on the scale of the study. Small areas of this vegetation have also been mapped in unit 10ar.

i) Shoreline shrubland

Shrubland: *Baeckea imbricata*

On coastal sandstone headlands low shrubland of *Baeckea imbricata* frequently provides the most seaward zone of continuous vegetation. It is rarely more than 20 m wide, though *Baeckea* can be found as a component of communities considerably further inland (Adam, Stricker et al. 1989). The low-growing shrub, *Baeckea imbricata*, predominates in this community — *Westringia fruticosa* is frequent, but not abundant. High inputs of salt-spray are experienced and saltmarsh species occur — *Sporobolus virginicus*, *Samolus repens*, *Zoysia macrantha*. At more inland localities *Baeckea imbricata* dominates communities in wet hollows, where the community is a form of wet heath. Associated species include *Epacris obtusifolia*, *Callistemon citrinus* and *Sprengelia incarnata*. Good examples occur at North Head (Horton 1986), Long Bay and La Perouse. A detailed account of seacliff and headland vegetation is given in Adam, Stricker et al. (1989).

ii) Coastal heath

Open-heath/closed-scrub: *Banksia ericifolia–Darwinia fascicularis*

On the landward side of the *Baeckea* low shrubland, Adam, Stricker et al. (1989) describe a *Banksia ericifolia–Westringia fruticosa* community and then a more extensive (up to 1 km inland) *Banksia ericifolia–Darwinia fascicularis* closed-heath community. Frequent species include *Allocasuarina distyla*, *Hakea teretifolia*, *Melaleuca nodosa*, *Dillwynia floribunda*, *Lasiopetalum ferrugineum*, *Baeckea imbricata*, *Leucopogon microphyllus*, *Lepidosperma viscidum*, *Eriostemon buxifolius* and *Epacris microphyla*. Drainage is an important factor in determining the presence of particular species, Clemens and Franklin (1980) recognising differences in heath vegetation on North Head related to soil depth and drainage.

Banksia ericifolia–Darwinia fascicularis closed-heath occurs extensively at North Head (Clemens & Franklin 1980, Horton 1986), Long Bay and La Perouse, and is widespread on Hawkesbury Sandstone on the Central Coast of NSW as well as on soils from Permian Sandstone near Jervis Bay.

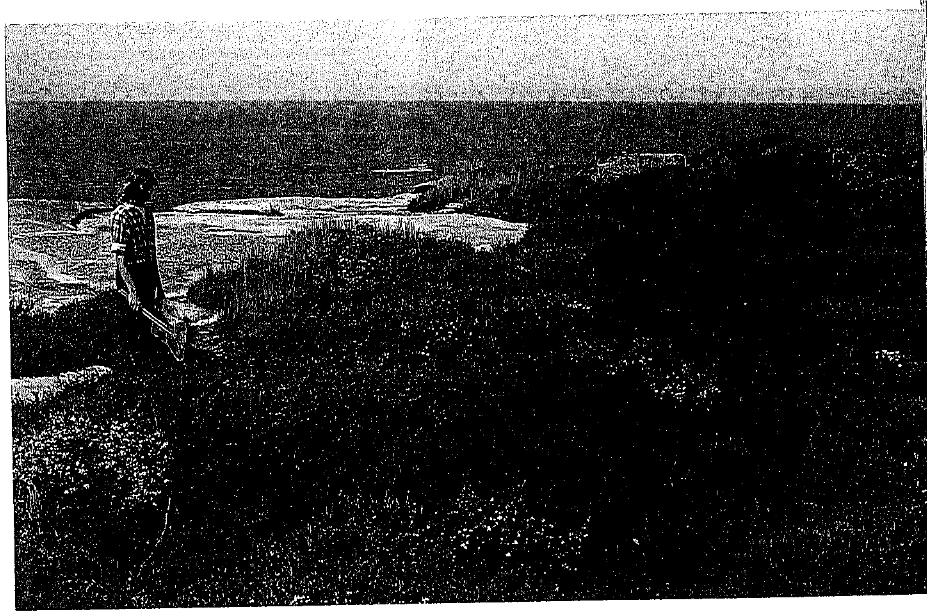


Figure 16. Coastal heath on sandstone rock platforms at Long Bay (map unit 21g(ii)).

iii) Open-heath/closed scrub: *Allocasuarina distyla–Banksia ericifolia*

This is similar to the previous community but occurs away from the immediate coastal influence and is widespread in Brisbane Water, Ku-ring-gai Chase and Garigal National Parks. It ranges from closed-scrub up to 4 m high to open-heath, with species such as *Banksia ericifolia, Allocasuarina distyla, Leptospermum trinervium, Phebalium squamulosum, Phyllota phylicoides, Angophora hispida* and *Pultenaea elliptica*.

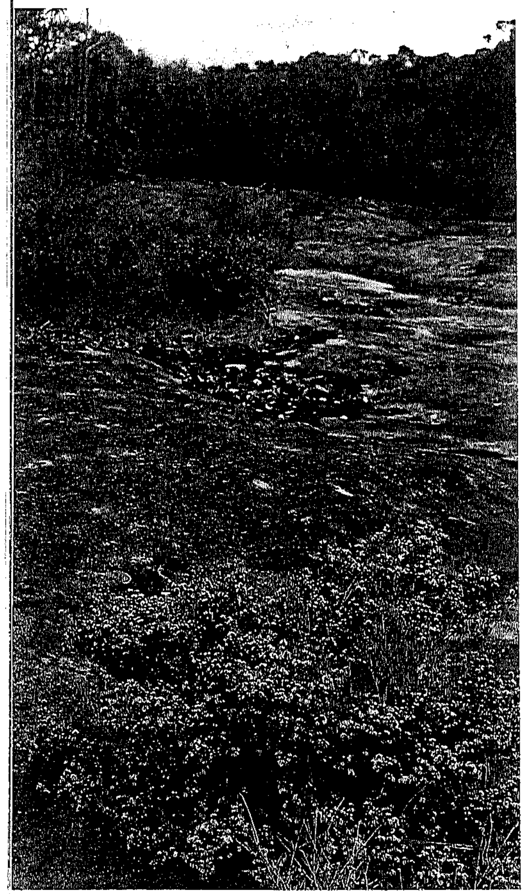


Figure 17. Extensive rocky outcrops with pockets of heath, map unit 21g(iv), occur in Brisbane Water National Park.

iv) Rocky outcrop heath

Open-heath: *Baeckea diosmifolia–Baeckea brevifolia*

Vegetation with a dense shrub cover to 1.5 m high among scattered, stunted emergent trees, occurs on broad, flat sandstone ridges with extensive rock outcrops, sometimes with occasional dense bonsai-like mats of *Baeckea* species (Sheringham & Sanders 1993). Shrubs include *Baeckea diosmifolia, Baeckea brevifolia, Allocasuarina distyla, Darwinia fascicularis, Kunzea capitata* and *Dillwynia sericea*. Such vegetation occurs commonly in Brisbane Water, Ku-ring-gai Chase and Garigal National Parks and in smaller parks in the Warringah area, for example at Bantry Bay (Upper Middle Harbour Conservation Committee 1974), and Manly-Warringah War Memorial Park (Benson 1981b).

v) Wet heath

Closed heath: *Hakea teretifolia–Banksia oblongifolia*

Closed-heath to 2 m high dominated by shrubs including *Banksia oblongifolia, Banksia ericifolia, Hakea teretifolia, Dillwynia floribunda, Epacris obtusifolia, Leptospermum squarrosum, Baeckea imbricata* and *Sprengelia incarnata* occurs on poorly-drained sandstone.

vi) Sedgeland/shrubland: *Banksia robur–Viminaria juncea–Gymnoschoenus sphaerocephalus*

Swamps form where drainage is permanently impeded. In the wettest areas these may be sedge swamps dominated by species of Cyperaceae and Restionaceae, or in drier sites, shrub swamps (Pidgeon 1938). Buchanan (1980) describes four distinct but intergrading swamp types for the Lambert Peninsula in Ku-ring-gai Chase National Park. Keith and Myerscough (1993) provide an excellent study of similar swamp vegetation on the Woronora Plateau.

vii) Open-scrub: *Angophora hispida*

Small patches of open-scrub with *Angophora hispida* occur in Marramarra National Park, either on ridges or associated with rock platforms. Characteristic species of these sites include *Calytrix tetragona, Dillwynia floribunda, Grevillea buxifolia, Petrophile pulchella* and *Platysace*

ericoides. This vegetation probably represents a low-rainfall variant (annual rainfall about 800 mm) of the more coastal sandstone heaths (annual rainfall 1000–1200 mm). Heath is rare in low rainfall sandstone areas where it is replaced by woodland, indicating the importance of high moisture and poor drainage in preventing tree growth in heath areas.

viii) Shrubland (mallee): *Eucalyptus luehmanniana*

Small localised occurrences of *Eucalyptus luehmanniana* mallee shrubland or woodland occur in Garigal and Ku-ring-gai National Parks. These occur on sheltered upper to mid slopes on south-westerly to south-easterly aspects where drainage is poor and often associated with patches of wet heath (Sheringham & Sanders 1993).

Map Unit 27a
Coastal Swamp Forest Complex

i) Open-forest: *Eucalyptus botryoides–Eucalyptus robusta*

This occurs on poorly-drained sites in the Pittwater area, such as the Warriewood wetlands, but has been extensively disturbed, and very little remains.

ii) Open-forest: *Livistona australis*

Localised patches of *Livistona australis*, Cabbage Palm, occur in open-forest along the Warringah Peninsula from Palm Beach to Avalon, and along sections of Deep and Middle Creeks, particularly near Wakehurst Parkway. It also formerly occurred along the southern foreshores of Port Jackson in Sydney's eastern suburbs between Woolloomooloo and Rose Bay, but no naturally occurring palms are known to survive there now.

iii) Scrub: *Melaleuca linariifolia–Melaleuca styphelioides*

Paperbark swamp 5–18 m high with mid-dense to sparse cover of trees of *Melaleuca linariifolia* and *Melaleuca styphelioides*, small trees of *Callicoma serratifolia* and *Acacia longifolia* and sedges and ferns, *Gahnia clarkei, Gahnia sieberiana* and *Blechnum camfieldii* are found on floodplain alluvium along Deep Creek on better-drained areas surrounding herbland (Sheringham & Sanders 1993).

Figure 18. Remnants of the Botany Swamps at Eastlakes, map unit 28c(i) — sedgeland and open water provide important habitat for waterbirds and other wildlife.

iv) Reedland: *Phragmites australis–Typha orientalis*

Patches of reedland up to 3 m high, dominated by mainly *Phragmites australis* or *Typha orientalis*, grow on alluvial soils in estuaries and creeks in areas inundated with water for long periods and often brackish.

v) Herbland: *Persicaria strigosa–Blechnum camfieldii–Triglochin procera–Baumea juncea*

Waterlogged soil on alluvial floodplain of Deep and Middle Creeks has dense cover of herbs and sedges up to 2 m high. Ground species include *Persicaria strigosa, Blechnum camfieldii, Triglochin procera, Baumea juncea, Hypolepis muelleri, Viola hederacea, Isachne globosa* and *Villarsia exaltata*. Emergent shrubs include *Melaleuca styphelioides, Melaleuca linariifolia, Acacia longifolia* and *Leptospermum juniperinum* (Sheringham & Sanders 1993).

Map Unit 28c
Coastal Freshwater Swamp

This unit occurs in coastal freshwater swamp habitats, most of which have now been reclaimed, dammed or badly disturbed. They were particularly abundant on the sand deposits of the Eastern Suburbs (see Benson & Howell 1990a), with smaller swamps in the Woy Woy–Umina area. The main surviving examples are the Lachlan Swamp in Centennial Park and the Botany Swamps at Eastlakes and Botany.

Figure 19. Old paperbarks, *Melaleuca quinquenervia*, with a ferny understorey in the Lachlan Swamp Reserve in Centennial Park (map unit 28c(ii)).

i) Open-sedgeland: *Eleocharis sphacelata–Baumea juncea–Persicaria decipiens*

Damming of the Botany Swamps last century provided one of Sydney's water supplies. Today there are lakes with open water and patches of tall emergent sedges, particularly *Eleocharis sphacelata*.

Areas of native vegetation are in the Millstream section of the Botany Swamps adjacent to Wentworth Avenue. Here, with patches of low woodland of *Melaleuca quinquenervia*, is sedgeland with Baumea articulata, *Baumea rubiginosa, Baumea juncea* and *Gahnia sieberiana*. There are also herbaceous species *Persicaria decipiens, Persicaria strigosa, Philydrum lanuginosum* and *Ludwigia peploides* subsp. *montevidensis*, and shrubs of *Leptospermum juniperinum, Callistemon citrinus* and *Viminaria juncea*. Unfortunately, as a result of disturbance, there is a considerable amount of exotic weed, in particular the shrub *Ludwigia peruviana*. The Water Board is taking steps to alleviate this problem and to rehabilitate the Wetlands.

ii) Low forest: *Melaleuca quinquenervia*

At the Lachlan Swamp Reserve in Centennial Park is a dense forest of *Melaleuca quinquenervia* with fern-banks of *Gleichenia dicarpa* and *Hypolepis muelleri*, and *Gahnia sieberiana*, still much the same as when described by Hamilton in 1919. 'These ferns [*Gleichenia dicarpa* and *Hypolepis muelleri*] may be observed engaged in such a competition in a peaty swamp in Centennial Park'. Extensive *Melaleuca* forest also occurred across the peaty flats behind Rose Bay (Hamilton 1919), whereas only a few individual trees survive today.

Major conservation areas

The rugged and inhospitable nature of the sandstone environments restrict development. As a result, many areas of natural vegetation remain, giving bushland surroundings to many Sydney suburbs. The importance of this urban bushland is now appreciated and a body of knowledge concerned with its management and protection is being developed by the various land management organisations together with input from research and teaching institutions and community groups.

A brief description of the vegetation of the major national parks and other conservation areas is given below. Plant species lists for most of these areas are compiled in Table 4, but it should be noted that the information available for different areas varies considerably. Many of the smaller urban bushland areas are described in Benson and Howell (1990a).

Angophora Reserve and Hudson Park

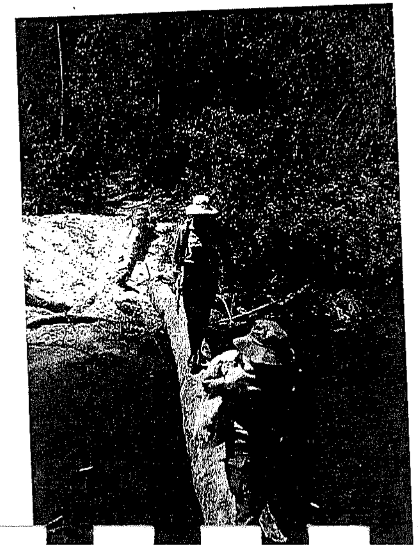
This is a reserve of about 18 ha at Avalon on Hawkesbury Sandstone capping and underlying Narrabeen Group (Newport Formation) interbedded shales and sandstones. Vegetation is *Angophora costata–Eucalyptus gummifera* woodland (about 8 ha), with a small area of fern swamp, *Gleichenia dicarpa* and sedge swamp, with *Lepyrodia scariosa* and *Epacris microphylla* on the Hawkesbury Sandstone; *Eucalyptus maculata* open-forest (about 8 ha) and a small area (about 0.5 ha) of *Livistona australis* palm stands on the Narrabeen Group soils (Smith & Smith 1993). A total of 293 vascular plant species have been recorded (227 native and 66 exotic), and the reserve includes the only known site around Sydney for the rare *Arthrochilus prolixus* (Smith & Smith 1993).

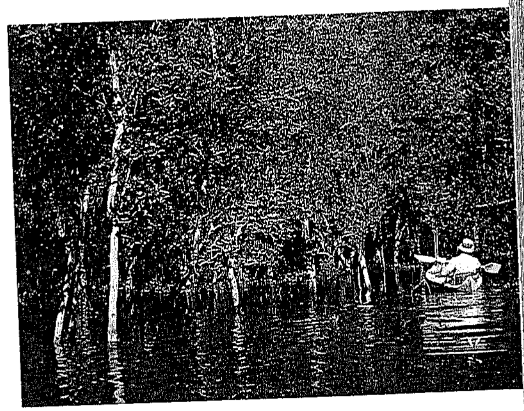
Barrenjoey Head

Barrenjoey Head at the southern entrance to Broken Bay is an isolated headland with a capping of Hawkesbury Sandstone overlying Narrabeen Group shales and sandstones. It is connected to the mainland by the thin strip of sand of Palm Beach. Woodland with *Eucalyptus botryoides* and *Banksia integrifolia* covers at least half of the headland extending from shore to ridgetop, particularly on the western half. Shrubs commonly found in the woodland understorey are *Pultenaea ferruginea* var. *deanei, Pultenaea daphnoides, Oxylobium ilicifolium* and *Jacksonia scoparia*.

Pockets of rainforest with *Acmena smithii* occur on shale soils in sheltered southerly aspects. Other species include *Backhousia myrtifolia, Syzigium oleosum, Pararchidendron pruinosum, Rhodomyrtus psidioides* (southern limit), *Diospyros australis, Guioa semiglauca, Cassine australis* var. *australis* and *Marsdenia rostrata*. *Tristaniopsis collina* is frequent in sheltered places and in the woodland, with occasional occurrences in heathland sheltered by large sandstone outcrops.

Allocasuarina distyla heathland occurs on clay soils on the upper parts of the headland and on the eastern end where it is more stunted. Common shrubs include *Hakea gibbosa, Acacia myrtifolia, Banksia ericifolia, Leptospermum trinervium, Lasiopetalum*





Figures 20 & 21. Conservation reserves have various forms of access that allow visitors to explore and experience the Sydney bush.

macrophyllum, *Isopogon anethifolius* and *Kunzea ambigua*. The small shrub *Mirbelia rubiifolia* and the sedge *Schoenus melanostachys* are very common in the lower stratum. *Leptospermum laevigatum* shrubland occurs on the lower southern slopes.

Berowra Valley Bushland Park

Berowra Valley Bushland Park (3880 ha in area) includes bushland along Berowra Creek and its tributaries from Pennant Hills to Berowra Waters. It was established as a reserve in its present form in 1987, but the southern part (640 ha south of Hornsby Rifle Range) has been a reserve, Elouera Bushland Natural Park, since 1964. The Park is administered by Hornsby Shire Council.

Smith and Smith (1990) carried out a detailed survey of the Park. They distinguished 17 plant communities; forest, woodland, heath and swamp communities associated with the dominant Hawkesbury Sandstone geology; taller eucalypt and low rainforest associated with more fertile soils; and eucalypt, *Casuarina*, mangrove and saltmarsh communities associated with the wider, tidal reaches of Berowra Creek. Several communities in the Park are poorly represented in other reserves. Especially important are taller forest communities characterised by *Eucalyptus saligna* and *Eucalyptus pilularis*.

Berowra Valley Bushland Park has a very rich flora, as is typical of vegetation on Hawkesbury Sandstone. A total of 517 native vascular plant species have been recorded. Ten of these species are on the national list of rare and threatened plants, including three species classified as vulnerable: *Eucalyptus camfieldii*, *Darwinia biflora* and *Tetratheca glandulosa*. Another four rare or threatened species have been recorded nearby and may also occur in the Park.

Bicentennial Park/Homebush Bay

Originally, Homebush Bay had the largest expanse of estuarine vegetation in Sydney Harbour, but this has been gradually reduced by extensive landfill projects beginning in the 1890s (Kachka 1993, Clarke & Benson 1988). Mangrove and some other wetland vegetation has been protected in Bicentennial Park, where boardwalks and an active environmental awareness program make these areas accessible. However, more important and undisturbed wetlands with extensive areas of saltmarsh, including populations of *Wilsonia backhousei*, *Halosarcia pergranulata* var. *pergranulata* and *Lampranthus tegens*, together with remnant Turpentine–Ironbark Forest (Map unit 9o) survive on military land at Silverwater. These areas are important because they have been protected from human disturbance — reports indicate a particularly high and abundant reptile fauna in the woodland — and should be maintained as limited access areas.

Botany Bay National Park (Cape Banks)

Vegetation at Cape Banks, Henry Head and La Perouse is part of Botany Bay National Park. Vegetation is mainly heath and open-forest on Hawkesbury sandstone,

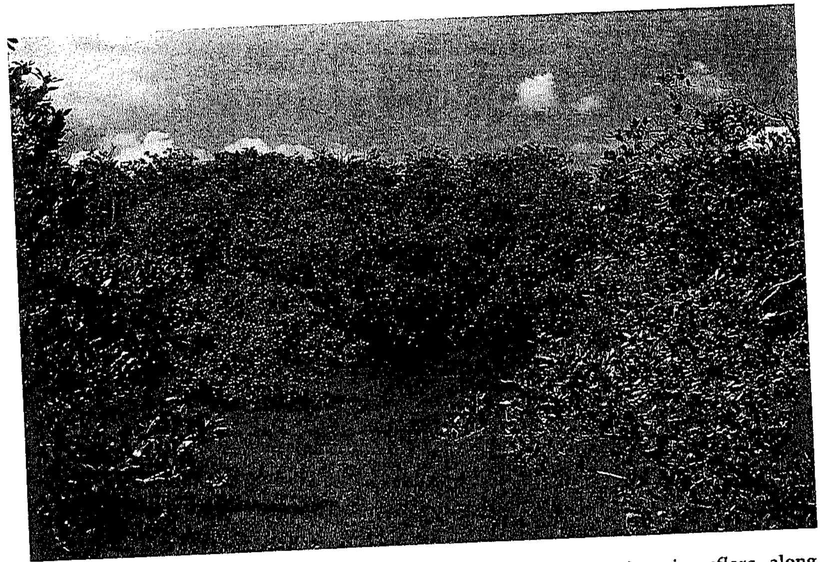


Figure 22. Mangroves, *Avicennia marina*, and saltmarsh, *Sarcocornia quinqueflora*, along Haslems Creek in Homebush Bay (map unit 4a). It is hoped that these will be retained during the development of the Olympic Games site.

and open-scrub of *Banksia integrifolia* on beach sand (Armstrong, Benson & Coveny 1976). The area is rich in native species, though the exotic weed, *Chrysanthemoides monilifera*, originally introduced to stabilise sand dunes, is a major problem in some areas. A small remnant of Pleistocene sand at Jennifer Street, La Perouse has *Banksia aemula* heath as well as important associated wetland vegetation, and has been recommended for conservation.

Bouddi National Park

Bouddi National Park is situated on the northern headland of Broken Bay, 45 km north of Sydney. Its vegetation has been described and mapped by McRae (1990), who described 15 plant communities related to habitat elements such as geology, geomorphology, climate and soil. The main components of the geology are Hawkesbury Sandstone and Narrabeen Series and the Park is important for the extensive areas of coastal vegetation on the latter. These include coastal grassland, heath and woodland and palm-dominated open-forest. A good account of the landscape, natural history and landuse is given in Strom (1986).

Brisbane Water National Park

The vegetation of Brisbane Water National Park has been described and mapped by Benson, J.S. and Fallding (1981). They described 15 plant communities; low open-forest, low open-woodland and open-woodland with dry or moist shrub understorey

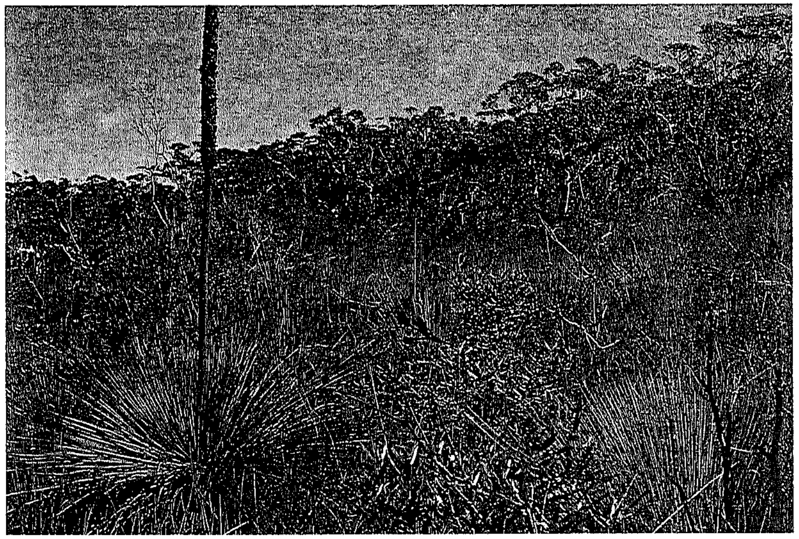


Figure 23. The effect of different drainage conditions can be seen here in Brisbane Water National Park — sedgeland on shallow poorly-drained soil in the foreground contrasts with woodland on better-drained soil.

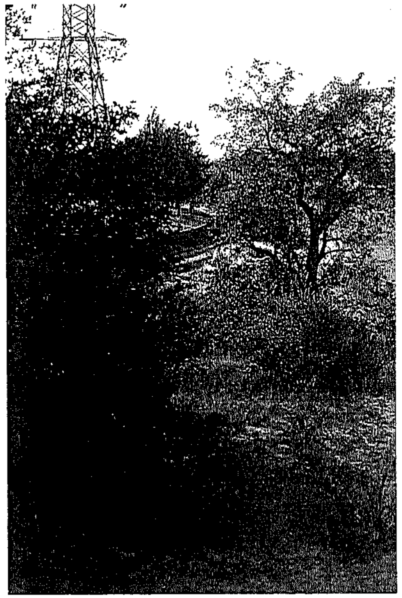


Figure 24. There is a small remnant of Turpentine Ironbark Forest on the clay soil above Cooks River at Campsie — a rare survivor of native vegetation along the River.

on the ridges and slopes of Hawkesbury Sandstone; open-forest on cooler aspects and on Narrabeen Group outcrops along the watercourses; sedgelands and open-scrub in higher, poorly-drained sites; coastal heath and rock outcrops with pockets of heath; closed-forest with rainforest species in valleys or along creeks, mainly on the Narrabeen group; and mangroves and rushland along tidal watercourses. A total of 657 native and exotic plant species were recorded. This includes ten considered to be rare or at risk.

Cooks River–Wolli Creek Valley

Though not primarily conserved as a nature reserve, remnants of native vegetation in Cooks River–Wolli Creek are the only remaining natural areas in inner south-western Sydney and need careful management. Cooks River includes very small localised patches of mangroves and reedland of *Phragmites australis*, and remnants of Turpentine–Ironbark Forest at Campsie (Benson 1992b) (see also Map unit 9o description). Vegetation at Wolli Creek includes eucalypt forest and heath on Hawkesbury Sandstone, freshwater marsh, saltmarsh and mangroves (Benson 1978b, Robinson 1986, 1987, Brown et al. 1988).

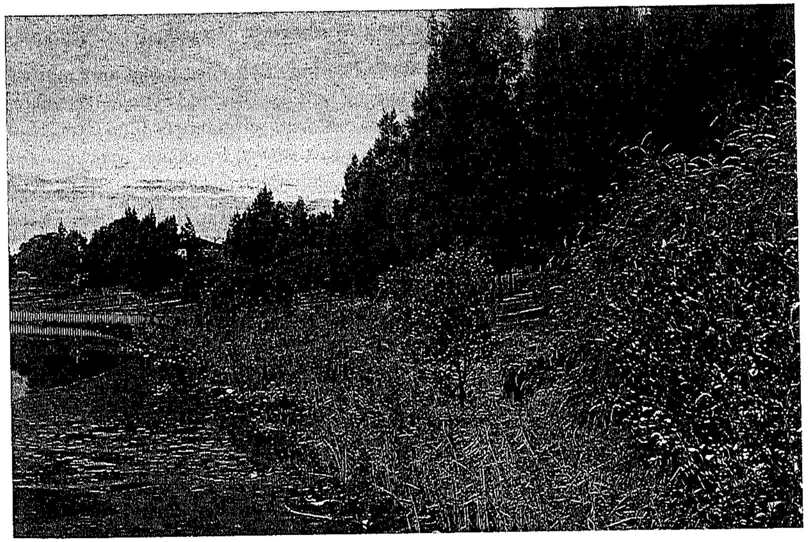


Figure 25. The Cooks River is mainly confined to a concrete or iron-lined channel, but here at Canterbury native reeds *Phragmites australis* grow on the bank. The rehabilitation of other bank sections using native species and the development of semi-natural vegetation with adjacent tree and shrub planting will provide much-needed wildlife habitat along the River and improve its appearance.

Figure 26. Creeks in sandstone gullies such as this in Garigal National Park provide sheltered and pleasant conditions. *Tristaniopsis laurina* is a frequent streamside species.

Cumberland and Darling Mills State Forests

These two forest areas together with the adjoining IBM Forest, demonstrate the influence of soil and geological changes on vegetation. Cumberland State Forest (40 ha) at West Pennant Hills has Wianamatta Shale soils with remnants of Blue Gum High Forest (Map unit 6b). Tree species include *Eucalyptus saligna, Eucalyptus paniculata, Eucalyptus tereticornis, Eucalyptus acmenoides* and *Angophora floribunda*. Darling Mills State Forest (50 ha) at North Rocks, 2 km further south and adjacent to Excelsior Park is dominated by massive outcrops of Hawkesbury Sandstone forming significant cliff faces, rock ledges and overhangs with a succession of sandstone terraces and escarpments. Vegetation here includes dry woodland of *Angophora bakeri* and *Eucalyptus gummifera* with shrubs of *Acacia linifolia, Leptospermum polygalifolium, Banksia serrata* and *Hakea sericea* as well as heath. Moist forest with *Eucalyptus pilularis–Eucalyptus saligna* and *Eucalyptus pilularis–Angophora costata–Eucalyptus piperita* is restricted to alluvial flats and sheltered hillsides. Details of these areas are given in the Forestry Management Plan (Forestry Commission of NSW 1984).

Dalrymple–Hay Nature Reserve

The need to conserve some remnants of such an impressive plant community as the Blue Gum High Forest (Map unit 6b) was recognised as far back as the 1930s when most of the forest had already been destroyed for farming or suburbs. At that time the NSW Forestry Commission planned to subdivide part of their Dalrymple–Hay State Forest at St Ives, but as a result of local action this Forest was preserved and later transferred to the National Parks and Wildlife Service as the Dalrymple–Hay

Nature Reserve. This Reserve has an area of 11 ha of *Eucalyptus pilularis, Eucalyptus paniculata, Angophora costata* and *Syncarpia glomulifera* trees with a shrub understorey on higher ground, and *Eucalyptus saligna* with a fern understorey along the main watercourse (Benson & Keith 1984a).

Garigal National Park — Narrabeen Lagoon catchment

The vegetation of Garigal National Park (Narrabeen Lagoon catchment) (approx. 820 ha) has been recently described and mapped by Sheringham and Sanders (1993) in an excellent report for the NSW National Parks and Wildlife Service. They describe and map 21 plant communities. These include extensive areas of heathland, woodland and open-forest on Hawkesbury Sandstone (Map units 10ar, 10ag, 21g) as well as much more limited and restricted areas of forest on remnant shale sites (9sf) and freshwater and estuarine reedland herbfield, paperbark swamp and swamp forest (27a).

Sheringham and Sanders (1993) found that differences in the major geological types, alluvial–sedimentary, were the main environmental influence on vegetation distribution, but that differences between shale and sandstone were less important. For vegetation on alluvial areas the depth, period of inundation and salinity of water are the major factors influencing species composition. The types with the highest conservation significance were the freshwater wetlands and swamps along the Deep Creek floodplain, and shale and lateritic forests restricted to the ridge along Forest Way and Mona Vale Road. Many of the wetlands are outside the Park boundary and have been recommended for addition to the Park as a matter of priority.

A list of over 600 species (both native and exotic) has been compiled for the National Park (Narrabeen Lagoon catchment) and surrounding Crown lands including species of national significance — *Grevillea caleyi, Tetratheca glandulosa, Eucalyptus luehmanniana, Lomandra brevis, Lomandra fluviatilis, Platysace stephensonii, Darwinia procera, Persoonia hirsuta, Genoplesium baueri, Hibbertia nitida* and *Angophora crassifolia* (Sheringham & Sanders 1993).

Garigal National Park — Middle Harbour Creek catchment

The vegetation types represented within the Middle Harbour Creek part of Garigal National Park (former Davidson State Recreation Area) include forest, woodland, heathland, scrubland, mangrove and saltmarsh, and vegetation of creek banks containing mesic species. Vegetation of particular importance includes areas of Coastal Sandstone Heath (map unit 21g), now scarce in Sydney due to urban spread. Examples may be seen on ridgetop areas of the Park — along the Cook St trail, parallel to Wakehurst Parkway above Bantry Bay, at the end of Matthews St, Davidson, and along part of the Stone Parade track to the Cascades. There is a significant stand of the rare mallee *Eucalyptus luehmanniana* in woodland on a south aspect slope beneath The Bluff.

There are also small remnants of ridgetop vegetation on the shale–sandstone transition, with soils rich in ironstone gravels. These remnants contain relatively uncommon species such as *Boronia rigens, Baeckea ramosissima* and *Leucopogon appressus*.

Vegetation along Bare Creek and upper Middle Harbour Creek includes the nationally significant species *Lomandra fluviatilis* and what is probably the largest known population of *Leptospermum deanei*. Further down Middle Harbour Creek are *Hibbertia nitida* and *Darwinia procera*. In upper-level creek sites, with more exposure to sunlight, are relatively uncommon plants with specific habitat requirements such as *Symphionema paludosum* and *Sprengelia incarnata*.

Gullies contain locally uncommon plant species such as *Cymbidium suave*, *Leucopogon lanceolatus* and *Boronia thujona* on the slopes. *Dracophyllum secundum*, *Rimacola elliptica* and *Epacris crassifolia* are found in crevices of rocky overhangs. Closer to the creeks are *Stenocarpus salignus*, *Lomatia myricoides*, *Drosera binata*, *Leucopogon amplexicaulis*, *Lycopodium deuterodensum*, *Blechnum ambiguum*, *Austromyrtus tenuifolia*, and *Hymenophyllum cupressiforme*. The very restricted shrub *Haloragodendron lucasii* occurs on an upper slope near Barra Brui.

Mangrove and saltmarsh are found in Bantry Bay and in Middle Harbour Creek and along tributaries from Roseville Bridge, upstream.

Georges River National Park

Hawkesbury Sandstone outcrops along the foreshores of the Georges River below East Hills. Downstream from here the river has the typical 'drowned valley' appearance characteristic of Sydney Harbour and Broken Bay. Georges River National Park includes foreshores downstream from Salt Pan Creek. Natural vegetation here is mostly woodland of *Angophora costata*, *Eucalyptus gummifera* and *Eucalyptus punctata*. On drier slopes are *Angophora bakeri* and *Allocasuarina littoralis*, while small patches of heath with *Angophora hispida* are found on some of the gravelly ridge-tops (Benson & Howell 1990a). Salt Pan Creek has areas of mangroves and saltmarsh.

Katandra Bushland Sanctuary

Katandra Bushland Sanctuary is a small reserve (11.5 ha) at Ingleside managed by a Department of Conservation and Land Management trust. Geology is Hawkesbury Sandstone with minor shale lenses, the aspect is easterly and the vegetation is mostly open-forest with closed-forest along the major creek lines. Main tree species include *Angophora costata*, *Eucalyptus gummifera*, *Eucalyptus piperita*, *Eucalyptus punctata* and *Eucalyptus umbra* (Map unit 10ag). The vegetation is generally moist and sheltered and includes species that are generally uncommon in Sydney including *Eucalyptus scias*, a tall tree in this habitat, the rainforest trees *Cryptocarya glaucescens*, *Cryptocarya microneura* and *Endiandra sieberi*, the shrubs *Bertya brownei*, *Boronia mollis*, *Boronia thujona*, *Prostanthera denticulata*, *Eupomatia laurina*, *Wilkiea huegeliana*, *Maytenus silvestris*, *Oxylobium ilicifolium*, *Correa reflexa*, and a vine *Passiflora cinnabarina*. *Cetatopetalum apetalum* is common along the creek lines with *Trochocarpa laurina*, *Livistona australis*, the tree fern *Cyathea australis* and the cycad *Macrozamia communis*. The uncommon, primitive fern *Tmesipteris truncata* grows on trunks of *Todea barbara*, while *Psilotum nudum* is often found in rock crevices, and *Hymenophyllum cupressiforme* and *Grammitis billardieri* are found on damp rock surfaces. There are a large number of orchids including several species of *Acianthus*, *Pterostylis* and *Cryptostylis*, also *Gastrodia* *sesamoides*, *Chiloglottis reflexa*, *Corybas aconitiflorus*, *Dendrobium speciossisima* and *Dendrobium linguiforme* on rocks, *Lyperanthus suaveolens* on damp rocks and *Cymbidium suave* in trees.

On the upper slope are sandstone woodland species including *Banksia ericifolia* and *Banksia serrata*, *Xanthorrhoea media*, *Xanthorrhoea arborea*, *Phebalium dentatum* and *Acacia oxycedrus*. With *Gahnia clarkei*, three species of *Gleichenia* form dense thickets in a hanging swamp.

Ku-ring-gai Chase National Park

Ku-ring-gai Chase National Park (14 709 ha) is one of the major national parks of the predominantly sandstone Hornsby Plateau north of Sydney.

The nature and distribution of the vegetation is strongly related to geology, soil, drainage and aspect. Thomas and Benson (1985a) recognised 21 plant communities. There is considerable variation within some communities and intergradation between communities is a common feature. A floristic analysis of the vegetation has been carried out by Outhred et al. (1985).

As a conservation area, Ku-ring-gai Chase National Park is particularly important for its large area of relatively undisturbed vegetation of the type that gives Sydney bushland its distinctive character. It is also important for conserving vegetation types that are significant in a regional and local context. These tend to be of limited size and are associated with unusual or remnant geological and topographical

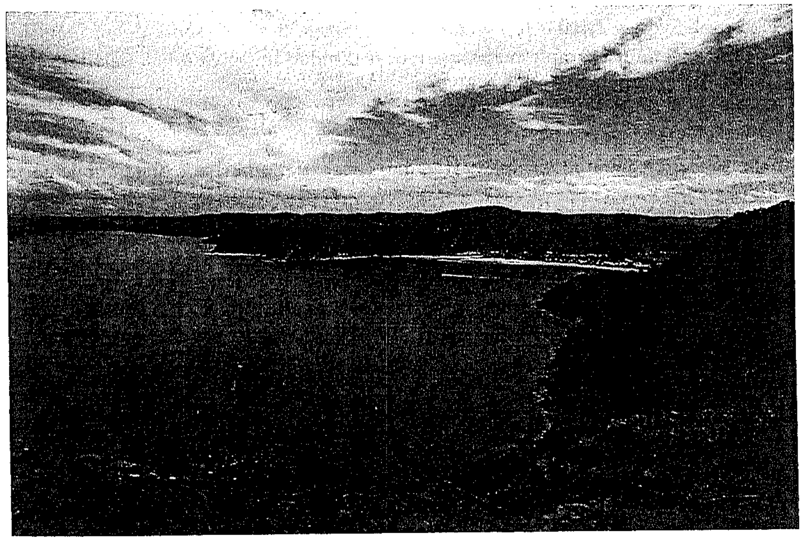


Figure 27. Extensive areas of sandstone country with woodland, heath and forest make up Ku-ring-gai Chase and Brisbane Water National Parks — here looking from Warrah Lookout towards Patonga Beach.

features e.g. Duffys Forest vegetation (map unit 9sf) and *Eucalyptus maculata–Eucalyptus paniculata* open-forest (part of map unit 9g).

A total of 566 native species from 119 families were recorded by Thomas and Benson (1985a), though Rose (1982) recorded 975 species, both native and exotic, over a longer period. Significant species recorded in Ku-ring-gai Chase include *Lomandra brevis, Genoplesium baueri, Leucopogon amplexicaulis, Austromyrtus tenuifolia, Darwinia biflora, Darwinia procera, Eucalyptus leuhmanniana, Eucalyptus squamosa, Grevillea caleyi, Boronia fraseri, Rulingia hermannifolia, Tetratheca glandulosa, Cryptostylis hunterana, Eucalyptus camfieldii, Blechnum ambiguum* and *Kunzea rupestris* (Thomas & Benson 1985a).

Fire is an important factor affecting vegetation in many Sydney bushland areas. Many species have adaptive mechanisms that enable them to survive individual fires, but frequent fires with only short periods between them may lead to possible long-term changes to vegetation with some species being lost; fire-free periods of at least 10 years are desirable for much of the vegetation to allow replenishment of plant seedbanks etc. (Thomas & Benson 1985a, Benson 1985).

As for other 'urban' national parks, weed invasion in Ku-ring-gai Chase is a serious problem, and is associated with run-off from urban development, areas of past habitation within the Park, tracks, watercourses, border areas, specific areas of high public usage and some small areas of undisturbed bushland.

The map showing the vegetation of Ku-ring-gai Chase National Park and the adjacent Muogamarra Nature Reserve prepared by Thomas and Benson (1985a) has been reproduced without change at a reduced scale (1:40 000 scale, 2 cm = 1 km), on the back of the Sydney 1:100 000 Vegetation Map Sheet. It shows more detail than the 1:100 000 sheet, for example map unit 10ar is divided into five units. Relationships between the two maps are given in Table 3.

Table 3. Plant communities in Ku-ring-gai Chase National Park and Muogamarra Nature Reserve

Summarised descriptions give map code, structure, habitat, geology and dominant species based on Thomas and Benson, 1985, *Vegetation survey of Ku-ring-gai Chase National Park* (Royal Botanic Gardens Sydney). Code in brackets at end shows relevant map unit for Sydney 1:100 000 map sheet.

1 Closed-forest
Tristaniopsis laurina, Ceratopetalum apetalum
Gully Rainforest in sheltered gullies close to sea level, Hawkesbury Sandstone soils **(10ag)**.

2 Low closed-forest/Closed-forest with emergent trees
Acmena smithii, Glochidion ferdinandi, Livistona australis, emergents —*Eucalyptus botryoides, Angophora floribunda*
Rainforest with emergent eucalypts. Sheltered slopes, mostly western Pittwater, Narrabeen Group soils **(9h)**.

3 Tall open-forest/Open-forest
Eucalyptus agglomerata, Angophora floribunda, Allocasuarina torulosa
Confined to breccia in Campbells Crater **(6c)**.

4 Open-forest
Eucalyptus paniculata, Eucalyptus umbra, Eucalyptus scias, Syncarpia glomulifera, Angophora floribunda
Clay soils from weathered volcanic dyke at West Head **(6c)**.

5 Open-forest
Eucalyptus maculata, Eucalyptus paniculata, Syncarpia glomulifera, Allocasuarina torulosa
Western Pittwater, on Narrabeen Group shales **(9g)**.

6 Open-forest
Angophora floribunda, Eucalyptus paniculata, Eucalyptus botryoides, Eucalyptus scias, Syncarpia glomulifera, Allocasuarina torulosa
Sheltered slopes, Western Pittwater, Narrabeen Group shales and sandstones **(9h)**.

7 Open-forest
Angophora floribunda, Eucalyptus punctata, Allocasuarina torulosa
Footslopes above saltwater estuaries and foreshores of Cowan Creek, Coal and Candle Creek, Smiths Creek and Hawkesbury River. Mostly Narrabeen Group **(9h)**.

8 Open-forest
Eucalyptus pilularis, Eucalyptus resinifera, Angophora costata, Syncarpia glomulifera
Upper Cockle Creek valley on Wianamatta Shale soils **(9o)**.

9 Open-forest
Eucalyptus piperita, Angophora costata, Eucalyptus gummifera, Eucalyptus umbra, Syncarpia glomulifera
Sheltered aspects on slopes, particularly steep south-facing slopes, Hawkesbury Sandstone soils including podsols **(10ag)**.

10A Open-forest
Eucalyptus capitellata, Eucalyptus gummifera, Eucalyptus sieberi, Eucalyptus haemastoma
Along Mona Vale Road on 'lateritic' soils from shale lenses now exposed as cappings on plateaus over Hawkesbury Sandstone **(9sf)**.

10B Open-forest/Low open-forest
Eucalyptus sieberi, Eucalyptus gummifera, Eucalyptus sparsifolia, Eucalyptus haemastoma
At Duffys Forest on 'lateritic' soils from shale lenses now exposed as cappings on plateaus over Hawkesbury Sandstone **(9sf)**.

11 Low open-forest
Eucalyptus racemosa, Eucalyptus gummifera, Eucalyptus sparsifolia, Eucalyptus sieberi
On flat ridgetops e.g. Windybanks Ridge, on Hawkesbury Sandstone with yellow-earth soils, clay sub-soils and ironstone fragments **(10ar)**.

12 Low open-forest with patches of Grassland
Allocasuarina torulosa, Allocasuarina littoralis, Banksia integrifolia, emergent trees: *Angophora costata, Eucalyptus botryoides*
Exposed sites on headlands with clay soils from the Narrabeen Group **(21a)**.

13 Woodland
Angophora costata, Eucalyptus gummifera, Eucalyptus umbra, Allocasuarina littoralis and (west of Cowan Creek) *Eucalyptus eximia*
Moderate to steep slopes, exposed aspects on Hawkesbury Sandstone **(10ar)**.

14 Low woodland
Eucalyptus camfieldii, Eucalyptus haemastoma, Eucalyptus gummifera
Clay soil with ironstone fragments on Hawkesbury Sandstone. Very restricted, West Head Road/ Elvina Bay Track **(10ar)**.

15 Low woodland/Low open-woodland

Eucalyptus gummifera, Eucalyptus haemastoma, Eucalyptus sparsifolia, Eucalyptus eximia (west of Cowan Creek), *Angophora bakeri* (in Muogamarra Nature Reserve). Low slope plateau areas: crests, spurs and upper slopes on Hawkesbury Sandstone **(10ar)**.

16 Low open-woodland (mallee)

Eucalyptus luehmanniana

Seepage zones on upper slopes with southerly aspects on Hawkesbury Sandstone. Uncommon **(10ar)**.

17 Closed scrub/Scrub-heath

Banksia ericifolia, Hakea teretifolia, Allocasuarina distyla, Leptospermum trinervium, Angophora hispida, emergents — *Eucalyptus haemastoma, Eucalyptus gummifera*

Poorly-drained areas on the plateaus, low slope areas on ridges, hillsides and sandstone benches and thin skeletal soils on ridgetops. Hawkesbury Sandstone **(21g)**.

18 Pockets of Heath on rocky outcrops

Baeckea brevifolia, Baeckea diosmifolia, Kunzea capitata, Calytrix tetragona, Darwinia fascicularis subsp. *fasicularis, Allocasuarina distyla*

Exposed rock platforms with shallow depressions, Hawkesbury Sandstone **(21g)**.

19 Tall open-scrub

Avicennia marina, Aegicerus corniculatum

Mangroves along tidal watercourses and mud flats. Mainly limited to Upper Cowan Creek, Smiths Creek, Cockle Creek and Porto Bay, Kimmerakong Bay, Joe Crafts Bay and Peats Bight **(4a)**.

20 Reedland/Rushland and *Casuarina* Woodland

Juncus kraussii, Phragmites australis, Sarcocornia quinqueflora, Baumea juncea, Sporobolus virginicus, Casuarina glauca

Alluvial flats associated with tidal creeks, on landward side of Mangroves (Community 19) **(4a)**.

21 Sedgeland/Shrubland

Gahnia sieberiana, Empodisma minus, Leptocarpus tenax, Schoenus brevifolius, Gymnoschoenus sphaerocephalus, Xyris operculata, shrubs — *Banksia robur, Sprengelia incarnata, Viminaria juncea, Callistemon citrinus*

Areas of impeded drainage with a consistently high watertable, Hawkesbury Sandstone **(21g)**.

Lane Cove River National Park

The Lane Cove River has incised a narrow valley through Ashfield Shale and Hawkesbury Sandstone. Since the rise in sea level about 6 000 years ago, the river and its tributaries have deposited alluvium in the lower river and estuary. Microclimatic variations resulting from differences in solar radiation due to aspect, slope and horizon factors have a major role in influencing vegetation patterns within various landscape types.

Lane Cove River National Park (formerly State Recreation Area) (400 ha in area) occupies a 10 km strip along the Lane Cove River from Browns Waterhole to Fullers Bridge. Surrounded by suburbs, it is probably one of the most intensively used bushland parks in Sydney.

Historical changes affecting fire regimes and vegetation patterns in the Lane Cove valley, particularly since the arrival of Europeans, have been studied by McLoughlin (1985) and Clark and McLoughlin (1986). The present vegetation of the National Park has been described by Clarke and Benson (1987), who recognise 15 plant

communities and record the occurrence of approximately 360 native species. Species of significance include *Darwinia biflora, Leptospermum deanei, Eucalyptus squamosa, Austromyrtus tenuifolia, Epacris crassifolia, Boronia polygalifolia* and *Leucopogon amplexicaulis.*

The lower valley is characterised by wide alluvial flats that are often intertidal and saline. Vegetation types include mangrove, saltmarsh and rushland. Although the alluvial deposits along the river have always been high in nutrient status they have probably been significantly enriched by run-off and siltation from urbanisation. Alluvial deposits become extensive in the middle section of the river where minor floodplains occur. Vegetation types include tall forest of *Eucalyptus pilularis–Eucalyptus saligna* (Map unit 6b) and *Eucalyptus pilularis–Eucalyptus piperita–Syncarpia glomulifera* (Map unit 10ag). Flooding of the Lane Cove River is a major factor influencing the alluvial vegetation, with minor floods depositing fine silt and weeds onto river flats.

Lower slopes and hills below Ashfield Shale have Hawkesbury Sandstone as their parent material and consist mainly, though not exclusively, of coarse sandstone. Minor shale and laminite lenses occur. These produce benches and breaks in the boulder-strewn landscape. Nutrient deficient lithosols are the main soil type on Hawkesbury Sandstone, although deeper yellow podzolic soils and red podzolic soils may develop on shale lenses. Open-forest of *Angophora costata–Eucalyptus piperita–Eucalyptus gummifera*, closed shrubland of *Banksia ericifolia–Leptospermum trinervium–Angophora hispida*, riparian shrubland of *Tristaniopsis laurina–Callicoma serratifolia–Lomatia myricoides* and woodland of *Eucalyptus racemosa–Eucalyptus gummifera–Allocasuarina littoralis* (Map unit 10ar) occur on these Hawkesbury Sandstone soils. The nutrient levels in some of these soils have been increased by urban run-off (Clements 1983).

Wianamatta Group Ashfield Shale (laminite and dark grey siltone) occurs on upper ridges, forming an undulating landscape with gentle slopes. Soils vary between brown and red podzolics on upper slopes to red and yellow podzolics on lower slopes and valleys. Open-forest of *Eucalyptus resinifera–Syncarpia glomulifera* (Map unit 9o) occurred here but has been mostly cleared. Numerous shale fragments near the surface of these soils are often a feature where they overlie Hawkesbury Sandstone.

As an area of natural vegetation containing this variety of habitats and plant communities within the suburban context, Lane Cove provides environmental experiences and education for a significant local and regional population. The range of landscapes in Lane Cove River National Park differ from those in the national parks of the upper Hornsby plateau and the Woronora Plateau; in particular the alluvial valley soils have more clay influence from the Wianamatta Shale of the surrounding ridgetops. With the added influence of the higher rainfall at this location, these valleys support types of tall forest now rare in the metropolitan area.

Lion Island Nature Reserve

Lion Island (8 ha), situated at the entrance to Broken Bay, is similar geologically to the nearby Brisbane Water National Park, with a Hawkesbury Sandstone capping on the eastern end and strata of the underlying Narrabeen Group exposed else-

Figure 28. Woodland with the twisted limbs of *Angophora costata* and understorey of *Xanthorrhoea arborea* on Lion Island in Broken Bay.

where. The main vegetation on the eastern end is low woodland of *Angophora costata* and *Eucalyptus botryoides*, with shrubs of *Banksia serrata*, *Exocarpos cupressiformis*, *Xanthorrhoea arborea*, *Platysace lanceolata*, *Hakea sericea*, *Dodonaea triquetra* and *Acacia ulicifolia* (Benson 1981a).

At the western end of the island is low open-forest of *Banksia integrifolia* and *Allocasuarina littoralis*. On more exposed sites this grades into scrub with *Leptospermum laevigatum* and *Banksia integrifolia*. The exotic *Lantana camara* is common in these situations.

On scree slopes at the eastern end of the island and exposed to the ocean is herbland with *Commelina cyanea*, *Lobelia alata* and *Dichondra repens*. Shrubs of *Westringia fruticosa* are found in cracks between large sandstone boulders and higher up in cracks and ledges on the cliff faces. Benson (1981a) gives a species list for the island.

Long Island Nature Reserve

Long Island Nature Reserve (73 ha), adjacent to Brooklyn, is a long narrow east-west oriented ridge and has similar vegetation to other Hawkesbury Sandstone islands such as Spectacle Island, although it has very little plateau vegetation.

Manly–Warringah War Memorial Park

Manly-Warringah War Memorial Park (480 ha), managed by Warringah Shire Council, is mostly catchment of Manly Reservoir and is surrounded by the suburbs of Frenchs

Forest, Allambie Heights, North Manly and Balgowlah; Wakehurst Golf Course and Garigal National Park. The geology is Hawkesbury Sandstone with some shale lenses. Much of the vegetation is woodland of *Eucalyptus gummifera* and *Eucalyptus haemastoma*; *Angophora crassifolia*, a small tree or mallee found only in the eastern parts of the Hornsby Plateau, is in low woodland near Frenchs Forest and there are small patches of *Eucalyptus obstans* in heath near Allambie Heights. On shallow soil on the ridges is heathland (Map unit 21g); shrubs are *Leptospermum trinervium*, *Darwinia fascicularis*, *Kunzea ambigua*, *Angophora hispida*, with *Actinotus helianthi*, *Blandfordia nobilis*, *Leucopogon* and *Epacris* species. *Allocasuarina distyla* and *Banksia ericifolia* are dominant in taller shrubland with *Banksia oblongifolia* and *Hakea teretifolia* in poorly-drained soil. In sheltered gullies is open-forest, mainly *Eucalyptus piperita* and *Angophora costata*. Shrub species in woodland/open-forest include *Dodonaea triquetra*, *Acacia terminalis*, *Persoonia pinifolia*, *Persoonia linearis*, *Pultenaea flexilis*, *Dillwynia retorta*, *Boronia pinnata*, *Crowea saligna*, *Eriostemon australasius*, *Ceratopetalum gummiferum*, and *Telopea speciosissima*. Some species restricted to creek lines are *Tristaniopsis laurina*, *Ceratopetalum apetalum*, *Callicoma serratifolia*, *Baeckea linifolia*, *Austromyrtus tenuifolia* and an uncommon sedge *Restio tetraphyllus* subsp. *meiostachys*. An uncommon orchid *Rimicola elliptica* was recorded on a moist rock ledge. Important wetland vegetation with *Eleocharis sphacelata*, *Juncus* species, *Baumea nuda*, *Philydrum lanuginosum*, *Persicaria decipiens*, *Schoenus melanostachys*, and *Schoenus brevifolius* provides habitat for birds at the northern end of the reservoir.

Marramarra National Park

Marramarra National Park is a major reserve (11 760 ha) northwest of Sydney, between the Hawkesbury River, Old Northern Road and Berowra Creek. It is mainly Hawkesbury Sandstone plateau country with some narrow cappings of Wianamatta Shale, mostly cleared, and several volcanic necks. The area is generally drier than Ku-ring-gai Chase National Park further east.

Mangroves, *Avicennia marina* and *Aegiceras corniculatum* grow in saline conditions on mudflats in bays and tidal stretches of creeks. These often have *Duboisia myoporoides* on the banks. Creek vegetation above the tidal limit, includes *Tristaniopsis laurina*, *Backhousia myrtifolia*, *Trochocarpa laurina*, *Leptospermum grandifolium* and occasionally *Leptospermum deanei*. The rare local endemic *Asterolasia elegans* is found on sheltered slopes near creeks, though *Asterolasia correifolia* is more common here. *Boronia fraseri*, *Boronia anemonifolia*, *Darwinia peduncularis*, *Prostanthera rhombea*, *Zieria involucrata*, and *Lasiopetalum macrophyllum* occur occasionally on creekbanks.

In gullies approaching Coba Bay, possibly with volcanic influence, there is tall open-forest of *Eucalyptus agglomerata*, with *Angophora floribunda* extending to the flats. *Platysace clelandii* is occasional on lower sheltered slopes here with *Allocasuarina torulosa*. In gullies, and on slopes with east to southerly aspects, is open-forest of *Eucalyptus piperita*, *Angophora costata* and *Allocasuarina littoralis* (map unit 10ag) with *Eucalyptus gummifera* and *Eucalyptus sparsifolia* in low open-forest on the edge of ridges (map unit 10ar).

Vegetation on dry ridges (and slopes with north to westerly aspect) is low-woodland to woodland of mainly *Eucalyptus eximia* and *Eucalyptus haemastoma*, often with *Eucalyptus punctata* and *Eucalyptus gummifera*. *Hakea bakeriana* occurs in small patches in woodland on ridges, *Doryanthes excelsa* also occurs north of Canoelands Ridge. There are occasional occurrences of *Eucalyptus squamosa* and patches of *Angophora bakeri*. On rocky parts, *Eucalyptus eximia* is interspersed with low shrubland, often with patches of *Grevillea linearifolia* (narrow-leaved form) and *Dillwynia sericea*. Common shrubs are *Zieria laevigata*, *Gompholobium grandiflorum*, *Leucopogon muticus* and less commonly *Eriostemon hispidulus*. A disjunct population of the south coast species, *Dampiera scottiana* occurs in *Eucalyptus haemastoma* woodland. Populations of *Kunzea rupestris* are rare on rock platforms and *Micromyrtus blakelyi* has been found in a similar habitat. There are some rocky ridgetops in the Park but only very limited areas of heath and sedgeswamp vegetation. Marramarra National Park is an important link between the coastal sandstone vegetation e.g. in Ku-ring-gai, and the more inland vegetation of the Blue Mountains and Wollemi regions.

Muogamarra Nature Reserve

Muogamarra Nature Reserve (2 234 ha) lies north of the suburbs of Cowan and Berowra Heights, and is bounded by Berowra Creek, the Hawkesbury River, the Pacific Highway and Main Northern Railway. To the east and west lie Ku-ring-gai Chase and Marramarra National Parks respectively, while north of the Hawkesbury is Brisbane Water National Park. Muogamarra forms an integral part of the landscape of northern Sydney and conserves a significant portion of the Sydney sandstone bushland.

The vegetation of Muogamarra has been described by Thomas and Benson (1985b) and mapped with the Ku-ring-gai map (see map on back of Sydney 1:100 000 sheet). The nature and distribution of the vegetation is strongly related to geology, soil, drainage and aspect. Within Muogamarra 11 plant communities were recognised including closed-forest, open-forest, low open-forest, woodland, low woodland/low open-woodland, closed scrub/scrub-heath, pockets of heath on rocky outcrops, tall open-scrub, reedland/rushland with woodland, and sedgeland/shrubland. There is considerable variation within some communities and intergradation between communities is a common feature.

Weed invasion is generally of minor significance, with the exception of the Peats Crater area, and is restricted to a few localised sites and some general occurrences along tracks.

Over 400 species from 95 families were recorded by Thomas and Benson (1985b). Significant species include *Lomandra brevis*, *Tetratheca glandulosa*, *Boronia fraseri*, *Micromyrtus blakelyi*, *Platysace clelandii*, *Austromyrtus tenuifolia*, *Eucalyptus squamosa* and *Blechnum ambiguum*.

Spectacle Island Nature Reserve

Spectacle Island Nature Reserve (36 ha) is a small island in the Hawkesbury River, near its junction with Mooney Mooney Creek. It is about 1 200 m long and 600 m wide, up to 120 m high, and capped with Hawkesbury Sandstone which overlies Narrabeen strata that outcrop along the lower slopes. Vegetation, described by Webb (1981), is similar to that of the nearby Brisbane Water and Ku-ring-gai Chase National Parks. On the flat sandstone top of the island is open-woodland with trees of *Eucalyptus gummifera* and *Angophora costata* with an open understorey of *Imperata cylindrica* and scattered shrubs of *Banksia marginata*, *Xylomelum pyriforme*, *Gompholobium latifolium* and *Kunzea ambigua* (map unit 10ar). This extends onto the steep, upper sandstone slopes. On the lower slopes, on soils from Narrabeen strata, trees of *Angophora floribunda* with a grassy understorey predominate on the north-facing slopes, *Eucalyptus punctata* on the relatively flat western end of the island, and denser vegetation with *Acacia elata*, *Allocasuarina torulosa* and *Allocasuarina littoralis* on the steep southern slopes. There are mesic gully species at the base of the sandstone cliffs on the southern side. This is all part of the Narrabeen Slopes Forest (map unit 9h).

Sydney Harbour National Park

Sydney Harbour National Park includes a number of significant areas of vegetation associated with the Harbour foreshores and islands. Substantial areas of North Head including the former Quarantine Station, Dobroyd Head, Middle Head, Bradleys Head and Ashton Park, parts of South Head and Nielsen Park, and Shark, Clark and Rodd Islands are included, though the original bushland on the islands has generally been cleared. Many of these areas were formerly military land and include a scattering of military relics within the bushland.

Remaining vegetation is almost all on Hawkesbury Sandstone, with the soils and degree of exposure to salt-laden sea spray together determining the structure and floristic composition. Exposed sites on shallow soils particularly on North Head and Dobroyd Head have Coastal Sandstone Heath (map unit 21g) which, because of the immediate coastal influence, includes shoreline species such as *Baeckea imbricata*, *Westringia fruticosa*, *Olearia tomentosa* and *Melaleuca hypericifolia* (see Adam, Stricker et al. 1989) as well as coastal heath of *Banksia ericifolia–Darwinia fascicularis*. In more sheltered sites open-forest and woodland with *Angophora costata*, *Eucalyptus botryoides*, *Eucalyptus gummifera* occur. A very restricted patch of Coastal Dune Heath (map unit 21b) with *Eucalyptus camfieldii* (Horton 1986) occurs on North Head.

Wallumatta Nature Reserve

Wallumatta Nature Reserve is a small reserve (about 5 ha) in East Ryde that retains an example of the Turpentine-Ironbark Forest of the Wianamatta Shale in areas of moderate rainfall (i.e. 900–1100 mm p.a.). In the metropolitan area only about 0.5% of this forest remains. Wallumatta includes over 90 plant species of the shale flora with a transition zone from shale to sandstone vegetation (Benson & Keith 1984c). The nearby Field of Mars Reserve includes good areas of sandstone but very little shale vegetation.

The National Parks and Wildlife Service, in association with the Ryde–Hunters Hill Flora and Fauna Preservation Society, has established a joint committee to oversee Wallumatta. Because it is a particularly important example of Sydney's remnant vegetation it will be used mainly for education, research and nature study.

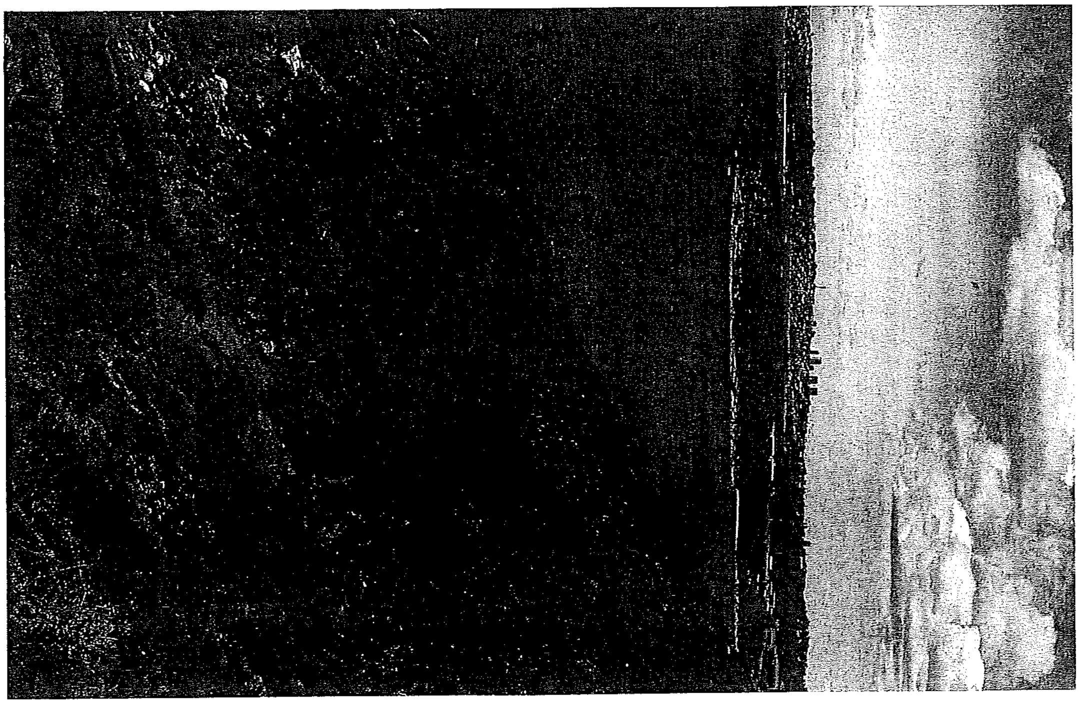
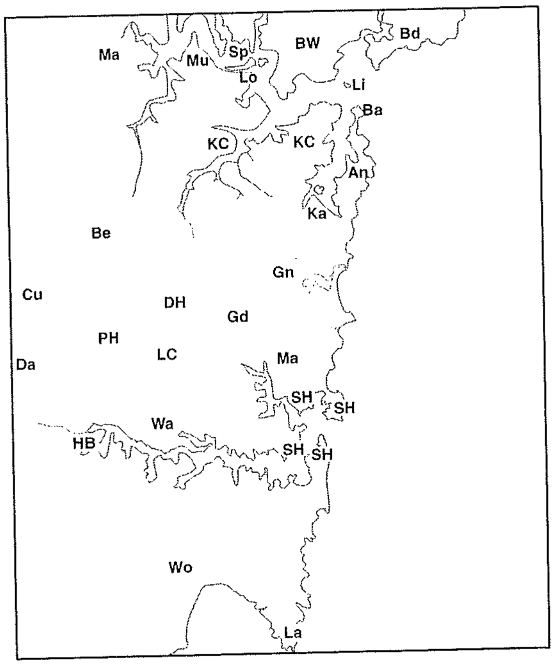


Figure 29. Heath and woodland at Dobroyd Head in Sydney Harbour National Park after an extensive fire in 1990. Periodic fire is an important factor in maintaining species composition in heathland.

Table 4. Native plant species recorded from major conservation areas in the Sydney map sheet area

Species are arranged alphabetically within families and major groups. List is based on various references (see below) with some additions by Doug Benson and Lyn McDougall. Areas are ordered north to south, with codes as follows.

Bd	Bouddi National Park (McRae 1990)
BW	Brisbane Water National Park (Benson & Fallding 1981)
Li	Lion Island Nature Reserve (Benson 1981a, McDougall 1989)
Sp	Spectacle Island Nature Reserve (Webb 1981)
Lo	Long Island Nature Reserve (Coveny & McDougall 1990)
Ma	Marramarra National Park (Benson et al. 1989, NPWS n.d., McDougall 1993)
Mu	Muogamarra Nature Reserve (Thomas & Benson 1985b)
Be	Berowra Valley Bushland Park (Smith & Smith 1990)
KC	Ku-ring-gai Chase National Park (Thomas & Benson 1985a)
Ba	Barrenjoey (McDougall 1994)
An	Angophora Reserve and Hudson Park (Smith & Smith 1993)
Ka	Katandra Bushland Sanctuary (Coveny, I.)
Gn	Garigal National Park: Deep Creek Catchment (Sheringham & Sanders 1993)
Gd	Garigal National Park: Davidson Park (McDougall & Conroy 1988–90)
Cu	Cumberland State Forest (Forestry Commission of NSW 1984)
PH	Pennant Hills Park (Beecroft Cheltenham Civic Trust 1976)
DH	Dalrymple Hay Nature Reserve (Benson & Keith 1984a)
Da	Darling Mills State Forest (FC of NSW 1984)
LC	Lane Cove National Park (Clarke & Benson 1987)
Ma	Manly Dam Memorial Park (Benson 1981)
Wa	Wallumatta Nature Reserve (Benson & Keith 1984c)
SH	Sydney Harbour National Park: includes North Head, Dobroyd Head, Bradleys Head, Nielsen Park (Holland 1980, NPWS n.d., Horton 1986)
HB	Homebush Bay (Kachka 1993)
Wo	Wolli Creek Valley (Robinson 1987)
La	La Perouse (Armstrong et al. 1976)



Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Ferns and fern allies																									
Adiantaceae																									
Adiantum aethiopicum	Bd	BW	Li		Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu		DH	Da	LC			SH		Wo	La
Adiantum formosum		BW							KC																
Adiantum hispidulum	Bd	BW					Mu	Be				Ka	Gn		Cu			Da	LC						
Adiantum silvaticum		BW							KC										LC						
Aspidiaceae																									
Polystichum australiense	Bd							Be																	
Aspleniaceae																									
Asplenium australasicum		BW							KC			Ka										SH		Wo	
Asplenium difforme			Li							Ba															La
Asplenium flabellifolium	Bd	BW	Li		Lo	Mm	Mu	Be	KC	Ba		Ka	Gn	Gd				Da	LC			SH		Wo	
Blechnaceae																									
Blechnum ambiguum		BW				Mm	Mu	Be	KC			Ka	Gn									SH			
Blechnum camfieldii	Bd	BW										Ka	Gn												
Blechnum cartilagineum	Bd	BW			Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu		DH	Da	LC			SH		Wo	La
Blechnum indicum													Gn												
Blechnum nudum		BW					Mu	Be						Gd					LC			SH			
Blechnum wattsii		BW																							
Doodia aspera	Bd	BW				Mm	Mu	Be	KC	Ba	An				Cu			Da	LC						
Doodia caudata		BW						Be	KC	Ba			Gn					Da				SH			
Cyatheaceae																									
Calochlaena dubia	Bd	BW			Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu		DH	Da	LC	Ma	Wa	SH		Wo	La
Cyathea australis		BW			Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd			DH			Ma				Wo	La
Davalliaceae																									
Arthropteris tenella									KC																
Davallia pyxidata	Bd	BW	Li		Lo	Mm	Mu	Be	KC			Ka	Gn							Ma		SH			
Dennstaedtiaceae																									
Dennstaedtia davallioides																			LC						
Histiopteris incisa		BW	Li			Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu			Da	LC	Ma		SH		Wo	La
Hypolepis muelleri		BW				Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu				LC	Ma		SH		Wo	La
Hypolepis punctata		BW																							
Pteridium esculentum	Bd	BW	Li		Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu		DH	Da	LC	Ma	Wa	SH		Wo	La
Dryopteridaceae																									
Lastreopsis decomposita	Bd	BW																							
Lastreopsis microsora		BW				Mm	Mu		KC																
Gleicheniaceae																									
Dicranopteris linearis						Mm	Mu																		
Gleichenia dicarpa	Bd	BW			Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd					LC	Ma		SH		Wo	La
Gleichenia microphylla		BW			Lo	Mm	Mu	Be	KC			Ka	Gn	Gd				Da				SH			
Gleichenia rupestris	Bd	BW				Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd								SH			La
Sticherus flabellatus		BW			Lo	Mm	Mu	Be	KC			Ka	Gn					Da	LC			SH			
Grammitidaceae																									
Grammitis billardieri		BW						Be				Ka													
Hymenophyllaceae																									
Hymenophyllum cupressiforme		BW				Mm	Mu	Be	KC			Ka	Gn	Gd				Da	LC						
Lindsaeaceae																									
Lindsaea dimorpha		BW																		Ma					
Lindsaea linearis	Bd	BW			Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu			Da	LC	Ma	Wa	SH			La
Lindsaea microphylla		BW			Lo	Mm	Mu	Be	KC	Ba		Ka	Gn	Gd	Cu		DH	Da	LC			SH			
Lycopodiaceae																									
Lycopodium cernuum		BW																							
Lycopodium deuterodensum		BW					Mu		KC					Gd											
Lycopodium laterale		BW				Mm	Mu	Be						Gd					LC						
Osmundaceae																									
Todea barbara	Bd	BW			Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd				Da		Ma		SH		Wo	
Polypodiaceae																									
Dictmia brownii		BW						Be																	
Microsorium scandens		BW																							
Platycerium bifurcatum	Bd	BW			Lo	Mm		Be		Ba		Ka			Cu							SH			
Pyrrosia rupestris		BW			Lo	Mm	Mu	Be	KC			Ka	Gn	Gd	Cu				LC			SH			

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Psilotaceae																									
Psilotum nudum		BW	Li				Mu	Be	KC	Ba	An	Ka	Gn	Gd					LC	Ma				Wo	
Tmesipteris truncata		BW										Ka	Gn												
Pteris tremula								Be				Ka			Cu										
Pteris umbrosa									KC																
Schizaeaceae																									
Schizaea bifida							Mu	Be	KC			Ka	Gn	Gd				Da	LC			SH			
Schizaea dichotoma		BW					Mu	Be					Gn	Gd											
Schizaea rupestris		BW				Mm	Mu					Ka	Gn	Gd											
Selaginellaceae																									
Selaginella uliginosa	Bd	BW									An	Ka	Gn	Gd						Ma		SH			La
Sinopteridaceae																									
Cheilanthes distans		BW			Lo		Mu	Be				Ka						Da							
Cheilanthes sieberi	Bd	BW	Li		Lo	Mm	Mu	Be	KC	Ba			Gn	Gd					LC		Wa	SH	HB		
Pellaea falcata		BW			Lo	Mm	Mu	Be	KC	Ba					Cu				LC			SH			
Thelypteridaceae																									
Christella dentata	Bd													Gd								SH			
Cycads																									
Zamiaceae																									
Macrozamia communis	Bd	BW	Li		Lo				KC		An	Ka	Gn											Wo	La
Conifers																									
Cupressaceae																									
Callitris rhomboidea								Be	KC					Gd											
Podocarpaceae																									
Podocarpus spinulosus	Bd	BW	Li					Be					Gn	Gd				Da	LC			SH		Wo	
Dicotyledons																									
Acanthaceae																									
Brunoniella australis				Sp					KC														HB		
Brunoniella pumilio									KC			Ka							LC						
Pseuderanthemum variabile	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn		Cu	PH	DH		LC		Wa				
Aizoaceae																									
Carpobrotus glaucescens	Bd	BW	Li																			SH			La
Tetragonia tetragonoides	Bd		Li		Lo			Be	KC					Gd					LC			SH	HB	Wo	
Amaranthaceae																									
Alternanthera denticulata							Mu	Be																	
Apiaceae																									
Actinotus helianthi	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH		Da	LC	Ma	Wa	SH		Wo	La
Actinotus minor	Bd	BW				Mm	Mu	Be	KC			Ka	Gn	Gd		PH			LC	Ma		SH			La
Apium prostratum	Bd	BW	Li		Lo	Mm		Be	KC																La
Centella asiatica	Bd	BW								Ba		Ka					DH				Wa	SH	HB	Wo	La
Daucus glochidiatus		BW				Mm																			
Hydrocotyle geraniifolia					Lo	Mm			KC																
Hydrocotyle laxiflora		BW				Mm	Mu	Be	KC		An	Ka			Cu				LC						
Hydrocotyle peduncularis					Lo	Mm			KC	Ba												SH	HB	Wo	
Hydrocotyle tripartita							Mu	Be							Cu										
Hydrocotyle verticillata																						SH			
Platysace clelandii						Mm	Mu																		
Platysace ericoides						Mm		Be										Da							La
Platysace lanceolata	Bd	BW	Li	Sp		Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd				Da	LC	Ma		SH		Wo	La
Platysace linearifolia	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH		Da	LC	Ma		SH		Wo	
Platysace stephensonii									KC				Gn												La
Trachymene incisa											An								LC		Wa				
Xanthosia dissecta		BW																							
Xanthosia pilosa	Bd	BW		Sp	Lo	Mm	Mu	Be	KC			Ka	Gn	Gd		PH		Da	LC	Ma		SH		Wo	La
Xanthosia tridentata	Bd	BW			Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd				Da	LC	Ma		SH		Wo	La
Apocynaceae																									
Parsonsia brownii								Be																	
Parsonsia straminea	Bd	BW	Li						KC	Ba	An	Ka	Gn		Cu				LC				HB		

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Araliaceae																									
Astrotricha crassifolia		BW																							
Astrotricha floccosa		BW		Sp	Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd				Da	LC			SH			
Astrotricha latifolia	Bd	BW				Mm													LC						
Polyscias murrayi		BW																							
Polyscias sambucifolia	Bd	BW						Be	KC		An	Ka	Gn	Gd	Cu	PH	DH	Da	LC		Wa	SH	HB	Wo	La
Asclepiadaceae																									
Marsdenia rostrata							Mu		KC	Ba	An											SH			
Marsdenia suaveolens	Bd	BW			Lo	Mm	Mu	Be		Ba		Ka	Gn	Gd		PH		Da	LC			SH			
Tylophora barbata						Mm		Be				Ka			Cu		DH		LC				HB		
Asteraceae																									
Actites megalocarpa														Gd											
Brachycome angustifolia				Sp					KC		An						DH		LC		Wa				
Brachycome multifida						Mm																			
Bracteantha bracteata																			LC						
Calotis dentex						Mm																			
Calotis lappulacea																							HB		
Cassinia aculeata		BW	Li													PH	DH				Wa				
Cassinia arcuata																							HB		
Cassinia aureonitens	Bd					Mm								Gd											
Cassinia compacta						Mm	Mu																		
Cassinia denticulata		BW			Lo		Mu	Be	KC					Gd		PH						SH			
Cassinia longifolia	Bd	BW						Be																	
Cassinia quinquefaria																PH									
Cassinia uncata	Bd									Ba	An	Ka													
Chrysocephalum apiculatum							Mu									PH		Da					HB		
Cotula australis																						SH	HB		La
Epaltes australis	Bd	BW			Lo			Be												Ma					La
Helichrysum elatum		BW							KC			Ka		Gd		PH			LC			SH			
Helichrysum scorpioides																PH	DH				Wa	SH			
Lagenifera stipitata		BW			Lo			Be			An	Ka	Gn				DH					SH		Wo	
Leptinella longipes		BW																					HB		La
Olearia microphylla								Be							Cu	PH			LC					Wo	
Olearia tomentosa	Bd	BW					Mu		KC	Ba		Ka	Gn	Gd					LC			SH			
Olearia viscidula															Cu										
Ozothamnus diosmifolius	Bd	BW		Sp		Mm	Mu	Be			An	Ka	Gn	Gd	Cu	PH	DH	Da	LC		Wa	SH	HB	Wo	
Pseudognaphalium luteoalbum			Li						KC																La
Senecio amygdalifolius																							HB		
Senecio bipinnatisectus	Bd					Mm	Mu		KC																
Senecio glomeratus																				Ma					La
Senecio hispidulus	Bd	BW						Be	KC				Gn		Cu						Wa	SH	HB	Wo	La
Senecio lautus															Cu				LC			SH	HB	Wo	La
Senecio linearifolius	Bd						Mu	Be	KC																
Senecio minimus		BW	Li					Be	KC						Cu										
Senecio quadridentatus								Be															HB		
Senecio vagus subsp. *eglandulosus*	Bd									Ba			Gn												
Sigesbeckia orientalis		BW				Mm	Mu	Be	KC				Gn		Cu		DH								
Solenogyne bellioides																			LC						
Vernonia cinerea var. *cinera*	Bd					Mm			KC		An	Ka					DH						HB		
Vittadinia muelleri																							HB		
Avicenniaceae																									
Avicennia marina subsp. *australasica*		BW		Sp	Lo	Mm	Mu	Be	KC					Gd					LC				HB	Wo	
Bauera microphylla																									La
Bauera rubioides	Bd	BW				Mm	Mu	Be	KC			Ka	Gn	Gd		PH			LC	Ma		SH			
Bignoniaceae																									
Pandorea pandorana	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC		Wa	SH	HB	Wo	
Callitrichaceae																									
Callitriche muelleri								Be																	
Campanulaceae																									
Wahlenbergia communis																							HB		
Wahlenbergia gracilis	Bd			Sp	Lo	Mm		Be		Ba	An	Ka	Gn		Cu							SH	HB	Wo	La
Wahlenbergia stricta subsp. *stricta*			Li			Mm											DH		LC						
Caryophyllaceae																									
Stellaria flaccida						Mm																			

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Casuarinaceae																									
Allocasuarina distyla	Bd	BW	Li			Mm	Mu	Be	KC	Ba		Ka	Gn	Gd					LC	Ma		SH			La
Allocasuarina littoralis	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH		Da	LC	Ma	Wa	SH		Wo	
Allocasuarina nana													Gn												
Allocasuarina portuensis																						SH			
Allocasuarina torulosa	Bd	BW		Sp	Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd	Cu	PH	DH	Da	LC		Wa	SH	HB		
Casuarina glauca		BW		Sp	Lo	Mm	Mu	Be	KC	Ba			Gn	Gd					LC			SH	HB	Wo	La
Celastraceae																									
Cassine australis var. *australis*		BW								Ba													HB		
Celastrus subspicata																PH									
Maytenus silvestris	Bd	BW					Mu	Be	KC			Ka			Cu		DH								
Chenopodiaceae																									
Atriplex australasica																							HB		
Atriplex semibaccata																							HB		
Chenopodium glaucum		BW											Gn										HB		
Einadia hastata													Gn												
Einadia nutans subsp. *linifolia*																							HB		
Einadia nutans subsp. *nutans*							Mu												LC						
Einadia polygonoides			Li					Be																	
Einadia trigonos subsp. *trigonos*															Cu										
Halosarcia pergranulata																							HB		
Rhagodia candolleana			Li																						
Sarcocornia quinqueflora		BW			Lo			Be	KC					Gd					LC			SH	HB	Wo	
Suaeda australis								Be	KC										LC				HB	Wo	
Chloanthes stoechadis	Bd	BW				Mm	Mu	Be	KC			Ka	Gn	Gd		PH						SH			La
Clusiaceae																									
Hypericum gramineum				Sp	Lo		Mu					Ka	Gn					Da				SH	HB		La
Hypericum japonicum		BW		Sp				Be							Cu				LC						
Convolvulaceae																									
Calystegia marginata													Gn												
Calystegia soldanella																									La

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Cuscuta australis						Mm																			
Dichondra repens	Bd	BW	Li		Lo	Mm	Mu	Be	KC	Ba	An	Ka			Cu		DH		LC		Wa	SH	HB		La
Polymeria calycina	Bd				Lo		Mu		KC				Gn										HB		
Wilsonia backhousei																							HB		
Crassulaceae																									
Crassula helmsii		BW																							
Crassula sieberiana	Bd	BW	Li		Lo	Mm		Be	KC	Ba	An	Ka							LC			SH		Wo	La
Cunoniaceae																									
Callicoma serratifolia		BW				Mm	Mu	Be	KC			Ka	Gn	Gd	Cu	PH		Da	LC	Ma		SH		Wo	
Ceratopetalum apetalum	Bd	BW		Sp		Mm	Mu	Be	KC			Ka	Gn	Gd		PH		Da	LC	Ma				Wo	
Ceratopetalum gummiferum		BW		Sp	Lo	Mm	Mu	Be	KC			Ka	Gn	Gd		PH		Da	LC	Ma		SH		Wo	La
Schizomeria ovata	Bd	BW				Mm	Mu		KC			Ka	Gn						LC			SH			
Dilleniaceae																									
Hibbertia acicularis																									La
Hibbertia aspera	Bd	BW				Mm	Mu	Be	KC				Gn		Cu		DH		LC		Wa		HB	Wo	
Hibbertia bracteata	Bd	BW				Mm	Mu	Be	KC			Ka	Gn	Gd					LC						
Hibbertia circumdans						Mm	Mu																		
Hibbertia cistiflora	Bd	BW				Mm	Mu	Be	KC				Gn	Gd					LC	Ma		SH			
Hibbertia dentata	Bd	BW	Li		Lo	Mm		Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC			SH		Wo	
Hibbertia diffusa					Lo	Mm			KC		An					PH			LC			SH		Wo	
Hibbertia empetrifolia	Bd	BW	Li		Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu			Da	LC	Ma		SH			La
Hibbertia fasciculata	Bd	BW						Be				Ka	Gn	Gd		PH				Ma		SH	HB		La
Hibbertia linearis		BW					Mu	Be	KC			Ka	Gn	Gd					LC	Ma		SH			
Hibbertia monogyna	Bd						Mu		KC																
Hibbertia nitida													Gn	Gd											
Hibbertia obtusifolia	Bd	BW	Li	Sp			Mu	Be			An							Da							
Hibbertia riparia	Bd							Be	KC														HB		
Hibbertia rufa		BW																				SH			
Hibbertia scandens	Bd	BW	Li					Be	KC	Ba			Gn	Gd	Cu		DH		LC			SH		Wo	La
Hibbertia serpyllifolia													Gn												
Droseraceae																									
Drosera auriculata	Bd	BW		Sp		Mm	Mu		KC			Ka	Gn	Gd		PH		Da	LC	Ma		SH		Wo	
Drosera binata	Bd	BW					Mu	Be	KC		An	Ka	Gn							Ma		SH			
Drosera peltata		BW				Mm	Mu	Be	KC			Ka	Gn	Gd				Da		Ma		SH			La
Drosera pygmaea		BW				Mm		Be	KC																La
Drosera spatulata	Bd	BW			Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd		PH			LC	Ma		SH			La

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Ebenaceae																									
Diospyros australis	Bd									Ba															
Elaeocarpaceae																									
Elaeocarpus reticulatus	Bd	BW		Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH		Da	LC	Ma	Wa	SH		Wo	La
Sloanea australis												Ka										SH			
Elatinaceae																									
Elatine gratioloides													Gn												La
Epacridaceae																									
Acrotriche divaricata	Bd	BW						Be	KC			Ka	Gn	Gd			DH								
Astroloma humifusum	Bd							Be										Da				SH	HB	Wo	
Astroloma pinifolium	Bd	BW							KC													SH			La
Brachyloma daphnoides	Bd	BW			Lo	Mm	Mu	Be	KC				Gn	Gd		PH			LC	Ma		SH		Wo	La
Dracophyllum secundum		BW		Sp	Lo	Mm	Mu	Be	KC				Gn	Gd		PH			LC						
Epacris crassifolia		BW					Mu	Be	KC				Gn	Gd					LC	Ma		SH			
Epacris longiflora	Bd	BW		Sp		Mm	Mu	Be	KC	Ba		Ka	Gn	Gd		PH			LC	Ma		SH		Wo	La
Epacris microphylla	Bd	BW					Mu	Be	KC		An		Gn	Gd		PH			LC	Ma		SH		Wo	La
Epacris obtusifolia		BW					Mu	Be	KC			Ka	Gn	Gd						Ma		SH			La
Epacris pulchella	Bd	BW		Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH		Da	LC	Ma	Wa	SH		Wo	
Epacris purpurascens																									
var. *purpurascens*		BW					Mu	Be								PH									
Epacris rigida																PH									
Leucopogon amplexicaulis		BW					Mu	Be	KC			Ka	Gn	Gd		PH			LC	Ma		SH		Wo	
Leucopogon appressus	Bd					Mm	Mu		KC				Gn	Gd											
Leucopogon deformis	Bd																								
Leucopogon ericoides	Bd	BW				Mm	Mu	Be	KC			Ka	Gn	Gd		PH			LC	Ma		SH			La
Leucopogon esquamatus	Bd	BW					Mu	Be	KC	Ba			Gn	Gd						Ma		SH			La
Leucopogon juniperinus	Bd							Be							Cu	PH	DH	Da	LC		Wa		HB	Wo	
Leucopogon lanceolatus								Be	KC			Ka	Gn	Gd	Cu	PH	DH	Da	LC					Wo	
Leucopogon margarodes		BW																							
Leucopogon microphyllus		BW				Mm	Mu	Be	KC				Gn	Gd		PH			LC	Ma		SH			
Leucopogon muticus						Mm		Be																	
Leucopogon parviflorus	Bd	BW								Ba															
Leucopogon setiger						Mm	Mu	Be	KC				Gn	Gd					LC						
Leucopogon virgatus																PH									La
Lissanthe sapida																			LC						
Lissanthe strigosa						Mm			KC				Gn	Gd						Ma	Wa	SH	HB		
Melichrus procumbens		BW									An							Da	LC						
Monotoca elliptica	Bd	BW	Li		Lo		Mu		KC	Ba		Ka	Gn	Gd					LC			SH		Wo	La
Monotoca scoparia	Bd	BW	Li			Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd					LC	Ma		SH			La
Sprengelia incarnata	Bd	BW					Mu	Be	KC			Ka	Gn	Gd								SH			La
Styphelia laeta subsp. *laeta*	Bd	BW							KC										LC						La
Styphelia laeta subsp. *latifolia*		BW																							
Styphelia longifolia		BW							KC			Ka	Gn	Gd		PH						SH			
Styphelia triflora								Be	KC				Gn	Gd		PH		Da		Ma		SH			La
Styphelia tubiflora	Bd	BW	Li				Mu	Be	KC				Gn	Gd		PH		Da	LC	Ma		SH		Wo	
Styphelia viridus subsp. *viridus*																									La
Trochocarpa laurina	Bd	BW				Mm	Mu	Be	KC			Ka				PH			LC						
Woollsia pungens	Bd	BW			Lo	Mm	Mu	Be	KC			Ka	Gn	Gd		PH		Da	LC	Ma		SH			La
Escalloniaceae																									
Abrophyllum ornans		BW							KC																
Euphorbiaceae																									
Amperea xiphoclada	Bd	BW				Mm	Mu	Be	KC		An	Ka	Gn	Gd	Cu			Da	LC			SH			La
Bertya brownii												Ka	Gn												
Breynia oblongifolia	Bd	BW			Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu		DH	Da	LC		Wa	SH	HB	Wo	La
Glochidion ferdinandi	Bd	BW			Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu				LC	Ma	Wa	SH		Wo	La
Micrantheum ericoides	Bd	BW	Li			Mm	Mu	Be	KC	Ba		Ka	Gn	Gd					LC	Ma	Wa	SH		Wo	
Monotaxis linifolia		BW					Mu					Ka	Gn	Gd						Ma		SH			La
Omalanthus populifolius	Bd								KC	Ba	An	Ka	Gn	Gd	Cu				LC		Wa	SH		Wo	
Phyllanthus gasstroemii		BW				Mm																	HB	Wo	
Phyllanthus hirtellus	Bd	BW	Li		Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd				Da	LC	Ma	Wa	SH	HB	Wo	
Poranthera corymbosa	Bd					Mm	Mu	Be	KC				Gn						LC						
Poranthera ericifolia	Bd	BW					Mu	Be	KC			Ka	Gn	Gd								SH			La
Poranthera microphylla		BW		Sp	Lo	Mm	Mu	Be	KC			Ka	Gn		Cu		DH				Wa	SH	HB	Wo	La
Pseudanthus orientalis	Bd																					SH			La
Pseudanthus pimeleoides		BW											Gn												
Ricinocarpos pinifolius	Bd	BW						Be	KC		An	Ka	Gn	Gd		PH			LC	Ma		SH			La
Eupomatiaceae																									
Eupomatia laurina	Bd	BW				Mm					An	Ka													

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Fabaceae–Faboideae																									
Almaleea paludosa		BW							KC																La
Aotus ericoides	Bd	BW					Mu	Be	KC		An		Gn	Gd										Wo	La
Bossiaea ensata	Bd	BW						Be	KC		An		Gn									SH			La
Bossiaea heterophylla	Bd	BW	Li			Mm	Mu	Be	KC			Ka	Gn	Gd		PH		Da	LC	Ma		SH		Wo	La
Bossiaea lenticularis						Mm																			
Bossiaea obcordata		BW				Mm		Be	KC				Gn	Gd		PH		Da	LC		Wa				
Bossiaea prostrata																							HB		
Bossiaea rhombifolia								Be																	
Bossiaea scolopendria	Bd	BW				Mm	Mu	Be	KC				Gn	Gd		PH			LC	Ma		SH			La
Bossiaea stephensonii		BW				Mm																			
Daviesia alata		BW							KC																
Daviesia corymbosa	Bd					Mm	Mu	Be																	
Daviesia ulicifolia	Bd	BW					Mu	Be							Cu					Ma	Wa	SH	HB		
Desmodium brachypodum	Bd					Mm																			
Desmodium rhytidophyllum		BW			Lo		Mu		KC		An		Gn				DH								
Desmodium varians		BW			Lo	Mm	Mu	Be	KC	Ba		Ka	Gn		Cu										
Dillwynia acicularis							Mu																		
Dillwynia floribunda var. *floribunda*	Bd	BW		Sp		Mm	Mu	Be	KC			Ka	Gn	Gd						Ma		SH			La
Dillwynia floribunda var. *teretifolia*						Mm	Mu	Be	KC				Gn	Gd		PH									
Dillwynia glaberrima	Bd															PH						SH			La
Dillwynia parvifolia																							HB		
Dillwynia retorta	Bd	BW	Li		Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd	Cu	PH		Da	LC	Ma	Wa	SH			La
Dillwynia sericea (D. rudis)	Bd	BW				Mm		Be					Gn	Gd					LC						
Glycine clandestina species complex		BW		Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka				PH			LC		Wa	SH	HB		La
Glycine microphylla													Gn												
Glycine tabacina species complex	Bd							Be	KC		An			Gd		PH	DH					SH	HB		
Gompholobium glabratum		BW				Mm	Mu	Be	KC					Gd		PH		Da	LC	Ma					La
Gompholobium grandiflorum	Bd	BW				Mm	Mu	Be	KC			Ka	Gn	Gd		PH			LC			SH			
Gompholobium latifolium	Bd	BW		Sp	Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd		PH			LC	Ma		SH			
Gompholobium minus									KC														HB		
Gompholobium pinnatum					Lo														LC						
Gompholobium virgatum	Bd																								
Goodia lotifolia						Mm																			
Hardenbergia violacea	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Hovea lanceolata								Be																	
Hovea linearis		BW		Sp	Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd		PH		Da	LC	Ma	Wa	SH			
Hovea longifolia								Be					Gn										HB		
Hovea purpurea						Mm																			
Indigofera australis	Bd	BW				Mm		Be							Cu		DH						HB		
Jacksonia scoparia	Bd					Mm				Ba															
Kennedia rubicunda	Bd	BW	Li	Sp		Mm	Mu	Be	KC	Ba	An	Ka	Gn		Cu	PH	DH	Da	LC		Wa	SH	HB	Wo	La
Mirbelia rubiifolia		BW	Li	Sp		Mm	Mu		KC	Ba			Gn	Gd					LC		Wa	SH			La
Mirbelia speciosa subsp. *speciosa*						Mm			KC																
Oxylobium cordifolium																									La
Oxylobium ilicifolium	Bd	BW	Li			Mm			KC	Ba	An	Ka	Gn					Da					HB		
Oxylobium scandens var. *scandens*							Mu								Cu										
Phyllota grandiflora								Be	KC			Ka		Gd				Da							
Phyllota phylicoides		BW				Mm	Mu	Be	KC				Gn	Gd		PH			LC	Ma		SH			
Platylobium formosum	Bd	BW			Lo		Mu	Be	KC		An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	
Pultenaea daphnoides	Bd	BW				Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH		Da	LC	Ma	Wa	SH		Wo	La
Pultenaea dentata																									La
Pultenaea elliptica	Bd	BW				Mm	Mu	Be	KC		An	Ka	Gn	Gd		PH			LC	Ma		SH			
Pultenaea ferruginea var. *deanei*	Bd	BW	Li			Mm				Ba															
Pultenaea ferruginea var. *ferruginea*						Mm	Mu																		
Pultenaea flexilis	Bd	BW		Sp	Lo	Mm	Mu	Be	KC			Ka	Gn	Gd		PH		Da	LC	Ma					
Pultenaea hispidula									KC				Gn							Ma					
Pultenaea linophyila							Mu	Be	KC				Gn	Gd						Ma				Wo	La
Pultenaea microphylla													Gn												
Pultenaea paleacea																PH									
Pultenaea polifolia							Mu		KC				Gn	Gd						Ma					
Pultenaea retusa				Sp				Be													Wa	SH			
Pultenaea rosmarinifolia		BW				Mm			KC	Ba						PH									
Pultenaea scabra								Be														SH			
Pultenaea stipularis								Be	KC				Gn	Gd		PH			LC	Ma		SH			
Pultenaea villosa								Be															HB		

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Sphaerolobium vimineum		BW						Be	KC							PH									La
Viminaria juncea		BW			Lo		Mu	Be	KC				Gn	Gd		PH			LC	Ma	Wa	SH		Wo	La
Zornia dyctiocarpa var. *dyctiocarpa*																PH									
Fabaceae–Mimosoideae																									
Acacia binervia													Gn	Gd					LC					Wo	
Acacia brownii						Mm														Ma					
Acacia buxifolia subsp. *buxifolia*								Be											LC						
Acacia decurrens						Mm	Mu	Be								PH		Da					HB		
Acacia echinula							Mu												LC						
Acacia elata	Bd	BW		Sp		Mm								Gd		PH			LC						
Acacia elongata var. *elongata*								Be												Ma					
Acacia falcata															Cu			Da			Wa		HB	Wo	
Acacia filicifolia	Bd					Mm																			
Acacia fimbriata		BW																							
Acacia floribunda		BW				Mm	Mu	Be	KC		An				Cu	PH	DH	Da						Wo	
Acacia hispidula						Mm		Be						Gd					LC					Wo	
Acacia implexa	Bd	BW			Lo	Mm	Mu		KC	Ba			Gn				DH					SH			La
Acacia irrorata subsp. *irrorata*	Bd	BW						Be					Gn	Gd											
Acacia linifolia		BW				Mm	Mu	Be				Ka	Gn	Gd		PH		Da	LC	Ma	Wa	SH		Wo	
Acacia longifolia		BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH		Da	LC	Ma	Wa	SH	HB	Wo	
Acacia longissima						Mm		Be	KC			Ka	Gn	Gd		PH	DH			Ma		SH	HB		
Acacia maidenii	Bd	BW		Sp											Cu										
Acacia myrtifolia	Bd	BW				Mm	Mu	Be	KC	Ba	An		Gn	Gd				Da	LC	Ma	Wa	SH	HB	Wo	La
Acacia oxycedrus	Bd	BW		Sp			Mu	Be	KC			Ka	Gn			PH									
Acacia parramattensis		BW				Mm		Be			An			Gd	Cu	PH			LC		Wa		HB	Wo	
Acacia parvipinnula								Be							Cu										
Acacia prominens		BW																							
Acacia quadrilateralis	Bd																								
Acacia schinoides		BW																							
Acacia sophorae	Bd																						HB		La
Acacia stricta													Gn		Cu	PH					Wa		HB		
Acacia suaveolens	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Acacia terminalis		BW				Mm	Mu	Be	KC			Ka	Gn	Gd		PH			LC	Ma	Wa	SH		Wo	La
Acacia ulicifolia	Bd	BW	Li		Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH		Da	LC	Ma	Wa	SH	HB	Wo	La
Pararchidendron pruinosum										Ba															
Flacourtiaceae																									
Scolopia braunii	Bd																								
Gentianaceae																									
Centaurium spicatum																							HB		
Geraniaceae																									
Erodium crinitum																									La
Geranium homeanum					Lo		Mu		KC						Cu				LC			SH			
Geranium potentilloides						Mm																			
Geranium solanderi var. *solanderi*		BW						Be							Cu		DH								
Pelargonium australe	Bd	BW																							La
Pelargonium inodorum	Bd	BW								Ba		Ka												Wo	
Goodeniaceae																									
Dampiera purpurea						Mm	Mu	Be	KC										LC						
Dampiera scottiana						Mm																			
Dampiera stricta	Bd	BW				Mm	Mu	Be	KC		An	Ka	Gn	Gd		PH		Da	LC	Ma		SH			La
Goodenia bellidifolia	Bd	BW	Li				Mu	Be	KC			Ka	Gn	Gd		PH			LC	Ma		SH			La
Goodenia dimorpha var. *dimorpha*		BW							KC										LC	Ma	Wa				
Goodenia hederacea					Lo				KC							PH		Da	LC		Wa		HB	Wo	
Goodenia heterophylla	Bd	BW		Sp	Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd	Cu	PH	DH	Da	LC			SH			
Goodenia ovata		BW	Li		Lo	Mm		Be	KC	Ba	An	Ka	Gn						LC				HB		La
Goodenia paniculata		BW			Lo								Gn										HB		
Goodenia stelligera						Mm							Gn			PH				Ma		SH			La
Scaevola albida								Be																	
Scaevola ramosissima	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH		Da	LC	Ma					La
Selliera radicans																									La
Velleia lyrata		BW						Be	KC													SH			
Haloragaceae																									
Gonocarpus micranthus		BW					Mu	Be			An	Ka	Gn	Gd					LC	Ma		SH			La
Gonocarpus salsoloides		BW						Be												Ma		SH			La
Gonocarpus tetragynus		BW					Mu	Be	KC					Gd				Da			Wa	SH	HB		La
Gonocarpus teucrioides	Bd	BW			Lo	Mm	Mu	Be	KC	Ba		Ka	Gn	Gd	Cu			Da	LC	Ma		SH		Wo	La
Haloragodendron lucasii														Gd											

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Lamiaceae																									
Hemigenia purpurea		BW					Mu	Be	KC				Gn	Gd		PH			LC	Ma		SH			
Lycopus australis							Mu																		
Plectranthus graveolens				Sp																					
Plectranthus parviflorus	Bd	BW		Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn		Cu		DH					SH			
Prostanthera denticulata									KC	Ba		Ka	Gn	Gd											
Prostanthera incana							Mu																		
Prostanthera linearis	Bd	BW				Mm	Mu	Be	KC				Gn	Gd					LC						
Prostanthera ovalifolia s. lat.					Lo	Mm	Mu	Be																	
Prostanthera rhombea		BW				Mm																			
Westringia fruticosa	Bd	BW	Li							Ba												SH			La
Lauraceae																									
Cassytha glabella	Bd		Li		Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH			LC			SH	HB		La
Cassytha pubescens		BW	Li		Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH	DH	Da	LC	Ma	Wa	SH	HB		La
Cryptocarya glaucescens		BW										Ka													
Endiandra sieberi	Bd	BW	Li		Lo				KC			Ka	Gn									SH			La
Lentibulariaceae																									
Utricularia biloba																									La
Utricularia dichotoma		BW						Be	KC											Ma		SH			La
Utricularia lateriflora	Bd	BW						Be				Ka													
Utricularia uliginosa		BW																							La
Lobeliaceae																									
Lobelia alata	Bd	BW	Li		Lo	Mm	Mu		KC	Ba	An			Gd					LC	Ma		SH		Wo	La
Lobelia dentata		BW						Be	KC			Ka	Gn	Gd				Da		Ma		SH			
Lobelia gibbosa		BW										Ka				PH									
Lobelia gracilis																					Wa	SH		Wo	
Pratia purpurascens	Bd	BW		Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC		Wa	SH	HB	Wo	
Loganiaceae																									
Logania albiflora	Bd	BW		Sp	Lo	Mm	Mu	Be	KC			Ka	Gn	Gd		PH				Ma		SH		Wo	
Logania pusilla							Mu					Ka													
Mitrasacme polymorpha	Bd	BW			Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd				Da	LC	Ma		SH			La

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Loranthaceae																									
Amyema congener																PH			LC					Wo	
Amyema gaudichaudii																							HB		
Amyema miquelii		BW																							
Amyema pendulum subsp. *pendulum*	Bd																								
Dendrophthoe vitellina	Bd						Mu	Be								PH			LC			SH	HB	Wo	
Muellerina celastroides		BW	Li		Lo		Mu			Ba												SH			
Muellerina eucalyptoides	Bd	BW					Mu							Gd											
Lythraceae																									
Lythrum hyssopifolia																							HB		
Malvaceae																									
Hibiscus diversifolius													Gn												
Howittia trilocularis	Bd	BW																							
Meliaceae																									
Melia azedarach								Be	KC				Gn		Cu										
Synoum glandulosum	Bd	BW		Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn						LC			SH			
Toona ciliata (Toona australis)									KC																
Menispermaceae																									
Sarcopetalum harveyanum	Bd	BW		Sp	Lo		Mu	Be	KC	Ba	An	Ka	Gn		Cu				LC			SH	HB	Wo	La
Stephania japonica var. *discolor*	Bd	BW	Li		Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn			PH			LC			SH			La
Menyanthaceae																									
Villarsia exaltata													Gn												
Monimiaceae																									
Doryphora sassafras		BW																							
Palmeria scandens		BW						Be																	
Wilkiea huegeliana	Bd	BW							KC	Ba	An	Ka													
Moraceae																									
Ficus coronata	Bd	BW					Mu	Be	KC	Ba			Gn						LC						
Ficus rubiginosa	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH						SH		Wo	
Ficus superba var. *henneana*		BW																							
Malaisia scandens	Bd																								

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Myoporaceae																									
Eremophila debilis																							HB		
Myoporum acuminatum	Bd	BW					Mu																		
Myoporum insulare	Bd	BW													Cu								HB		
Myrsinaceae																									
Aegiceras corniculatum	Bd	BW			Lo	Mm	Mu	Be	KC										LC				HB		
Rapanea howittiana	Bd	BW	Li				Mu			Ba		Ka										SH			La
Rapanea variabilis	Bd	BW	Li		Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH					SH	HB	Wo	La
Myrtaceae																									
Acmena smithii	Bd	BW	Li	Sp		Mm	Mu	Be	KC	Ba	An	Ka	Gn			PH		Da	LC			SH			La
Angophora bakeri					Lo	Mm	Mu	Be										Da	LC		Wa				
Angophora costata	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd	Cu	PH	DH	Da		Ma	Wa	SH		Wo	La
Angophora crassifolia									KC				Gn	Gd					LC	Ma					
Angophora floribunda	Bd	BW		Sp	Lo	Mm	Mu	Be	KC		An				Cu		DH		LC				HB	Wo	
Angophora hispida	Bd	BW				Mm	Mu	Be	KC				Gn	Gd		PH			LC	Ma		SH			
Austromyrtus tenuifolia		BW				Mm	Mu	Be	KC				Gn	Gd		PH			LC	Ma					
Backhousia myrtifolia	Bd	BW		Sp	Lo	Mm	Mu	Be	KC	Ba		Ka	Gn	Gd		PH		Da	LC						
Baeckea brevifolia	Bd	BW				Mm	Mu	Be	KC				Gn						LC			SH			
Baeckea densifolia													Gn	Gd		PH				Ma					
Baeckea diosmifolia	Bd	BW				Mm	Mu	Be	KC				Gn	Gd					LC	Ma		SH			
Baeckea imbricata	Bd	BW	Li				Mu	Be	KC	Ba			Gn	Gd						Ma		SH			La
Baeckea linifolia		BW				Mm	Mu	Be	KC		An	Ka	Gn	Gd		PH				Ma					
Baeckea ramosissima	Bd												Gn	Gd					LC			SH			
Baeckea virgata					Lo			Be					Gn						LC						
Callistemon citrinus	Bd	BW					Mu	Be	KC		An		Gn	Gd		PH			LC	Ma		SH		Wo	La
Callistemon linearifolius			Li	Sp			Mu		KC				Gn												
Callistemon linearis	Bd	BW					Mu	Be	KC	Ba		Ka	Gn	Gd					LC	Ma	Wa	SH		Wo	La
Callistemon pinifolius													Gn												La
Callistemon rigidus												Ka	Gn							Ma					
Callistemon salignus													Gn						LC			SH			
Calytrix tetragona	Bd	BW				Mm	Mu	Be	KC				Gn	Gd		PH			LC	Ma		SH			La
Darwinia biflora						Mm		Be	KC										LC						
Darwinia fascicularis		BW				Mm	Mu	Be	KC		An	Ka	Gn	Gd					LC	Ma		SH			La
Darwinia glaucophylla		BW																							
Darwinia leptantha																						SH			La
Darwinia peduncularis						Mm		Be																	
Darwinia procera		BW				Mm			KC				Gn	Gd											
Eucalyptus acmenoides		BW				Mm									Cu										
Eucalyptus agglomerata						Mm			KC																
Eucalyptus beyeriana						Mm																			
Eucalyptus botryoides	Bd	BW	Li						KC	Ba	An		Gn									SH		Wo	La
Eucalyptus camfieldii								Be	KC													SH			
Eucalyptus capitellata	Bd	BW						Be	KC				Gn	Gd						Ma					
Eucalyptus deanei	Bd	BW																							
Eucalyptus eugenioides						Mm																			
Eucalyptus eximia		BW				Mm	Mu	Be	KC	Ba															
Eucalyptus fibrosa																							HB		
Eucalyptus globoidea		BW				Mm		Be								PH		Da			Wa	SH	HB		
Eucalyptus grandis													Gn												
Eucalyptus gummifera	Bd	BW		Sp	Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd	Cu	PH		Da	LC	Ma	Wa	SH	HB	Wo	La
Eucalyptus haemastoma	Bd	BW				Mm	Mu	Be	KC		An	Ka	Gn	Gd		PH			LC	Ma	Wa	SH	HB	Wo	
Eucalyptus longifolia																							HB		
Eucalyptus luehmanniana		BW							KC				Gn	Gd											
Eucalyptus maculata	Bd	BW							KC		An														
Eucalyptus moluccana																							HB		
Eucalyptus multicaulis	Bd	BW						Be						Gd											
Eucalyptus oblonga		BW						Be	KC				Gn	Gd						Ma					
Eucalyptus obstans													Gn							Ma		SH			
Eucalyptus paniculata	Bd	BW	Li					Be	KC		An	Ka	Gn	Gd	Cu	PH	DH		LC		Wa		HB		
Eucalyptus pilularis	Bd					Mm		Be	KC					Gd	Cu	PH	DH	Da					HB	Wo	
Eucalyptus piperita	Bd	BW		Sp	Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd		PH		Da	LC	Ma	Wa	SH		Wo	
Eucalyptus punctata	Bd	BW		Sp	Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd						Ma	Wa	SH	HB		
Eucalyptus racemosa						Mm	Mu	Be	KC				Gn	Gd						Ma					
Eucalyptus resinifera		BW		Sp		Mm		Be	KC						Cu	PH			LC		Wa		HB		
Eucalyptus robusta	Bd										An		Gn									SH		Wo	La
Eucalyptus saligna								Be						Gd	Cu		DH	Da	LC						
Eucalyptus scias subsp. *scias*	Bd	BW							KC			Ka	Gn												
Eucalyptus sclerophylla						Mm																			
Eucalyptus sieberi		BW					Mu	Be	KC				Gn	Gd						Ma					
Eucalyptus sparsifolia						Mm																			
Eucalyptus squamosa		BW				Mm	Mu	Be	KC				Gn												
Eucalyptus tereticornis						Mm									Cu				LC			SH			

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Eucalyptus umbra	Bd	BW		Sp	Lo		Mu		KC		An	Ka	Gn	Gd				Da		Ma		SH			
Kunzea ambigua	Bd	BW	Li	Sp	Lo		Mu	Be	Kc	Ba	An	Ka		Gd	Cu	PH		Da	LC	Ma	Wa	SH	HB	Wo	La
Kunzea capitata		BW				Mm	Mu	Be	KC				Gn	Gd					LC	Ma		SH			
Kunzea rupestris						Mm			KC																
Leptospermum arachnoides		BW				Mm	Mu	Be	KC				Gn	Gd		PH			LC	Ma		SH			La
Leptospermum deanei						Mm								Gd		PH									
Leptospermum grandifolium		BW				Mm		Be					Gn	Gd						Ma					
Leptospermum juniperinum	Bd	BW					Mu		KC		An	Ka	Gn	Gd						Ma		SH			La
Leptospermum laevigatum	Bd	BW	Li							Ba				Gd					LC			SH			La
Leptospermum parvifolium		BW				Mm			KC					Gd						Ma					
Leptospermum polygalifolium	Bd	BW				Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH		Da	LC	Ma		SH		Wo	La
Leptospermum scoparium	Bd	BW																							
Leptospermum squarrosum	Bd	BW				Mm	Mu	Be	KC	Ba		Ka	Gn	Gd					LC	Ma		SH			La
Leptospermum trinervium	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH		Da	LC	Ma	Wa	SH		Wo	La
Melaleuca armillaris																						SH			La
Melaleuca biconvexa	Bd																								
Melaleuca deanei		BW						Be						Gd											
Melaleuca decora																					Wa				
Melaleuca ericifolia					Lo																			Wo	
Melaleuca hypericifolia										Ba								Da				SH			
Melaleuca linariifolia	Bd						Mu	Be					Gn											Wo	La
Melaleuca nodosa																PH						SH	HB	Wo	La
Melaleuca quinquenervia					Lo																	SH			
Melaleuca squamea																									La
Melaleuca styphelioides	Bd	BW											Gn	Gd							Wa		HB	Wo	
Melaleuca thymifolia	Bd															PH								Wo	La
Micromyrtus blakelyi						Mm	Mu																		
Micromyrtus ciliata	Bd					Mm	Mu	Be	KC					Gd					LC	Ma					
Rhodamnia rubescens	Bd					Mm			KC								DH								
Rhodomyrtus psidioides										Ba															
Syncarpia glomulifera	Bd	BW			Lo	Mm	Mu	Be	KC		An	Ka		Gd	Cu	PH	DH	Da	LC		Wa	SH	HB	Wo	
Syzigium australe																						SH			
Syzigium oleosum	Bd	BW								Ba			Gn												
Syzygium paniculatum																								Wo	
Tristania neriifolia		BW					Mu	Be					Gn	Gd		PH									
Tristaniopsis collina	Bd				Lo			Be	KC	Ba				Gd								SH		Wo	
Tristaniopsis laurina	Bd	BW		Sp		Mm	Mu	Be	KC			Ka	Gn	Gd		PH		Da	LC					Wo	
Olacaceae																									
Olax stricta		BW				Mm	Mu	Be	KC				Gn	Gd					LC	Ma		SH			
Oleaceae																									
Notelaea longifolia	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu		DH	Da	LC		Wa	SH	HB	Wo	La
Notelaea ovata								Be	KC				Gn									SH		Wo	
Notelaea venosa	Bd	BW				Mm			KC																
Onagraceae																									
Epilobium billardierianum								Be	KC														HB	Wo	
Ludwigia peploides																							HB		
Oxalidaceae																									
Oxalis exilis																	DH								
Oxalis rubens													Gn												
Oxalis thompsoniae										Ba															
Passifloraceae																									
Passiflora cinnabarina												Ka													
Passiflora herbertiana							Mu		KC						Cu				LC						
Peperomiaceae																									
Peperomia blanda var. *floribunda*					Lo																				
Peperomia tetraphylla		BW																							
Pittosporaceae																									
Billardiera scandens var. *scandens*	Bd	BW	Li		Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Bursaria spinosa var. *spinosa*		BW		Sp	Lo	Mm	Mu	Be	KC			Ka	Gn		Cu	PH	DH				Wa		HB	Wo	
Citriobatus pauciflorus	Bd	BW				Mm									Cu										
Pittosporum revolutum	Bd	BW				Mm	Mu	Be	KC	Ba	An	Ka	Gn		Cu	PH	DH	Da	LC			SH	HB	Wo	La
Pittosporum undulatum	Bd	BW	Li		Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB		La
Rhytidosporum procumbens						Mm	Mu	Be	KC				Gn	Gd		PH			LC						
Plantaginaceae																									
Plantago debilis		BW																							
Plantaginaceae																									
Plantago hispida	Bd		Li																						

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Polygalaceae																									
Comesperma defoliatum									KC										LC						
Comesperma ericinum	Bd	BW				Mm	Mu	Be	KC			Ka	Gn	Gd		PH		Da	LC	Ma		SH			La
Comesperma sphaerocarpum		BW							KC			Ka	Gn												
Comesperma volubile		BW				Mm	Mu	Be	KC			Ka	Gn			PH		Da							
Polygonaceae																									
Muehlenbeckia gracillima		BW					Mu							Gd											
Persicaria decipiens		BW					Mu	Be	KC		An		Gn									SH	HB	Wo	La
Persicaria hydropiper								Be			An		Gn												
Persicaria lapathifolia									KC															Wo	
Persicaria praetermissa							Mu																		
Persicaria strigosa													Gn											Wo	
Polygonum plebeium																							HB		
Rumex brownii		BW	Li				Mu	Be																	
Portulacaceae																									
Calandrinia pickeringii			Li		Lo	Mm			KC			Ka							LC			SH			
Portulaca oleracea		BW						Be																	
Primulaceae																									
Samolus repens		BW			Lo	Mm	Mu	Be	KC				Gn	Gd					LC				HB		La
Proteaceae																									
Banksia aemula	Bd																					SH			La
Banksia ericifolia var. ericifolia	Bd	BW	Li			Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH			LC	Ma		SH			La
Banksia integrifolia	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH			LC			SH		Wo	La
Banksia marginata				Sp		Mm	Mu	Be	KC				Gn	Gd		PH			LC	Ma		SH			
Banksia oblongifolia	Bd	BW				Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH			LC	Ma		SH		Wo	La
Banksia robur		BW							KC													SH			La
Banksia serrata	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH		Da	LC	Ma	Wa	SH		Wo	La
Banksia spinulosa var. *collina*	Bd							Be																	
Banksia spinulosa var. *spinulosa*		BW		Sp	Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd		PH		Da	LC	Ma	Wa	SH		Wo	
Conospermum longifolium	Bd	BW				Mm	Mu	Be	KC			Ka	Gn	Gd		PH				Ma		SH			
Conospermum taxifolium	Bd	BW						Be	KC				Gn	Gd		PH			LC	Ma		SH			La
Conospermum tenuifolium		BW							KC																
Grevillea buxifolia subsp. *buxifolia*		BW				Mm	Mu	Be	KC			Ka	Gn	Gd		PH		Da	LC	Ma		SH		Wo	
Grevillea buxifolia subsp. *sphacelata*																						SH			
Grevillea caleyi									KC				Gn	Gd											
Grevillea linearifolia	Bd	BW						Be	KC		An		Gn	Gd		PH		Da	LC	Ma		SH	HB		
Grevillea linearifolia (*G. parviflora*)						Mm																SH			
Grevillea mucronulata						Mm			KC																
Grevillea sericea		BW		Sp		Mm	Mu	Be	KC		An	Ka	Gn			PH		Da	LC	Ma	Wa	SH		Wo	
Grevillea shiressii		BW																							
Grevillea speciosa		BW				Mm		Be	KC		An		Gn	Gd		PH		Da	LC	Ma		SH			
Hakea bakeriana						Mm		Be											LC						
Hakea dactyloides	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd		PH			LC	Ma		SH		Wo	La
Hakea gibbosa	Bd	BW				Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH			LC	Ma		SH			La
Hakea propinqua		BW				Mm	Mu	Be	KC				Gn	Gd					LC						
Hakea salicifolia		BW						Be			An		Gn	Gd				Da	LC						
Hakea sericea	Bd	BW	Li			Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH		Da	LC		Wa	SH		Wo	
Hakea teretifolia	Bd	BW	Li			Mm	Mu	Be	KC	Ba		Ka	Gn	Gd		PH			LC	Ma		SH			La
Isopogon anemonifolius	Bd	BW				Mm	Mu	Be	KC		An		Gn		Cu	PH		Da	LC					Wo	La
Isopogon anethifolius	Bd	BW	Li				Mu	Be	KC	Ba			Gn	Gd	Cu	PH		Da	LC	Ma		SH			
Lambertia formosa	Bd	BW				Mm	Mu	Be	KC		An	Ka	Gn	Gd		PH		Da	LC	Ma		SH		Wo	La
Lomatia myricoides		BW				Mm	Mu	Be	KC				Gn	Gd		PH			LC						
Lomatia silaifolia	Bd	BW			Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH		Da	LC	Ma	Wa	SH		Wo	La
Persoonia hirsuta subsp. *hirsuta*							Mu																		
Persoonia isophylla	Bd	BW							KC																
Persoonia lanceolata	Bd	BW				Mm	Mu	Be	KC			Ka	Gn	Gd					LC	Ma	Wa	SH			La
Persoonia laurina subsp. *laurina*						Mm		Be	KC				Gn			PH		Da	LC	Ma	Wa			Wo	
Persoonia levis	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH	DH	Da	LC	Ma	Wa	SH		Wo	La
Persoonia linearis	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH		Wo	
Persoonia mollis subsp. *mollis*									KC																
Persoonia pinifolia		BW				Mm	Mu	Be	KC			Ka	Gn	Gd		PH			LC	Ma					
Petrophile pulchella	Bd	BW	Li			Mm	Mu	Be	KC		An	Ka	Gn	Gd		PH		Da	LC	Ma		SH			La
Petrophile sessilis	Bd																		LC						
Stenocarpus salignus		BW				Mm	Mu	Be	KC			Ka	Gn	Gd				Da	LC						
Symphionema paludosum		BW												Gd											
Telopea speciosissima	Bd	BW					Mu	Be	KC			Ka	Gn	Gd		PH		Da	LC	Ma		SH			
Xylomelum pyriforme	Bd	BW		Sp	Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd		PH		Da	LC	Ma	Wa	SH		Wo	La

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Ranunculaceae																									
Clematis aristata	Bd	BW			Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd	Cu	PH	DH	Da	LC			SH	HB		
Clematis glycinoides var. *glycinoides*							Mu	Be	KC	Ba	An				Cu	PH	DH		LC		Wa	SH	HB	Wo	
Ranunculus inundatus													Gn												
Ranunculus plebeius							Mu							Gd											
Rhamnaceae																									
Alphitonia excelsa		BW				Mm	Mu		KC			Ka													
Cryptandra amara var. *amara*						Mm	Mu	Be		Ba			Gn	Gd								SH			La
Cryptandra ericoides		BW							KC				Gn	Gd								SH			
Pomaderris aspera								Be								PH									
Pomaderris discolor						Mm		Be											LC					Wo	
Pomaderris eliptica		BW		Sp				Be					Gn	Gd		PH				Ma		SH			
Pomaderris ferruginea	Bd	BW				Mm			KC				Gn	Gd	Cu							SH	HB		
Pomaderris intermedia		BW	Li		Lo	Mm	Mu	Be					Gn	Gd									HB	Wo.	
Pomaderris lanigera	Bd						Mu	Be	KC	Ba	An	Ka	Gn										HB		
Pomaderris ligustrina		BW																							
Rosaceae																									
Rubus hillii	Bd	BW				Mm	Mu		KC		An		Gn									SH			
Rubus parvifolius		BW	Li			Mm				Ba							DH								
Rubus rosifolius	Bd					Mm			KC						Cu										
Rubiaceae																									
Canthium coprosmoides		BW							KC			Ka													
Coprosma quadrifida								Be																	
Galium binifolium		BW						Be	KC			Ka			Cu			Da							
Galium propinquum		BW				Mm	Mu																		
Morinda jasminoides	Bd	BW		Sp			Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH		Da				SH			
Opercularia aspera	Bd	BW			Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu			Da	LC	Ma		SH	HB	Wo	La
Opercularia diphylla									KC														HB		
Opercularia hispida					Lo		Mu		KC																
Opercularia varia		BW					Mu	Be	KC			Ka	Gn					Da	LC	Ma		SH	HB		La
Pomax umbellata	Bd	BW			Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu			Da	LC	Ma	Wa	SH	HB	Wo	La
Psychotria loniceroides	Bd																								
Rutaceae																									
Acronychia oblongifolia																						SH			
Asterolasia correifolia	Bd	BW				Mm	Mu		KC			Ka	Gn												
Asterolasia elegans						Mm																			
Boronia anemonifolia		BW				Mm																			
Boronia floribunda								Be	KC					Gd		PH									
Boronia fraseri		BW				Mm	Mu	Be	KC																
Boronia ledifolia		BW				Mm	Mu	Be	KC		An	Ka	Gn	Gd		PH			LC	Ma		SH			
Boronia mollis								Be				Ka													
Boronia parviflora		BW						Be																	La
Boronia pinnata		BW				Mm	Mu	Be	KC			Ka	Gn	Gd		PH			LC	Ma					
Boronia polygalifolia		BW																	LC						
Boronia rigens							Mu																		La
Boronia serrulata		BW				Mm	Mu	Be	KC				Gn												
Boronia thujona												Ka	Gn	Gd											
Correa alba var. *alba*										Ba												SH			La
Correa lawrenciana var. *macrocalyx*		BW																							
Correa reflexa	Bd	BW		Sp	Lo	Mm	Mu	Be	KC	Ba		Ka	Gn			PH		Da	LC			SH			La
Crowea saligna	Bd	BW							KC			Ka	Gn	Gd						Ma		SH			
Eriostemon australasius	Bd	BW	Li			Mm	Mu	Be	KC			Ka	Gn	Gd				Da		Ma		SH			La
Eriostemon buxifolius		BW	Li						KC					Gd								SH			La
Eriostemon hispidulus	Bd					Mm	Mu	Be																	
Eriostemon myoporoides																									La
Eriostemon scaber subsp. *scaber*																								Wo	
Phebalium dentatum		BW					Mu	Be	KC			Ka	Gn	Gd		PH			LC						
Phebalium diosmeum								Be														SH		Wo	
Phebalium squamulosum subsp. *argenteum*		BW																							
Phebalium squamulosum subsp. *squamulosum*		BW				Mm	Mu		KC				Gn	Gd						Ma					
Philotheca salsolifolia		BW					Mu	Be	KC				Gn	Gd					LC	Ma		SH			La
Zieria involucrata						Mm																			
Zieria laevigata		BW				Mm	Mu	Be	KC				Gn	Gd						Ma		SH			La
Zieria pilosa	Bd	BW				Mm	Mu	Be	KC			Ka	Gn	Gd		PH			LC			SH		Wo	La
Zieria smithii subsp. *A*	Bd	BW						Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC				HB	Wo	

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Sambucaceae																									
Sambucus gaudichaudiana								Be																	
Santalaceae																									
Exocarpos cupressiformis	Bd	BW	Li	Sp	Lo	Mm	Mu		KC		An	Ka			Cu		DH	Da	LC		Wa	SH	HB	Wo	La
Exocarpos strictus								Be																	
Leptomeria acida		BW			Lo		Mu	Be	KC			Ka	Gn			PH			LC						
Sapindaceae																									
Alectryon subcinereus		BW																							
Cupaniopsis anacardioides																						SH			
Dodonaea camfieldii		BW																							
Dodonaea pinnata		BW				Mm	Mu		KC				Gn												
Dodonaea triquetra	Bd	BW	Li			Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH		LC	Ma	Wa	SH	HB	Wo	La
Guioa semiglauca	Bd	BW								Ba															
Scrophulariaceae																									
Veronica calycina								Be														SH		Wo	
Veronica plebeia		BW				Mm	Mu	Be			An			Gd	Cu		DH	Da	LC		Wa	SH	HB		
Solanaceae																									
Duboisia myoporoides	Bd	BW				Mm							Gn												
Solanum americanum (*S. nodiflorum*)		BW	Li			Mm		Be		Ba	An	Ka			Cu	PH									La
Solanum campanulatum		BW					Mu		KC																
Solanum opacum (*S. nigrum*)								Be					Gn		Cu							SH			La
Solanum prinophyllum		BW				Mm	Mu	Be	KC		An	Ka			Cu										
Solanum pungetium		BW				Mm									Cu										
Stackhousiaceae																									
Stackhousia monogyna		BW																							
Stackhousia nuda		BW							KC				Gn			PH									La
Stackhousia viminea		BW				Mm	Mu	Be	KC			Ka	Gn	Gd					LC	Ma			HB		
Sterculiaceae																									
Brachychiton populneus	Bd																						HB		
Lasiopetalum ferrugineum	Bd	BW		Sp		Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH		Da		Ma	Wa	SH			La
Lasiopetalum macrophyllum		BW		Sp		Mm			KC	Ba															
Lasiopetalum parviflorum								Be										Da					HB		
Lasiopetalum rufum						Mm	Mu		KC					Gd											
Rulingia dasyphylla									KC				Gn						LC						
Rulingia hermanniifolia	Bd																					SH			La
Seringia arborescens									KC																
Stylidiaceae																									
Stylidium graminifolium																									La
Stylidium lineare		BW					Mu	Be	KC				Gn	Gd					LC	Ma		SH			
Stylidium productum		BW	Li		Lo	Mm	Mu	Be	KC			Ka	Gn	Gd		PH			LC	Ma	Wa			Wo	
Symplocaceae																									
Symplocos thwaitesii		BW																							
Thymelaeaceae																									
Pimelea curviflora var. *curviflora*																				Ma					
Pimelea curviflora var. *gracilis*							Mu																		
Pimelea glauca		BW																							
Pimelea latifolia subsp. *hirsuta*		BW							KC																
Pimelea linifolia subsp. *linifolia*	Bd	BW					Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH		Da	LC	Ma	Wa	SH		Wo	La
Wikstroemia indica	Bd	BW	Li							Ba												SH			
Tetratheca ericifolia	Bd	BW					Mu	Be	KC			Ka	Gn	Gd						Ma					
Tetratheca glandulosa						Mm	Mu	Be	KC				Gn	Gd				Da	LC	Ma					
Tetratheca shiressii		BW																							
Tetratheca thymifolia	Bd	BW				Mm	Mu	Be	KC		An	Ka	Gn												
Ulmaceae																									
Trema aspera		BW				Mm	Mu	Be	KC		An	Ka	Gn						LC					Wo	
Urticaceae																									
Urtica incisa								Be																	
Verbenaceae																									
Clerodendrum tomentosum	Bd	BW		Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu		DH		LC			SH	HB		

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Violaceae																									
Hybanthus monopetalus	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC							PH			LC						La
Hybanthus vernonii subsp. *vernonii*						Mm	Mu	Be				Ka	Gn	Gd											
Hymenanthera dentata								Be																	
Viola betonicifolia	Bd																								
Viola hederacea		BW				Mm	Mu	Be	KC		An	Ka	Gn	Gd	Cu	PH		Da	LC			SH	HB		La
Viola sieberiana							Mu						Gn	Gd											
Vitaceae																									
Cayratia clematidea	Bd	BW		Sp	Lo	Mm	Mu	Be	KC		An				Cu	PH							HB		
Cissus antarctica	Bd	BW	Li						KC	Ba												SH			
Cissus hypoglauca	Bd	BW		Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH			LC			SH			La
Winteraceae																									
Tasmannia insipida		BW							KC																
Monocotyledons																									
Agavaceae																									
Doryanthes excelsa		BW				Mm																			
Amaryllidaceae																									
Crinum pedunculatum			Li																						La
Anthericaceae (Liliaceae)																									
Alania endlicheri		BW																							
Arthropodium milleflorum									KC						Cu										
Arthropodium minus		BW			Lo																				
Caesia parviflora								Be					Gn	Gd		PH			LC					Wo	
Caesia vittata		BW	Li	Sp		Mm			KC		An	Ka					DH	Da		Ma					
Laxmannia gracilis		BW						Be						Gd					LC	Ma			HB		
Sowerbaea juncea	Bd	BW							KC					Gd						Ma					La
Thysanotus juncifolius	Bd	BW			Lo		Mu		KC		An			Gd		PH		Da				SH			
Thysanotus tuberosus		BW		Sp			Mu						Gn			PH		Da	LC	Ma		SH			La
Tricoryne elatior		BW			Lo		Mu																		
Tricoryne simplex								Be										Da	LC						
Araceae																									
Gymnostachys anceps	Bd	BW			Lo	Mm	Mu		KC			Ka													
Archontophoenix cunninghamiana	Bd																								
Livistona australis	Bd	BW				Mm	Mu		KC	Ba	An	Ka	Gn									SH		Wo	
Asphodeliaceae (Liliaceae)																									
Bulbine bulbosa								Be																	
Centrolepidaceae																									
Centrolepis fascicularis												Ka										SH			La
Centrolepis strigosa								Be						Gd								SH		Wo	La
Colchicaceae (Liliaceae)																									
Burchardia umbellata		BW					Mu	Be	KC		An	Ka		Gd		PH			LC	Ma		SH		Wo	La
Commelinaceae																									
Aneilema acuminatum						Mm																			
Commelina cyanea	Bd		Li		Lo	Mm	Mu	Be	KC	Ba	An		Gn			PH			LC			SH	HB	Wo	La
Cyperaceae																									
Baumea acuta		BW																				SH			La
Baumea articulata					Lo								Gn												
Baumea gunnii																									La
Baumea juncea		BW		Sp	Lo	Mm	Mu		KC				Gn	Gd					LC			SH			La
Baumea muelleri												Ka													
Baumea nuda *(Schoenus nudus)*												Ka								Ma					La
Baumea rubiginosa		BW					Mu		KC		An			Gd					LC						La
Baumea teretifolia																									La
Bolboschoenus caldwelli																							HB		
Carex appressa	Bd	BW					Mu															SH			
Carex breviculmis									KC						Cu										
Carex fascicularis							Mu																		
Carex pumila																									La
Caustis flexuosa	Bd	BW		Sp	Lo	Mm	Mu	Be	KC			Ka	Gn	Gd		PH		Da	LC	Ma		SH			
Caustis pentandra	Bd	BW	Li			Mm	Mu	Be	KC				Gn	Gd					LC	Ma		SH			La
Chorizandra cymbaria		BW											Gn	Gd											La
Chorizandra sphaerocephala		BW																							La

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Cyathochaeta diandra	Bd	BW			Lo	Mm	Mu	Be	KC			Ka	Gn	Gd		PH		Da	LC	Ma	Wa	SH	HB		La
Cyperus laevis		BW							KC		An											SH			
Cyperus polystachyos		BW			Lo			Be	KC		An											SH	HB		La
Cyperus sanguinolentus																							HB		
Cyperus tetraphyllus															Cu										
Eleocharis gracilis							Mu						Gn												
Eleocharis minuta																									La
Eleocharis sphacelata		BW											Gn							Ma					La
Fimbristylis dichotoma								Be			An													Wo	
Gahnia aspera		BW				Mm	Mu	Be	KC	Ba															
Gahnia clarkei	Bd	BW			Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd								SH			
Gahnia erythrocarpa		BW	Li		Lo		Mu	Be	KC	Ba		Ka	Gn	Gd						Ma					
Gahnia melanocarpa	Bd	BW						Be	KC	Ba		Ka													
Gahnia microstachya								Be	KC																
Gahnia radula		BW																							
Gahnia sieberiana		BW				Mm	Mu	Be	KC			Ka	Gn	Gd	Cu			Da	LC			SH			La
Gymnoschoenus sphaerocephalus		BW							KC																La
Isolepis cernua																									La
Isolepis inundata		BW					Mu	Be				Ka		Gd					LC			SH	HB		La
Isolepis nodosa	Bd	BW	Li		Lo	Mm	Mu		KC	Ba	An		Gn	Gd					LC			SH	HB		La
Lepidosperma concavum		BW			Lo	Mm	Mu		KC	Ba		Ka										SH			La
Lepidosperma elatius		BW																							
Lepidosperma filiforme		BW					Mu	Be	KC				Gn	Gd						Ma		SH			La
Lepidosperma forsythii																									La
Lepidosperma laterale	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH		Da	LC	Ma	Wa	SH	HB	Wo	
Lepidosperma limicola		BW							KC									Da							
Lepidosperma neesii		BW					Mu					Ka	Gn	Gd						Ma		SH			La
Lepidosperma urophorum		BW																							
Lepidosperma viscidum	Bd	BW					Mu	Be	KC				Gn	Gd						Ma		SH			
Ptilothrix deusta	Bd	BW					Mu	Be	KC		An		Gn	Gd		PH		Da	LC	Ma		SH			La
Schoenoplectus validus		BW											Gn						LC				HB		
Schoenus apogon					Lo						An		Gn						LC			SH	HB		La
Schoenus brevifolius	Bd	BW						Be	KC			Ka	Gn	Gd					LC	Ma		SH			La
Schoenus ericetorum	Bd	BW					Mu							Gd				Da	LC	Ma					La
Schoenus imberbis		BW	Li	Sp	Lo	Mm	Mu	Be	KC			Ka	Gn	Gd		PH			LC	Ma		SH			
Schoenus lepidosperma		BW						Be	KC																
Schoenus maschalinus								Be														SH			
Schoenus melanostachys	Bd	BW	Li			Mm	Mu	Be		Ba	An	Ka	Gn	Gd				Da	LC	Ma	Wa			Wo	
Schoenus moorei														Gd						Ma					
Schoenus nitens																									La
Schoenus paludosus		BW					Mu	Be					Gn	Gd								SH			La
Schoenus turbinatus		BW				Mm		Be																	
Schoenus villosus		BW						Be																	
Tetraria capillaris		BW																				SH			
Tricostularia pauciflora		BW							KC				Gn									SH			La
Dioscoreaceae																									
Dioscorea transversa	Bd	BW							KC																
Eriocaulaceae																									
Eriocaulon scariosum																									La
Haemodoraceae																									
Haemodorum corymbosum		BW					Mu	Be	KC				Gn	Gd						Ma					La
Haemodorum planifolium	Bd	BW					Mu	Be	KC		An	Ka		Gd		PH			LC	Ma		SH			
Hydrocharitaceae																									
Ottelia ovalifolia																			LC						La
Hypoxidaceae																									
Hypoxis hygrometrica																			LC						
Iridaceae																									
Libertia paniculata	Bd	BW																							
Patersonia fragilis		BW						Be														SH			La
Patersonia glabrata	Bd	BW		Sp	Lo		Mu	Be	KC	Ba		Ka	Gn	Gd		PH		Da	LC	Ma		SH			La
Patersonia longifolia		BW				Mm	Mu	Be																Wo	
Patersonia sericea	Bd	BW				Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH		Da	LC	Ma		SH			
Juncaceae																									
Juncus continuus	Bd				Lo		Mu	Be			An	Ka	Gn	Gd						Ma		SH			
Juncus kraussii subsp. *australiensis*	Bd	BW			Lo	Mm	Mu	Be	KC	Ba			Gn	Gd					LC				HB		La

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Juncus pallidus																						SH			La
Juncus planifolius	Bd	BW					Mu	Be	KC			Ka							LC	Ma		SH			La
Juncus prismatocarpus		BW						Be					Gn							Ma		SH			
Juncus subsecundus								Be																	
Juncus usitatus		BW				Mm	Mu	Be	KC	Ba												SH	HB		La
Juncaginaceae																									
Triglochin procerum		BW											Gn									SH	HB		
Triglochin striatum	Bd	BW						Be						Gd					LC				HB	Wo	La
Lemnaceae																									
Spirodela punctata						Mm																			
Lomandraceae																									
Lomandra brevis		BW						Be					Gn												
Lomandra confertifolia	Bd	BW		Sp	Lo		Mu	Be	KC																
Lomandra cylindrica		BW					Mu	Be	KC			Ka		Gd				Da	LC						
Lomandra filiformis	Bd	BW	Li		Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd	Cu			Da	LC	Ma	Wa	SH		Wo	La
Lomandra fluviatilis						Mm		Be					Gn	Gd											
Lomandra glauca	Bd	BW		Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH		Da	LC	Ma		SH	HB		La
Lomandra gracilis				Sp	Lo		Mu	Be				Ka	Gn	Gd	Cu			Da	LC						
Lomandra longifolia	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Lomandra micrantha								Be																	
Lomandra multiflora	Bd	BW				Mm	Mu	Be	KC	Ba	An	Ka		Gd	Cu	PH			LC	Ma	Wa				La
Lomandra obliqua	Bd	BW		Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH		Da	LC	Ma	Wa	SH		Wo	La
Luzuriaceae (Philesiaceae)																									
Eustrephus latifolius	Bd	BW	Li		Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC			SH	HB	Wo	La
Geitonoplesium cymosum	Bd	BW				Mm	Mu	Be	KC	Ba	An	Ka	Gn		Cu				LC			SH			La
Orchidaceae																									
Acianthus caudatus var. *caudatus*		BW				Mm		Be				Ka	Gn			PH				Ma					
Acianthus exsertus						Mm		Be				Ka	Gn		Cu	PH			LC						
Acianthus fornicatus		BW				Mm	Mu	Be				Ka	Gn			PH						SH			La
Arthrochilus proxilus											An	Ka													
Bulbophyllum crassulifolium		BW																							
Bulbophyllum exiguum		BW				Mm			KC																
Caladenia caerulea						Mm							Gn			PH				Ma					
Caladenia carnea var. *carnea*		BW		Sp		Mm		Be			An	Ka	Gn			PH			LC			SH			
Caladenia catenata (C. alba)		BW				Mm	Mu	Be	KC		An		Gn	Gd	Cu	PH	DH					SH			
Caladenia deformis						Mm																			
Caladenia testacea						Mm		Be																	
Caleana major	Bd	BW				Mm			KC			Ka	Gn	Gd		PH									La
Calochilus campestris		BW				Mm					An	Ka	Gn			PH		Da	LC			SH	HB		
Calochilus paludosus		BW				Mm							Gn												La
Calochilus robertsonii			Li			Mm							Gn	Gd				Da							La
Chiloglottis diphylla													Gn												
Chiloglottis reflexa						Mm		Be			An	Ka	Gn			PH								Wo	
Chiloglottis trapeziformis											An		Gn									SH			
Corybas aconitoflorus						Mm						Ka	Gn			PH									
Corybas pruinosus															Cu	PH									
Corybas unguiculatus													Gn												
Cryptostylis erecta	Bd	BW	Li			Mm		Be	KC		An	Ka	Gn	Gd		PH			LC		Wa	SH			La
Cryptostylis subulata						Mm	Mu	Be	KC	Ba		Ka	Gn	Gd		PH			LC			SH			
Cymbidium suave	Bd	BW			Lo	Mm	Mu	Be	KC			Ka	Gn	Gd		PH			LC						
Cyrtostylis reniformis		BW							KC																
Dendrobium aemulum		BW										Ka													
Dendrobium linguiforme	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba		Ka	Gn	Gd		PH						SH			
Dendrobium speciosum	Bd	BW	Li			Mm	Mu	Be	KC			Ka	Gn	Gd		PH						SH			
Dendrobium striolatum									KC																
Dendrobium teretifolium						Mm																			
Dipodium punctatum	Bd	BW	Li			Mm	Mu	Be	KC		An	Ka	Gn	Gd	Cu	PH						SH			
Dipodium variegatum													Gn	Gd											
Diuris aurea	Bd	BW				Mm			KC		An		Gn			PH		Da	LC						
Diuris brevifolia																						SH			
Diuris sulphurea						Mm																			
Eriochilus cucullatus		BW				Mm							Gn												
Galeola cassythoides																						SH			
Gastrodia sesamoides		BW						Be				Ka										SH			
Genoplesium baueri						Mm							Gn			PH									
Genoplesium fimbriatum											An		Gn												
Genoplesium pumilum													Gn												
Glossodia major		BW				Mm							Gn			PH									
Glossodia minor		BW				Mm	Mu	Be	KC				Gn	Gd		PH			LC	Ma					

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Liparis reflexa	Bd	BW			Lo	Mm	Mu	Be	KC			Ka	Gn	Gd											
Lyperanthus nigricans		BW				Mm																			
Lyperanthus suaveolens		BW				Mm	Mu						Gn					Da							La
Microtis parviflora											An		Gn												
Microtis rara													Gn												
Microtis unifolia		BW				Mm		Be				Ka	Gn					Da							La
Orthoceras strictum						Mm			KC				Gn									SH			
Plectorrhiza tridentata		BW																							
Prasophyllum aureoviride		BW																							
Prasophyllum australe																PH									
Prasophyllum elatum		BW				Mm	Mu		KC				Gn			PH			LC	Ma					
Prasophyllum fimbriatum		BW												Gd		PH									
Prasophyllum morrissii		BW				Mm																			
Prasophyllum ruppii var. *ruppii*																PH									
Prasophyllum striatum								Be					Gn												
Pterostylis acuminata						Mm		Be			An	Ka	Gn			PH									La
Pterostylis baptistii													Gn												
Pterostylis coccinea																			LC						
Pterostylis concinna													Gn									SH			
Pterostylis curta		BW				Mm				Ba			Gn									SH			
Pterostylis daintreana						Mm							Gn												
Pterostylis grandiflora												Ka	Gn			PH									
Pterostylis longifolia		BW						Be				Ka	Gn	Gd		PH									
Pterostylis nutans		BW		Sp					KC		An	Ka	Gn			PH					Wa	SH			
Pterostylis obtusa						Mm																			
Pterostylis ophioglossa			Li																						
Pterostylis parviflora						Mm										PH									
Pterostylis pedunculata		BW											Gn		Cu										
Rimacola elliptica		BW											Gn	Gd					LC	Ma					
Sarcochilus australis						Mm										PH									
Spiranthes sinensis																									
subsp. *australis*		BW						Be					Gn												
Thelymitra carnea													Gn												
Thelymitra ixioides var. *ixioides*		BW		Sp		Mm	Mu	Be	KC		An	Ka	Gn	Gd		PH			LC			SH			
Thelymitra media									KC							PH									
Thelymitra nuda													Gn												
Thelymitra pauciflora						Mm							Gn												La
Thelymitra rubra var. *rubra*																PH									
Philydraceae																									
Philydrum lanuginosum		BW						Be	KC				Gn											Wo	
Phormiaceae (Liliaceae)																									
Blandfordia nobilis								Be	KC			Ka	Gn	Gd		PH				Ma		SH			La
Dianella caerulea var. *caerulea*	Bd	BW	Li		Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd		PH	DH	Da	LC	Ma	Wa	SH	HB		La
Dianella caerulea var. *producta*						Mm				Ba			Gn									SH		Wo	
Dianella longifolia																									
var. *longifolia*		BW				Mm	Mu	Be															HB		
Dianella prunina						Mm							Gn	Gd					LC						
Dianella revoluta		BW	Li	Sp	Lo	Mm	Mu	Be	KC					Gd	Cu	PH		Da	LC	Ma	Wa	SH	HB	Wo	La
Stypandra glauca	Bd					Mm			KC																
Thelionema caespitosum																PH			LC	Ma		SH			
Thelionema umbellatum	Bd	BW							KC					Gd								SH			La
Poaceae																									
Agrostis aemula																							HB		
Agrostis avenacea		BW										Ka	Gn										HB		La
Agrostis billardieri																									La
Ancistrachne maidenii								Be																	
Anisopogon avenaceus	Bd	BW			Lo	Mm	Mu	Be	KC		An	Ka	Gn	Gd					LC	Ma		SH			
Aristida benthamii																									
var. *spinulifera*		BW			Lo			Be																	
Aristida calycina var. *calycina*							Mu																		
Aristida ramosa var. *ramosa*																			LC				HB	Wo	La
Aristida vagans		BW		Sp	Lo			Be	KC		An	Ka	Gn					Da	LC		Wa	SH	HB	Wo	
Aristida warburgii		BW										Ka											HB	Wo	La
Austrofestuca littoralis	Bd																								La
Chionochloa pallida	Bd																								
Cymbopogon refractus		BW		Sp	Lo			Be	KC		An	Ka	Gn										HB	Wo	La
Cynodon dactylon		BW					Mu	Be														SH	HB		La
Danthonia linkii var. *linkii*								Be															HB		
Danthonia longifolia						Mm						Ka										SH			
Danthonia pilosa var. *pilosa*	Bd																								
Danthonia setacea																				Ma			HB		
Danthonia tenuior							Mu	Be	KC		An	Ka	Gn	Gd			DH	Da		Ma		SH	HB	Wo	La
Deyeuxia decipiens												Ka						Da		Ma					
Deyeuxia quadriseta	Bd											Ka													

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Dichelachne crinita						Mm														Ma		SH	HB		La
Dichelachne micrantha		BW		Sp		Mm	Mu	Be	KC		An	Ka					DH	Da	LC	Ma		SH	HB		La
Dichelachne rara		BW						Be				Ka			Cu		DH	Da						Wo	
Digitaria brownii								Be																	
Digitaria didactyla	Bd												Gn									SH			La
Digitaria diffusa								Be																	
Digitaria parviflora	Bd	BW			Lo		Mu	Be	KC		An	Ka	Gn		Cu							SH		Wo	
Digitaria ramularis								Be																	
Echinopogon caespitosus	Bd	BW			Lo	Mm	Mu	Be			An	Ka	Gn	Gd			DH		LC		Wa	SH	HB	Wo	
Echinopogon ovatus							Mu	Be	KC								DH				Wa		HB		
Elymus scaber var. *scaber*																							HB		
Entolasia marginata	Bd	BW					Mu	Be	KC		An	Ka	Gn	Gd							Wa	SH	HB		
Entolasia stricta	Bd	BW	Li		Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu			Da	LC	Ma	Wa	SH	HB		La
Eragrostis benthamii				Sp				Be				Ka											HB		
Eragrostis brownii	Bd	BW			Lo	Mm	Mu	Be	KC		An	Ka	Gn					Da		'Ma		SH	HB	Wo	La
Eragrostis leptostachya					Lo		Mu	Be															HB		
Hemarthria uncinata var. *uncinata*	Bd	BW																				SH			La
Imperata cylindrica var. *major*	Bd	BW		Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Isachne globosa													Gn												
Microlaena stipoides var. *stipoides*		BW			Lo		Mu	Be			An	Ka	Gn	Gd	Cu		DH	Da	LC	Ma	Wa		HB	Wo	La
Oplismenus aemulus		BW				Mm		Be			An				Cu		DH	Da				SH			
Oplismenus imbecillis	Bd	BW				Mm	Mu	Be	KC	Ba	An	Ka	Gn		Cu			Da			Wa	SH			
Panicum effusum											An														
Panicum obseptum								Be			An														
Panicum simile	Bd	BW			Lo		Mu	Be	KC		An	Ka	Gn				DH		LC		Wa	SH	HB	Wo	La
Paspalidium albovillosum												Ka													
Paspalidium aversum																							HB		
Paspalidium distans	Bd	BW			Lo						An	Ka										SH			La
Paspalum distichum (*P. paspalodes*)																							HB		
Paspalum orbiculare												Ka													
Paspalum vaginatum (*P. distichum*)														Gd											
Phragmites australis	Bd	BW	Li			Mm	Mu	Be	KC				Gn	Gd					LC				HB	Wo	La
Plinthanthesis paradoxa												Ka													La
Poa affinis	Bd	BW	Li			Mm	Mu	Be	KC		An	Ka		Gd								SH			
Poa labillardieri																							HB		
Poa poiformis	Bd								KC																La
Poa queenslandica																					Wa				
Poa sieberiana var. *sieberiana*																							HB		
Sacciolepis indica																						SH			
Spinifex sericeus	Bd		Li																						La
Sporobolus elongatus															Cu										
Sporobolus virginicus var. *virginicus*				Sp	Lo	Mm	Mu	Be	KC				Gn	Gd					LC				HB		
Stipa mollis																									La
Stipa pubescens		BW			Lo		Mu	Be	KC		An	Ka									Wa		HB		
Stipa ramosissima								Be															HB		
Stipa rudis subsp. *rudis*	Bd																								
Tetrarrhena juncea		BW					Mu		KC			Ka		Gd											
Themeda australis	Bd	BW	Li		Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Zoysia macrantha									KC					Gd								SH	HB		La
Potamogetonaceae																									
Ruppia maritima																							HB		
Restionaceae																									
Empodisma minus		BW					Mu	Be	KC		An	Ka	Gn	Gd					LC	Ma		SH			La
Hypolaena fastigiata	Bd	BW						Be	KC				Gn							Ma		SH			La
Leptocarpus tenax		BW						Be	KC			Ka	Gn	Gd						Ma		SH			La
Lepyrodia anarthria							Mu																		
Lepyrodia scariosa	Bd	BW				Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd				Da	LC	Ma		SH		Wo	La
Restio complanatus		BW										Ka	Gn	Gd								SH			La
Restio dimorphus		BW							KC				Gn	Gd						Ma		SH			
Restio fastigiatus		BW						Be	KC			Ka	Gn	Gd						Ma		SH			
Restio gracilis		BW																							
Restio tetraphyllus	Bd	BW							KC				Gn							Ma		SH			La
Ripogonaceae (Smilacaceae)																									
Ripogonum album																PH									
Ripogonum fawcettianum	Bd																								

Botanical name	Bd	BW	Li	Sp	Lo	Ma	Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH	DH	Da	LC	Ma	Wa	SH	HB	Wo	La
Smilacaceae																									
Smilax australis	Bd	BW				Mm	Mu	Be	KC	Ba	An	Ka	Gn						LC				HB		
Smilax glyciphylla	Bd	BW	Li		Lo		Mu	Be	KC	Ba	An	Ka	Gn	Gd	Cu	PH		Da	LC	Ma		SH		Wo	La
Typhaceae																									
Typha domingensis																							HB		
Typha orientalis								Be	KC				Gn						LC			SH	HB		
Uvulariaceae (Liliaceae)																									
Schelhammera undulata	Bd	BW			Lo	Mm			KC	Ba	An	Ka	Gn						LC			SH			
Xanthorrhoeaceae																									
Xanthorrhoea arborea	Bd	BW	Li	Sp	Lo	Mm	Mu	Be	KC	Ba	An	Ka	Gn	Gd		PH			LC			SH			
Xanthorrhoea macronema	Bd	BW		Sp		Mm			KC																
Xanthorrhoea media	Bd					Mm	Mu	Be	KC			Ka	Gn	Gd		PH			LC	Ma	Wa	SH		Wo	
Xanthorrhoea minor													Gn		Cu						Wa	SH			
Xanthorrhoea resinifera (*X. resinosa*)		BW		Sp		Mm	Mu	Be	KC				Gn	Gd				Da		Ma		SH			La
Xyridaceae																									
Xyris complanata								Be																	
Xyris gracilis subsp. *gracilis*	Bd	BW		Sp	Lo			Be	KC				Gn	Gd								SH			La
Xyris gracillis subsp. *laxa*		BW		Sp					KC																
Xyris juncea								Be	KC																
Xyris operculata	Bd	BW		Sp		Mm	Mu		KC				Gn									SH			La

Discussion

Regional affinities

Sydney's Hawkesbury Sandstone vegetation is part of the world-renowned Sydney Basin sandstone flora. The flora represents probably the richest assemblage of xeromorphic species in eastern Australia and is a remnant of the xeromorphic assemblage that has spanned the continent in the past, especially in the south (Beadle 1981). Sandstone vegetation is part of Beadle's Eucalypt Woodlands and Forests on Soils of Low Fertility Chiefly on the Eastern Coastal Lowlands (Beadle 1981), and Coastal sandstone in particular of his *Eucalyptus gummifera–Eucalyptus racemosa–Eucalyptus sieberi* Alliance.

The forests on shale are part of Beadle's Tall Eucalyptus Forests of the Eastern Coastal Lowlands mostly on Soils of Higher Fertility, and generally attributable to his *Eucalyptus pilularis* Alliance, *Eucalyptus maculata* Alliance or *Eucalyptus saligna* Alliance.

The coastal sand dune remnants are probably the southern extremity of the north coastal Wallum country (and part of Beadle's *Banksia aemula* [=*B. serratifolia*] and related Alliances). Saltmarsh vegetation includes mixtures of tropical and temperate influences, while mangroves, with only two species in the Sydney area, reflect a decreasing species richness in southern Australia.

Historical changes

The vegetation map provides a picture of the distribution of vegetation at one point in the present time, and while it is obvious that these patterns have changed since 1788 as a result of clearing, it is not always appreciated that there has been considerable change in vegetation distribution as climate and geological patterns have changed over thousands and millions of years. Although our knowledge of these past conditions is still sketchy, we are beginning to see some of the patterns, at least of the more recent past. For example, during the last 1.8 million years (in the Quaternary Period) colder and warmer periods alternated (Chapman et al. 1982, Benson & Howell 1990a). Dune sands were blown inland from the coast where today's southern and eastern suburbs lie. About 20 000 years ago, during the coldest part of the last of the Pleistocene ice ages, the sea fell to its lowest level, 120–140 m below the present. As it rose again to reach its present level about 6 000 years ago, it drowned the coastal river valleys to form Broken Bay and Pittwater, Sydney Harbour, Botany Bay and Port Hacking, and swept up the offshore sands on to the modern beaches, sometimes damming smaller streams to form lagoons such as at Narrabeen and Dee Why.

Pollen and charcoal analyses of sediments from South Salvation Creek Swamp in Ku-ring-gai Chase National Park (Kodela & Dodson 1989) indicate that pollen influx has been dominated by local swamp species and dry sclerophyll heath and woodland taxa for the last 6 000 radiocarbon years, but that fluctuations in their abundances and/or distributions have occurred. These are likely to be the result of a combination of factors, including watertable fluctuations, seasonal drought, fire activity, interspecific competition, the natural changing patterns in species distributions and the impact of Aboriginal and European people. None of these recent vegetation changes could be ascribed directly to climatic shifts, though changes in swamp and terrestrial pollen taxa around 2000 B.P. may indicate a drier climate than the present.

The impact of the Aborigines

Aboriginal people have been associated with the Sydney area for many thousands of years. Favoured living places were along the shorelines and along the Hawkesbury–Nepean River flats (Kohen & Lampert 1987, Kohen & Downing 1992).

On the coast plentiful supplies of seafood were supplemented with fruits, nectar, roots and tubers from plants growing on the extensive sand dunes and swamps that stretched from Bondi to Botany Bay and in the shrubby woodland and open-forest of the rocky harbour foreshores and nearby sandstone country (Benson & Howell 1990a). Sandstone gullies with rainforest-type vegetation would have provided further food sources, together with rocky overhangs and caves suitable for shelters and work sites.

It is hard to tell whether Aboriginal people altered the natural distribution or abundance of any food species either deliberately by planting, or accidentally by leaving remains associated with camp sites, nor is there evidence for changes in species abundance due to over-exploitation. However, Aboriginal people affected the vegetation by their use of fire and there has been a considerable amount written on this (e.g. see Nicholson, 1981). Many accounts contain very generalised statements often making reference to Aboriginal fire usage in Central and Northern Australia. Such usage does not necessarily apply to Southern Australia and, as far as the Sydney area is concerned, only limited observations were recorded before the effects of European settlement quickly overwhelmed Aboriginal society.

Possibly the most important point is that the Aborigines are likely to have managed different types of country differently. For example, they are likely to have burnt the open grassy understorey of the typical Cumberland Plain vegetation of western Sydney fairly frequently, probably with creeping or low-intensity fires. Such fires would have stimulated green shoots and provided favourable conditions for grazing animals. They would also have stimulated flowering in tuberous herbs such as orchids, which would have made them conspicuous. It is likely that such fires burnt at low intensity, as the trees were well-spaced and there would be limited fuel build-up. Such fires would be easily stopped by geographical features such as creeks, or indeed tracks, resulting in a patchy mosaic of burnt areas.

On the sandstone areas, however, it is likely that there were fewer fires, but that they burnt at higher intensities. Because of the shrubby nature of the vegetation, there would probably have been less game, and Aboriginal movement would have been more restricted by the topography than on the open Cumberland Plain. It seems less likely that deliberate burning would have been carried out on a broadscale basis, and more likely to have been localised around campsites and travelling routes to keep them clear, as well as around small-scale hunting sites such as individual

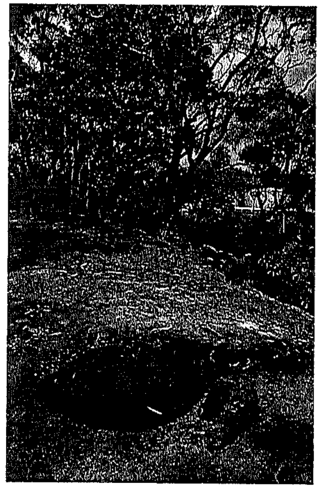


Figure 30. Signs of Aboriginal occupation, such as these axe-grinding grooves beside a rock pool, may still be found in bushland reserves within a few kilometres of the city centre.

trees. It is likely that hot summer fires would have been a feature of the sandstone areas, possibly on a 10–20 year cycle. On the sandstone the understorey is shrubby and very varied. Most species regenerate after fire, but some are killed, and it takes 3–10 years for recovery to reproductive maturity of most of these shrub species (Bradstock & Myerscough 1981, Benson 1985, Bradstock 1990). Clark & McLoughlin (1986) report similar findings for the Lane Cove valley catchment, where burning was likely to have been more frequent on the shale ridges (at 1–5 year intervals) than on the sandstone slopes (7–15 year intervals).

The impact of the Europeans

An idea of how the country around Sydney appeared to the British colonists comes through in this 1827 description by writer Peter Cunningham, not to be confused with Allan Cunningham, the botanist. 'In Cumberland, the land immediately bordering upon the coast is of a light, barren, sandy nature, thinly be sprinkled with stunted bushes; while from ten to fifteen miles interiorly, it consists of a poor clayey or ironstone soil, thickly covered with our usual evergreen forest timber and underwood. Beyond this commences a fine timbered country, perfectly clear of bush, through which you might, generally speaking, drive a gig in all directions, without any impediment in the shape of rocks, scrubs or close forest. This description of country commences immediately beyond Parramatta on one hand, and Liverpool on the other; stretching in length south easterly obliquely towards the sea, about forty miles and varying in breadth near twenty. The soil upon the immediate banks of the rivers is generally rich flooded alluvial, but in the forests partakes commonly of a poor clayey or ironstone nature, yet bearing tolerably crops, even without manure, at the outset'.

This extract clearly shows how the geology and its accompanying vegetation directed the pattern of settlement. The barren Hawkesbury Sandstone and aeolian sand deposits of the country around Port Jackson, particularly the present Eastern Suburbs, i.e. 'immediately bordering upon the coast', with its stunted sclerophyllous vegetation, was agriculturally useless to the settlers. 'Ten to fifteen miles interiorly' would have included country from Homebush and Bankstown, west to Parramatta and Liverpool which had Wianamatta Shale with ironstones and clay soil. This would have supported eucalypt open forests with shrubby understoreys including much Paperbark, *Melaleuca decora*. Beyond Liverpool and Parramatta is the 'fine timbered' Cumberland Plain, gently undulating to flat country with deep clay soils supporting an open grassy woodland community. The rich alluvial soils on the river banks are mentioned, but no reference is made of the tall open forest that this supported. Much of this forest, particularly on the Hawkesbury, had been cleared for agriculture by 1830.

From very early days some plant communitites were sought and cleared, while others were avoided. With the exception of small areas at Sydney (at Farm Cove) and at Rose Hill, the first intensively cultivated lands were the rich alluvial flats of the Hawkesbury–Nepean River at Windsor and Richmond. At the same time the grassy woodlands of the Cumberland Plain were beginning to be grazed. Sheep were the main grazing animals and were at first tended by shepherds until fencing made them redundant. The granting of land was followed by sporadic clearing of trees to encourage the growth of grass, then more extensive ring-barking or sapping. Extensive areas were often cleared of every tree. In 1844, for example, Mrs Meredith described how 'Homebush', halfway between Sydney and Parramatta, had been completely cleared of every tree for 1000 acres (Benson & Howell 1990a). Along the North Shore, and the northern suburbs from Epping to Hornsby, the tall open-forests of Blackbutt and Blue Gum were logged and then, because of the good soil and high rainfall, cleared to make way for dairy farms and orchards. In contrast, the shrubby forests and woodlands on the Hawkesbury Sandstone, because of their poor agricultural soils, remained largely undisturbed and were used only as sources of firewood, fence posts or small timber.

From the 1850s railway lines were built, radiating from Sydney. For engineering reasons these followed the most level routes. This was generally along the Wianamatta Shale country to the west and south, and later along the North Shore ridge to Hornsby. Suburbs followed the railways, and by the turn of the century extensive housing had spread from Sydney to Burwood in the west and to Hurstville in the south. Electric tramways made other areas accessible for housing, particularly in the harbourside Eastern suburbs, where the rows of stepped terrace houses which were built emphasize the steep nature of the original sandstone topography. Ferry services opened other harbourside sandstone sites to suburban development; for example Balmain, Mosman and the lower North Shore.

The North Shore railway, the car and the Sydney Harbour Bridge made the North Shore area increasingly accessible. Its remnant tall Blackbutts and Blue Gum trees, its milder climate, compared with the western suburbs of Sydney, and the adjacent

natural bushland gullies along the rugged Lane Cove River valley and upper Middle Harbour have made this one of the most sought after of Sydney's suburban areas. Particularly since the Second World War, bushland on Hawkesbury Sandstone has been increasingly cleared for suburban housing though there has been an increasing interest in retaining native vegetation as urban bushland. By contrast, and mainly because of the gentler topography of the country and lack of obviously colourful shrubs, bushland on the shale areas of western Sydney has been cleared for suburban development with little recognition given to any native plants that manage to survive.

Rare or endangered species

The occurrence of species in the major conservation areas (Table 4) gives a measure of the floristic richness of the map sheet area. For example, 566 native species and 82 exotic species have been recorded from Ku-ring-gai Chase National Park (Thomas & Benson 1985a). Seventy-eight significant plant species are listed for the Sydney map sheet area (Table 5), forty-one of which are listed as nationally rare or endangered species (Briggs & Leigh 1988) or of regional significance. Species listed are either rare, threatened or of botanical significance in terms of geographic distribution. The list contains species of varying rarity and conservation status: for example, *Allocasuarina portuensis* is a recently discovered species restricted to Sydney Harbour National Park; a number of the *Darwinia* species have locally restricted distributions; and *Tetratheca juncea* originally occurred in the Carlton to Undercliff area but is now almost certainly extinct there (Payne 1993). *Lampranthus tegens*, possibly originating in South Africa but not able to be equated with any known African species, therefore needs protection of populations here (Benson & McDougall 1993). Other species are restricted to fragments of almost totally cleared vegetation types, e.g. Eastern Suburbs *Banksia* scrub. Vegetation surveys for major conservation reserves generally include specific lists for those areas (e.g. Thomas & Benson 1985a, b).

Figure 31. The rare plant *Kunzea rupestris* is confined to a few rock platforms in north-western Sydney.

Table 5. Species of particular conservation significance within the Sydney 1:100 000 map sheet area

Species listed here are either rare or threatened, or of botanical significance in terms of geographic distribution or localised populations disjunct from other occurrences. Localities refer to Sydney map sheet occurrences. Conservation codings are from Briggs & Leigh (1988) with current ROTAP updatings. Nth = northern, Sth = southern, NP = National Park, NR = Nature Reserve

Family/species	Habitat/locality	Significance
Aizoaceae		
Lampranthus tegens	Saltmarsh, Homebush Bay	Only known wild populations of this species (Benson & McDougall 1993)
Apiaceae		
Lilaeopsis polyantha	Dee Why Lagoon	Local population
Platysace clelandii	Muogamarra NR, Marramarra Creek	2RCa
Platysace stephensonii	Ridgetop, Deep Creek	3RC-
Araliaceae		
Astrotricha crassifolia	Woy Woy, Warrah	Local endemic
Casuarinaceae		
Allocasuarina diminuta	Kingsford	Local disjunct population
Allocasuarina nana	Ridgetop, Deep Creek	Local disjunct population
Allocasuarina portuensis	Nielsen Park	2ECit, local endemic
Chenopodiaceae		
Halosarcia pergranulata subsp. *pergranulata*	Saltmarsh, Homebush Bay	Local disjunct population
Convolvulaceae		
Wilsonia backhousei	Saltmarsh, Homebush Bay	Local population, rare
Dilleniaceae		
Hibbertia nitida	Thornleigh, Garigal NP, Oatley	2RC-
Hibbertia virgata	Sand dunes, Eastern Suburbs	Nth-limit
Epacridaceae		
Epacris purpurascens var. *purpurascens*	Gosford–Sydney	2KC-, local endemic
Euphorbiaceae		
Bertya brownii	Katandra, Mona Vale	2RC-, Sth-limit
Pseudanthus pimeleoides	Open-forest, ridges, Terrey Hills	Local populations, rare
Fabaceae		
Acacia bynoeana	Pennant Hills, Northbridge, Mosman, Cooks River	3VC-, probably locally extinct
Acacia quadrilateralis	Malabar	Sth-limit, locally extinct
Acacia pubescens	Bankstown, Belmore, Flemington, Rookwood	2VCa
Daviesia umbellulata	Pittwater	Rare local population
Mirbelia speciosa	Marramarra, Ku-ring-gai	Uncommon
Pultenaea dentata	Coastal heath, La Perouse Nth-limit	Local disjunct population
Pultenaea hispidula	Belrose, Allambie, shale/lateritic soils	Local populations, uncommon
Pultenaea pedunculata	Yennora	Local population, probably extinct in NSW
Pultenaea viscosa	Open-forest, Pennant Hills Park	Rare
Goodeniaceae		
Dampiera scottiana	Marramarra	Local disjunct population Nth-limit
Haloragaceae		
Gonocarpus salsoloides	North Head, Rose Bay, La Perouse	3RCa, local populations
Haloragodendron lucasii	Barra brui	2ECi, local endemic, rare
Lamiaceae		
Prostanthera denticulata	Lower hillslopes, Ku-ring-gai Chase NP Garigal NP	Local endemic, uncommon
Loganiaceae		
Logania pusilla	Muogamarra, Katandra	Local populations, rare
Myrtaceae		
Angophora crassifolia	Ridgetop, Deep Creek Frenchs Forest	2RCa, local endemic
Darwinia biflora	Hawkesbury River–Port Jackson	2VCa, local endemic
Darwinia diminuta	Terrey Hills–Manly–Sutherland–Bulli	3RCi, local endemic
Darwinia leptantha	Coastal heath, North Head–Cronulla	Local disjunct population
Darwinia peduncularis	Hornsby–Hawkesbury River	3RCi, local disjunct populations
Darwinia procera	Gosford–Manly	2RCa, local endemic
Eucalyptus acmenoides	Wianamatta Shale, Galston, Ryde	Rare, Sth-limit
Eucalyptus camfieldii	North Head, Killara, Hornsby, Ku-ring-gai Chase NP, Dural	2VCi, local populations
Eucalyptus capitellata	Residual clay cappings Brisbane Water NP St Ives, Allambie Heights	Local populations, now uncommon
Eucalyptus luehmanniana	Heath on sandstone, northern Sydney	2RCa, local populations
Eucalyptus robusta	Swamp-forest, Gosford, Pittwater	Local populations, now rare

Eucalyptus scias	Pittwater–Warringah	Local populations, rare
Kunzea rupestris	Canoelands, Ku-ring-gai Chase NP	2VCi, local endemic
Leptospermum deanei	Marramarra Creek, Pennant Hills Park, Middle Harbour Creek	2V, local endemic
Melaleuca deanei	Dry scrub, Hornsby, Pennant Hills Park, Lane Cove, Garigal NP, Earlwood	3RC-, local populations
Micromyrtus blakelyi	Rocky ridges, Muogamarra NR, Marramarra NP	2VCi-, local endemic
Syzygium paniculatum	Balgowlah, Wolli Creek	3VCi, local populations
Proteaceae		
Banksia aemula	Pleistocene sand, Bouddi, North Head, La Perouse	Local disjunct populations, southern limit
Grevillea caleyi	Terrey Hills to Belrose	2ECi, local endemic
Grevillea linearifolia (narrow-leaved form)	Marramarra, Arcadia	Local form
Hakea bakeriana	Marramarra	Rare, Sth-limit
Persoonia hirsuta	Deep Creek	3KCi
Persoonia mollis subsp. *maxima*	Hornsby	2E, local endemic subspecies
Symphionema paludosum	Brisbane Water NP, Belrose	Local populations, uncommon
Rutaceae		
Asterolasia elegans	Moist forest, north of Maroota	2ECi, restricted local endemic
Boronia floribunda	Open-forest, Pennant Hills Turramurra, Garigal NP	Uncommon
Boronia fraseri	Ku-ring-gai Chase NP Marramarra NP	2RCa, local endemic
Boronia serrulata	Brisbane Water, Arcadia, Ku-ring-gai Chase NP	2RC-, rare, once common in northern Sydney
Zieria involucrata	Marramarra Creek	2RCa
Sterculiaceae		
Lasiopetalum joyceae	Ku-ring-gai Chase NP, Arcadia	2RC-, local endemic
Lasiopetalum macrophyllum	Marramarra, Ku-ring-gai	Uncommon
Rulingia hermaniifolia	Coastal heath, Bouddi–Cronulla	3RCa, Nth-limit, rare
Tremandraceae		
Tetratheca glandulosa	Wisemans Ferry–Port Jackson	2VC-, local populations, Sth-limit
Tetratheca juncea	Sandstone, Carlton–Tempe, Rookwood	3VCi, Sth-limit, locally extinct
Tetratheca neglecta	Sandstone, Arncliffe–Como	3RC-, rare, Nth-limit

Monocotyledons		
Anthericaceae		
Alania endlicheri	Moist cliff-faces, Arcadia	Local population
Araceae		
Typhonium eliosurum	Patonga Creek	3RC-, rare
Cyperaceae		
Baumea muelleri	Damp heath, Katandra, Oxford Falls	Sth-limit
Gahnia filum	Saltmarsh, Georges River	Nth-limit
Lomandraceae		
Lomandra brevis	Ku-ring-gai Chase NP, Deep Creek, Kogarah	2RC-
Lomandra fluviatilis	Marramarra Creek, Deep Creek	3RCa
Orchidaceae		
Arthrochilus prolixus	Avalon	Rare local population, southern limit
Caladenia tesselata	Berowra, Castlecrag, Tempe, Penshurst	3V, probably locally extinct
Corybas undulatus	St Ives, Frenchs Forest	3KC-, probably locally extinct
Cryptostylis hunteriana	Ku-ring-gai Chase NP	3VC-
Genoplesium baueri	Ku-ring-gai Chase NP, Deep Creek	3RC-
Sarcochilus australis	Marramarra	Uncommon
Poaceae		
Ancistrachne maidenii	Berowra Creek	2KC-, local endemic
Deyeuxia appressa	Saltpan Creek, Killara	2E, local endemic

Conservation of vegetation

Despite the impact of the city of Sydney and its suburban sprawl, a surprising amount of natural vegetation has managed to survive. This includes large parklands on the edge of the suburban areas and many small patches within them. Survival has mainly been fortuitous, rather than planned. Because of the extent of the Hawkesbury Sandstone with its very limited agricultural capacity, many areas have remained uncleared, much as Crown land during the agricultural expansion of the nineteeth century.

The obvious attractiveness of the Hawkesbury Sandstone landscape scenery and flora and the relative uselessness of the land for farming led to pressure from the early and farsighted 'preservationists', in particular Eccleston du Faur, for the establishment of Ku-ring-gai Chase in 1892, Sydney's second major conservation area (following National Park (later Royal N.P) dedicated in 1879 for similar reasons). Lane Cove River National Park followed. Muogamarra Nature Reserve began as a private 'nature reserve' and was enlarged with Crown land. Marramarra National Park and Davidson State Recreation Area (now part of Garigal N.P.) were formed out of the considerable reserves of Crown land still available up to the 1980s. Similarly, the Commonwealth Government's holding of land on Sydney Harbour and Botany Bay for defence purposes inadvertently preserved much land that could have been built over but which was to become the nucleus for Sydney Harbour National Park. The rugged nature of the Hawkesbury sandstone landscape also resulted in small parks and reserves often being left in housing subdivisions in inaccessible sites.

Elsewhere the native vegetation disappeared. On the Wianamatta Shale soils woodland was cleared for grazing and agriculture, and then for suburban housing. Similar suburban development replaced the vegetation on the Eastern Suburbs sand dunes. Even with the far-sighted setting aside of Centennial Park, only a trifling patch of the original *Banksia* scrub survives, in the Bird Sanctuary. More extensive remnants survive at Long Bay and La Perouse, again largely because of Commonwealth Government control for military purposes. It is hoped these bushland areas will eventually be formally conserved. Reclamation programs to turn the mangrove and estuarine vegetation of the Parramatta and Georges Rivers into playing fields have been promoted for most of this century and have only just been stopped in time, leaving some remnants such as at Homebush Bay. Changes such as the cessation of landfill of mangroves have come about because of increased public awareness of the value of natural vegetation and the need to maintain biological diversity. This concern is now also directed towards the management and maintenance of reserved areas. There are two particularly pressing problems — exotic weed invasion and fire.

The invasion of urban bushland by exotic weed species was specifically highlighted by Adamson and Buchanan (1974), though the spread of weeds along watercourses into undisturbed areas is mentioned by Pidgeon (1938). *Ligustrum sinense* and *Ligustrum lucidum* (Privet species), *Lantana camara*, *Tradescantia albiflora* and a host of other weed species of garden escape origin, are able to invade normally resistant natural bushland where there has been some form of disturbance, particularly involving the addition of soil nutrients (Clements 1983). Characteristically these weeds form extensive thickets along creeks and drainage lines. The best method of restricting weed proliferation is to stop nutrients entering the soil from stormwater run-off and from creek floodwaters, and ways of reducing this have been suggested by Bliss et al. (1983). A method of hand-weeding was originated by Joan and Eileen Bradley in Mosman bushland (Bradley & Bradley 1966–74, Bradley 1971) and has been successfully developed as part of a bushland management strategy by the National Trust and other groups (National Trust 1991 — this also includes a list of its bushland surveys, Buchanan 1989, Bradley 1988).

The fragmentation of bushland in suburban areas and the potential fire hazard has led to the increased use of regular controlled burning for fuel reduction in some areas and decreased use of fire in others (Clark & McLoughlin 1986). Most of Sydney's native vegetation is adapted to fire, but at different frequencies for the different types and communities, because of aspect and topography. Although some species may regenerate well after fire, other species may be destroyed by frequent fire

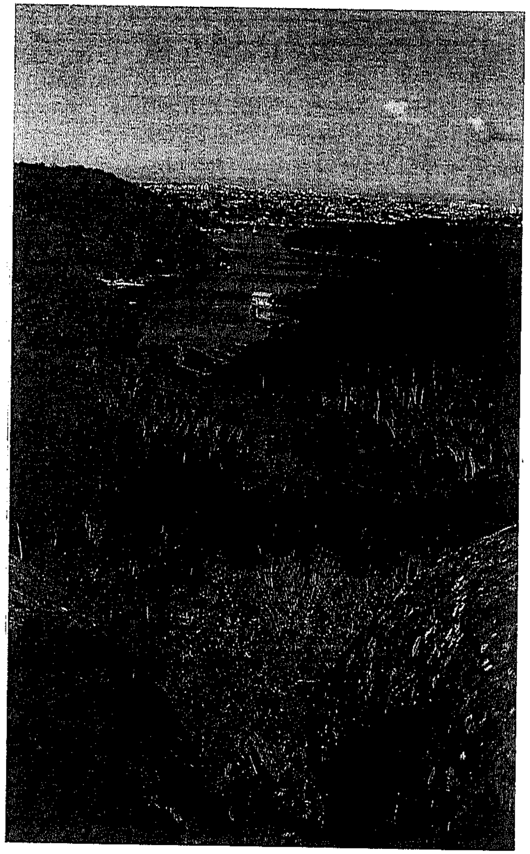
which does not allow adequate time intervals for the build-up of seed banks (Benson 1985, Bradstock 1990). This means that the length of time between fires needed for species survival varies from community to community. Fire intensity is also an important factor; low intensity burns may not stimulate adequate native seedling regeneration while allowing weed growth (Bradley 1971). Different fire management approaches are therefore needed for different communities.

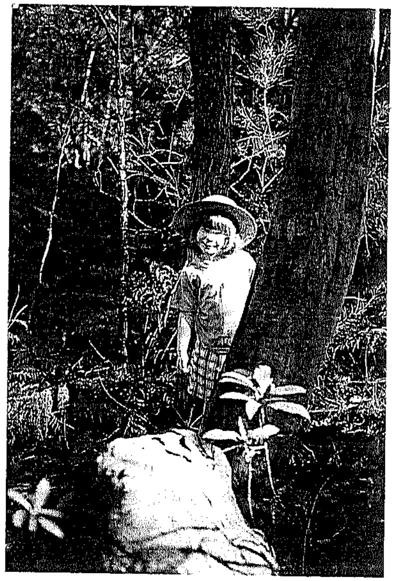
In the absence of fire, there is a tendency for species of wetter sites, such as *Pittosporum undulatum*, to predominate at the expense of those requiring fire for germination, such as members of the Fabaceae (Auld & O'Connell 1991). To achieve a balance between these factors, a long-term management program will need information based on observations on the behaviour of a wide range of species, together with a range of management options including the use of fire and selective land clearing.

The future

Sydney's bushland setting provides a major contribution to the individual character of the city. But bushland is still threatened by direct destruction for urban and recreational development, and indirectly by nutrient run-off, weed invasion, and shortsighted management. Bushland is particularly vulnerable to the 'tyranny of small decisions'. In the face of this, much of the responsibility for ensuring careful management of urban bushland has fallen to local residents and organisations keen to maintain the local identity of bushland areas. Public awareness of the need for protection and professional management of bushland is increasing, and recognition of its value needs to be supported by government policies and planning provisions at federal, state and local levels.

Such management involves the employment of professionally trained staff and the development of appropriate bushland and catchment management techniques. Management will often be constrained by lack of knowledge on the responses of plant species and vegetation. Additional supporting research is needed, as researchers are currently faced with a wide array of problems needing investigation. In the meantime, decisions will need to be made in terms of the reversibility of actions and keeping future options open. Successful conservation aims to maintain current levels of biological diversity, and this must be seen as a guiding principle.





Figures 32 & 33. Bushland slopes and gullies near urban areas provide a unique opportunity for Sydneysiders to grow up experiencing the natural world within the context of a city.

Acknowledgements

We wish to thank Helen Bryant for assistance in the collection of data, Bob Coveny for his generous assistance with plant identifications, Nining McCann and Commonwealth Employment Program (CEP) funding for assistance with the map, Lyn McDougall for assistance with the diagrams and the final manuscript, and a number of typists who assisted at different times, including Celia McGregor, Josie Sahagun, Cindy Douglas, Belinda Crews and Melinda Coles. Thanks also go to Richard McRae, Jeff Thomas and Peter Clarke for unlimited access to their data, and Chris Pratten, Lawrie Johnson, Graham Quint, Paul Adam, David Keith, Phillip Kodela, Peter Myerscough and others who provided comments and observations.

References

Adam, P. (1991) *Flora and vegetation of the eastern part of the RAN Armaments Depot Newington* (NSW Govt, Property Services Group: Sydney).

Adam, P., Stricker, P. & Anderson, D.J. (1989) Species richness and soil phosphorus in plant communities in coastal New South Wales. *Australian Journal of Ecology* 14: 189–198.

Adam, P., Stricker, P., Wiecek, B.M. & Anderson, D.J. (1989) The vegetation of sea cliffs and headlands in New South Wales, Australia. *Australian Journal of Ecology* 14: 515–547.

Adamson, D & Buchanan, R. (1974) Exotic plants in urban bushland in the Sydney region. *Proceedings of the Weed Society of New South Wales* 6: 24–27.

Allaway & Clarke (1987) Wolli Creek estuarine wetlands. *Coast & Wetlands Society Newsletter* Number 22 (November).

Andrews, A. (1984) *The Devil's wilderness: George Caley's journey to Mount Banks 1804.* (Blubber Head Press: Hobart).

Armstrong, J., Benson, D.H. & Coveny, R. (1976) The vegetation of La Perouse. Unpub. report (Royal Botanic Gardens: Sydney).

Atkinson, James (1826) *An account of the state of agriculture and grazing in New South Wales.* Facsimile Edn (Sydney University Press: Sydney, 1975).

Auld, T.D. (1986) Population dynamics of the shrub *Acacia suaveolens* (Sm.) Willd.: Fire and the transition to seedlings. *Australian Journal of Ecology* 11: 373–85.

Auld, T.D. & Myerscough, P.J. (1986) Population dynamics of the shrub *Acacia suaveolens* (Sm.) Willd.: Seed production and predispersal seed predation *Australian Journal of Ecology* 11: 219–234.

Auld, T.D. & O'Connell, M.A. (1991) Predicting patterns of post-fire germination in 35 eastern Australian Fabaceae. *Australian Journal of Ecology* 16: 53–70.

Beadle, N.C.W. (1953) The edaphic factor in plant ecology with a special note on soil phosphates. *Ecology* 34: 426–428.

Beadle, N.C.W. (1962) Soil phosphate and the delimitation of plant communities in eastern Australia. *Ecology* 43: 281–288.

Beadle, N.C.W. (1966) Soil phosphate and its role in molding segments of the Australian flora and vegetation with special reference to xeromorphy and sclerophylly. *Ecology* 47: 991–1007.

Beadle, N.C.W. (1981) *The vegetation of Australia* (Cambridge University Press: Cambridge).

Beadle, N.C.W. & Costin, A.B., (1952) Ecological classification and nomenclature. *Proceedings of the Linnean Society of New South Wales* 77: 61–74.

Beecroft Cheltenham Civic Trust (1976) *A plan of management for Pennant Hills Park and some surrounding bushland* (Beecroft Cheltenham Civic Trust: Beecroft).

Benson, D.H. (1974) Reconnaissance vegetation survey of Duffys Forest–Terry Hills area. Unpub. report (copy held in Royal Botanic Gardens Library).

Benson, D.H. (1975) Brief survey of native vegetation at Rawson Park, Mosman. Unpub report (copy held in Royal Botanic Gardens Library).

Benson, D.H. (1978a) Brief survey of vegetation at Long Bay Rifle Range. Unpub. report (copy held in Royal Botanic Gardens Library).

Benson, D.H. (1978b) Brief vegetation survey–Wolli Creek–Undercliffe to Bexley North. Unpub. report (copy held in the Royal Botanic Gardens Library).

Benson, D.H. (1979a) Native vegetation of Deep Creek, Narrabeen. Unpub. report (copy held in the Royal Botanic Gardens Library).

Benson, D.H. (1979b) Report on native vegetation–Edna May Hunt Reserve, Hillside Crescent, Epping. Unpub. report (copy held in the Royal Botanic Gardens Library).

Benson, D.H. (1980a) Explanatory notes for the Sydney 1:100 000 vegetation map sheet. Unpub. (Royal Botanic Gardens: Sydney).

Benson, D.H. (1980b) Species recorded from Joe's Mountain, Elouera Bushland Reserve in area not burnt since 1957. Unpub. report (copy held in the Royal Botanic Gardens Library).

Benson, D.H. (1980c) Report on native vegetation, Vineyard Creek Catchment Reserve, Telopea, New South Wales. Unpub. report (copy held in Royal Botanic Gardens Library).

Benson, D.H. (1981a) Vegetation of Lion Island, Broken Bay, New South Wales. *Cunninghamia* 1: 121–123.

Benson, D.H. (1981b) Native vegetation of Warringah–Manly War Memorial Park. Unpub. report (copy held in Royal Botanic Gardens Library).

Benson, D.H. (1983) Plant species originally native in Concord Municipality. Appendix 1 in S. Coupe, *Concord; a centenary history 1883–1983* (Concord Municipal Council: Concord).
Benson, D.H. (1984) List of plants growing on Bar Island, Hawkesbury River. Unpub. report (Royal Botanic Gardens: Sydney).
Benson, D.H. (1985) Maturation periods for fire-sensitive shrub species in Hawkesbury Sandstone vegetation. *Cunninghamia* 1(3): 339–349.
Benson, D.H. (1986a) The vegetation of the Gosford and Lake Macquarie 1:100 000 vegetation map sheet. *Cunninghamia* 1(4): 467–489.
Benson, D.H. (1986b) Native vegetation–Brush Farm Park, Eastwood. Unpub. report (Royal Botanic Gardens Sydney).
Benson, D.H. (1992a) The natural vegetation of the Penrith 1:100 000 map sheet. *Cunninghamia* 2(4): 541–596.
Benson, D.H. (1992b) Botanical significance of native vegetation, Third Avenue, Campsie. Unpub. report (Royal Botanic Gardens: Sydney).
Benson, D.H. & Howell, J. (1990a) *Taken for granted: the bushland of Sydney and its suburbs.* (Kangaroo Press: Kenthurst).
Benson, D.H. & Howell, J. (1990b) Sydney's vegetation 1788–1988: utilization, degradation and rehabilitation. *Proceedings of the Ecological Society of Australia* 16: 115–127.
Benson, D.H., Howell, J. & McDougall, L. (1989) Vegetation of Big Bay Island, Marramarra Creek, Hawkesbury River, NSW. Unpub. report (copy held in the Royal Botanic Gardens Library).
Benson, D.H. & Keith, D.A. (1984a) Floristic List for Dalrymple Hay Nature Reserve. Unpub. report (copy held in the Royal Botanic Gardens Library).
Benson, D.H. & Keith, D.A. (1984b) Native vegetation, Fagan Park, Galston. Unpub. (Royal Botanic Gardens Sydney).
Benson, D.H. & Keith, D.A. (1984c) Floristic List for Macquarie Hospital Bushland, Twin and Cressy Road, East Ryde. Unpub. report (copy held in the Royal Botanic Gardens Library).
Benson, D.H. & Keith, D.A. (1985) Species list for the Leo Smith Reserve, Ramsgate. Unpub. report (copy held in the Royal Botanic Gardens Library).
Benson, D.H. & Keith, D.A. (1990) The natural vegetation of the Wallerawang 1:100 000 map sheet. *Cunninghamia* 2(2): 305–335.
Benson, D.H. & McDougall, L. (1993) Ecology of Sydney plant species part 1: ferns, fern-allies, cycads, conifers and dicotyledon families Acanthaceae to Asclepiadaceae. *Cunninghamia* 3(2): 257–422.
Benson, D.H. & Melrose, S.C. (1993) Floristic lists of New South Wales. *Cunninghamia* 3(1): 167–213.
Benson, J.S. & Falding, H.B. (1981) Vegetation survey of Brisbane Water National Park and environs. *Cunninghamia* 1: 79–113.
Blaxell, D.F. & Pickard, J. (1969) Floristic list–Lane Cove River. Unpub. report (copy held in the Royal Botanic Gardens Library).
Bliss, P.J., Riley, S.J. & Adamson, D. (1983) Towards rational guidelines for urban stormwater disposal into flora preservation areas. *Shire and Municipal Record* 191: 181–185.
Bradley, E. & Bradley, J. (1966–1974) Local native plant species, Rawson Park, Mosman, New South Wales. Results of periodic plant surveys, 1966–1974. Unpub. report (copy held in the Royal Botanic Gardens, Library).
Bradley, J. (1971) *Bush regeneration* (The Mosman Parklands and Ashton Park Association: Mosman).
Bradley, J. (1988) *Bringing back the bush: the Bradley method of bush regeneration* (Lansdowne Press: Sydney).
Bradstock, R.A. (1990) Demography of woody plants in relation to fire: *Banksia serrata* L.f. and *Isopogon anemonifolius* (Salisb.) Knight. *Australian Journal of Ecology* 15: 117–132.
Bradstock, R.A. & Myerscough, P.J. (1981) Fire effects on seed release and the emergence and establishment of seedlings in *Banksia ericifolia* L.f. *Australian Journal of Botany* 29: 521–531.
Briggs, J. & Leigh, J. (1988) *Rare or threatened Australian plants.* Revised edn. Special Publication No.14. (Australian National Parks & Wildlife Service: Canberra).
Broadbent, J.A. & Buchanan, R. (1984) Ecological studies for extension of Rutledge Street across Brush Farm Park from Brush Road to Marsden Road, Eastwood. (Unpub. Report).

Brough, P., McLuckie, J. & Petrie, A.H.K. (1924) An ecological study of the flora of Mount Wilson I. The vegetation of the basalt. *Proceedings of the Linnean Society of New South Wales* 49: 475–498.
Brown, K.R., Krassoi, F.R., Angus, C. & Underwood, P. (1988) The mangroves of Wolli Creek, Sydney. *Wetlands (Australia)* 8: 27–29.
Bryant, H.J. & Benson, D.H. (1981) Recent floristic lists of New South Wales. *Cunninghamia* 1(1): 59–77.
Buchanan, R. (1978) Blackwood (National Trust of Australia (NSW) Unpub.).
Buchanan, R. (1979a) *Mowbray Park; description and management.* (Mowbray Park Preservation Society: Lane Cove).
Buchanan, R. (1979b) Burley Griffin Lodge Avalon. Unpub. (National Trust of Australia: NSW).
Buchanan, R. (1980) The Lambert Peninsula, Ku-ring-gai Chase National Park. Physiography and the distribution of podzols, shrub lands and swamps, with details of the swamp vegetation and sediments. *Proceedings of the Linnean Society of New South Wales* 104: 73–94.
Buchanan, R. (1987) The Ludovic Blackwood Memorial Sanctuary — description and management: ten years of bush regeneration assessment of permantent transects (National Trust of Australia (NSW) Unpub.).
Buchanan, R. (1989) *Bush regeneration: recovering Australian landscapes.* (TAFE Student Learning Publications: Sydney).
Buchanan, R. & Humphreys, G.S. (1980) The vegetation on two podzols on the Hornsby Plateau, Sydney. *Proceedings of the Linnean Society of New South Wales* 104: 49–71.
Bureau of Meteorology (1979) *Climatic survey–Sydney, region 5, New South Wales.* (Department of Science & the Environment: Canberra).
Burges, A. & Drover, D. P. (1952) The rate of podzol development in sands of the Woy Woy district, N.S.W. *Australian Journal of Botany* 1: 83–95.
Burrell, J. (1981) Invasion of coastal heath by *Leptospermum laevigatum. Australian Journal of Botany* 29: 747–764.
Centre of Environmental Studies (1978) *A Bicentennial Park for Sydney: Homebush Bay.* Report prepared for Concord Council by Macquarie University.
Chapman, D.M., Geary, M., Roy, P.S. & Thom, B.G. (1982) *Coastal evolution and coastal erosion in New South Wales.* (Coastal Council of NSW: Sydney).
Chapman, G.A. & Murphy, C.L. (1989) *Soil landscapes of the Sydney 1:100 000 sheet.* (Soil Conservation Service Of N.S.W.: Sydney).
Clark, S.S. & McLoughlin, L.C. (1986) Historical and biological evidence for fire regimes in the Sydney region prior to the arrival of Europeans: implications for future bushland management. *Australian Geographer* 17: 101–112.
Clarke, L.D. & Hannon, N.J. (1967) The mangrove swamps and salt marsh communities of the Sydney district. I. Vegetation, soils and climate. *Journal of Ecology* 55: 753–771
Clarke, L.D. & Hannon, N.J. (1969) The mangrove swamps and salt marsh communities of the Sydney district. II. The holocoenotic complex with particular reference to physiography. *Journal of Ecology* 57: 213–234.
Clarke, L.D. & Hannon N.J. (1970) The mangrove swamps and salt marsh communities of the Sydney district. III. Plant growth in relation to salinity and waterlogging. *Journal of Ecology* 58: 351–369.
Clarke, L.D. & Hannon, N.J. (1971) The mangrove swamps and salt marsh communities of the Sydney district. IV. The significance of species interaction. *Journal of Ecology* 59: 535–553.
Clarke, P.J. & Benson, D.H. (1987) Vegetation survey of Lane Cove River State Recreation Area. (Royal Botanic Gardens: Sydney).
Clarke, P. & Benson, D. (1988) The natural vegetation of Homebush Bay — two hundred years of changes. *Wetlands (Australia)* 8(1): 3–15.
Cleland, J.B. (1914) List of plants growing upon Milson Island, Hawkesbury River. *Bureau of Microbiology* 3rd report., 218–225.
Clemens, J. & Franklin, M.H. (1980) A description of coastal heath at North Head, Sydney Harbour National Park: Impact of recreation and other disturbance since 1951. *Australian Journal of Botany* 28: 463–478.
Clements A. (1983) Suburban development and the resultant changes in the vegetation of the bushland of the northern Sydney region. *Australian Journal of Ecology* 8: 307–319.

Collins, David (1798) *An account of the English colony in New South Wales.* (Facsimile Edition, B. Fletcher (ed.) (Royal Australian Historical Society/ A.H. & A.W. Reed: Sydney 1975).

Corbett, J.R. (1972) Soils of the Sydney area. In *The city as a life system?* Ed. H.A. Nix. *Proceedings of the Ecological Society of Australia* 7: 41–76.

Costin, P. (1986) Loquat Valley bushland group — plant species list. Unpub. report (copy held in the Royal Botanic Gardens Library).

Coveny, R. Checklists of plant sightings and collections for various areas. Unpub. reports (copies held in the Royal Botanic Gardens Library):

a. Brush Farm, Eastwood, Sydney, (1978),
b. Cheltenham, Sydney, (1965–78),
c. Cowan to Jerusalem Bay, Ku-ring-gai Chase, Sydney, (1965–70),
d. Cumberland State Forest, Baulkam Hills, Sydney, (1976),
e. Darvall Park, Denistone Sydney, (1978) Additions and corrections, (1979)
f. Deep Creek, Narrabeen, Sydney, (1965–75),
g. Dee Why Lagoon, Sydney, (1970–72),
h. Elouera Bushland Reserve, Sydney, (1970)
i. Frenchs Forest, Sydney, (1965–70),
j. Glebe Gully, Randwick, Sydney, (1977),
k. Hallstrom Nature Reserve, Muogamarra, North of Sydney, (1962–69),
l. Katandra Sanctuary, Mona Vale, Sydney, (1975–79, 1988),
m. Lake Parramatta Reserve, Sydney, (1960–65),
n. Mt Ku-ring-gai to Apple Tree Bay, Sydney, (1960–65),
o. Manly Reservoir, Sydney, (1965–70),
p. North Head, Sydney, (1967).

Coveny, R.G. & McDougall, L. (1990) Plant species on Long Island Nature Reserve, Hawkesbury River. Unpub. report (copy held in the Royal Botanic Gardens Library).

Cunningham, P. (1827) *Two years in New South Wales* (London).

Currey, J.E.B. (ed.) (1966) *Reflections on the Colony of New South Wales: George Caley.* (Lansdowne Press: Melbourne).

Davis, C. (1936) Plant ecology of the Bulli district. I. Stratigraphy, physiography and climate; general distribution of plant communities and interpretation. *Proceedings of the Linnean Society of New South Wales* 61: 285–297.

Davis, C. (1941a) Plant ecology of the Bulli district. II. Plant communities of the plateau and scarp. *Proceedings of the Linnean Society of New South Wales* 66: 1–19.

Davis, C. (1941b) Plant ecology of the Bulli district. II. Plant communities of the coastal slopes and plain. *Proceedings of the Linnean Society of New South Wales* 66: 20–32.

Forestry Commission of NSW (1984) *Management plan for Cumberland Management area.*

Hamilton, A.A. (1918) Topographical, ecological and taxonomic notes on the ocean shoreline vegetation of the Port Jackson district. *Journal and Proceedings of the Royal Society of New South Wales* 51: 287–355.

Hamilton, A.A. (1919) An ecological study of the saltmarsh vegetation in the Port Jackson district. *Proceedings of the Linnean Society of New South Wales* 44: 463–513.

Hannon, N.J. (1956) The status of nitrogen in the Hawkesbury Sandstone soils and their plant communities in the Sydney district I. The significance and level of nitrogen. *Proceedings of the Linnean Society of New South Wales* 81: 199–243.

Hannon, N.J. (1958) The status of nitrogen in the Hawkesbury Sandstone soils and their plant communities in the Sydney district II. The distribution and circulation of nitrogen. *Proceedings of the Linnean Society of New South Wales* 83: 65–85.

Harden, G.J. (ed) (1990–3) *Flora of New South Wales Volumes 1–4* (NSW University Press: Kensington).

Hawkins, R. (1994) *The convict timbergetters of Pennant Hills: a history and biographical register* (Hornsby Shire Historical Society: Sydney).

Herbert, C. (ed.) (1983) *Geology of the Sydney 1:100 000 sheet 9130.* (N.S.W. Department of Mineral Resources: Sydney).

Holland, D. (1980) Mount Trefle: a general and botanical study within Sydney Harbour National Park (Unpub. student report to Ryde School of Horticulture).

Horton, S. (1986) A vegetation survey of North Head. Draft report (National Parks & Wildlife Service of New South Wales).

Kachka, A.M. (1993) *Vegetation survey of Homebush Bay.* (NSW Govt, Property Services Group: Sydney).

Kartzoff, M. (1969) *Nature and a city: the native vegetation of the Sydney area.* (Edwards & Shaw: Sydney).

Keith, D.A. (1988) Floristic lists of New South Wales (III). *Cunninghamia* 2(1): 39–73.

Keith, D.A. & Benson, D.H. (1988) The natural vegetation of the Katoomba 1:100 000 map sheet. *Cunninghamia* 2(1): 107–143.

Keith, D.A. & Myerscough, P.J. (1993) Floristics and soil relations of upland swamp vegetation near Sydney. *Australian Journal of Ecology* 18: 325–344.

Kodela, P.G. & Dodson, J.R. (1989) A late Holocene vegetation and fire record from Ku-ring-gai Chase National Park, New South Wales. *Proceedings of the Linnean Society of New South Wales* 110: 317–326.

Kohen, J.L. & Lampert, R. (1987) Hunters and fishers in the Sydney region. In *Australians to 1788* (S.J. Mulvaney & P.J. White eds. Fairfax, Syme & Weldon Associates: Sydney).

Kohen, J.L. & Downing, A.J. (1992) Aboriginal use of plants on the western Cumberland Plain. *Sydney Basin Naturalist* 1: 1–8.

Kratochvil, M., Hannon, N.J. & Clarke, L.D. (1973) Mangrove swamp and salt marsh communities in southern Australia. *Proceedings of the Linnean Society of New South Wales* 97: 262–274.

Lee, I. (1925) *Early explorers in Australia* (Methuen & Co: London).

McDougall, L. (1989) Lion Island, additional species. Unpub. report (copy held in the Royal Botanic Gardens Library).

McDougall, L. (1993) Plant list for Marramarra National Park. Unpub. (Royal Botanic Gardens Sydney).

McDougall, L. (1994) List of plant species for Barrenjoey Headland. Unpub. (Royal Botanic Gardens Sydney).

McDougall, L. & Conroy, R. (1988–90) Species list for Davidson Park State Recreation Area. Unpub. (National Parks & Wildlife Service: Ku-ring-gai).

McKern, J.G. (1962) Deep Creek–Narrabeen proposed parks. List of some plants. *Australian Wild Life* 4: 4–7.

McLoughlin, L. (1985) *The Middle Lane Cove River: A history and a future.* Monograph No.1 Centre for Environmental and Urban Studies (Macquarie University: Sydney).

McLuckie, J. & Petrie, A.H.K. (1926) An ecological study of the flora of Mount Wilson III. The vegetation of the valleys. *Proceedings of the Linnean Society of New South Wales* 51: 94–113.

McRae, R.H.D.(1990) Vegetation of Bouddi Peninsula, New South Wales. *Cunninghamia* 2(2): 263–293.

Maiden, J.H. (1889) *The useful native plants of Australia.* (Facsimile edn. Compendium: Melbourne 1975).

Maiden, J.H. (1902) List of plants growing without cultivation in the Outer Domain. *Annual Report for Botanic Gardens and Domain for year 1902,* 29.

Meredith, Mrs Charles (1844) *Notes and Sketches of New South Wales.* (Facsimile edn. Penguin Books: Harmondsworth, 1973).

Myerscough P.J. & Carolin R.C. (1986) The vegetation of the Eurunderie sand mass, headlands and previous islands in the Myall Lakes area, New South Wales. *Cunninghamia* 1(4): 399–466.

National Trust (1991) *Urban bushland: a National Trust policy paper.* (National Trust of Australia (NSW: Sydney).

NSW Department of Mines (1966) *Sydney 1:250 000 Geological Series Sheet.* Edition 3. (Department of Mines: Sydney).

NSW Department of Mineral Resources (1983) *Sydney 1:100 000 Geological Series Sheet 9130 (Edition 1)* (Department of Mineral Resources: Sydney).

NSW National Parks & Wildlife Service (1994) List of plant species in Marramarra National Park (from database).

NSW National Parks & Wildlife Service (1994) Lists of plant species for Bradleys Head, Clifton Gardens, Dobroyd Head, Neilsen Park.

Nicholson, P.H. (1981) Fire and the Australian Aborigine — an enigma. Chapter 3 in *Fire and the Australian biota.* (A.M. Gill, R.H. Groves & I.R. Noble eds. Australian Academy of Science: Canberra).

Outhred, R., Lainson, R., Lamb, R & Outhred, D. (1985) A floristic survey of Ku-ring-gai Chase National Park. *Cunninghamia* 1: 313–338.

Payne, R.J. (1993) Prediction of the habitat for *Tetratheca juncea* in the Munmorah area, near Wyong, New South Wales. *Cunninghamia* 3(1): 147–154.

Petrie, A.H.K. (1925) An ecological study of the flora of Mount Wilson II. The *Eucalyptus* forests. *Proceedings of the Linnean Society of New South Wales* 50: 145–166.

Phillip, Arthur (1789) *The voyage of Governor Phillip to Botany Bay*. Facsimile edition Hutchinson Group (Australia): Melbourne 1982).

Phillips, M.E. (1947) Vegetation of the Wianamatta Shale and associated soil types. M.Sc. thesis (University of Sydney).

Pickard, J. (1972) Annotated bibliography of floristic lists of New South Wales. *Contributions from the N.S.W. National Herbarium* 4: 291–317.

Pickard, J. (1974) Report on saline swamp–Calna and Berowra Creeks. Unpub. report (copy held in Royal Botanic Gardens Library).

Pidgeon, I.M. (1937) The ecology of the Central Coastal area of New South Wales. I. The environment and general features of the vegetation. *Proceedings of the Linnean Society of New South Wales* 62: 315–340.

Pidgeon, I.M. (1938) The ecology of the Central Coastal area of New South Wales. II. Plant succession on the Hawkesbury Sandstone. *Proceedings of the Linnean Society of New South Wales* 63: 1–26.

Pidgeon, I.M. (1940) The ecology of the Central Coastal area of New South Wales. III. Types of primary succession. *Proceedings of the Linnean Society of New South Wales* 65: 1–26.

Pidgeon, I.M. (1941) The ecology of the Central Coastal area of New South Wales. IV. Forest types on soils from Hawkesbury Sandstone and Wianamatta Shale. *Proceedings of the Linnean Society of New South Wales* 66: 113–137.

Pratten, C.H. (1993) A parable of a sower — Ashfield's first land grant. *Journal of the Ashfield & District Historical Society* 10: 14–32.

Price, G.A. (1979) The vegetation of Duck River and Rookwood Cemetery, Auburn. Unpub. report (copy held in the Royal Botanic Gardens Library).

Raymond, J. (1832) The New South Wales calendar and general Post Office directory (Stephens & Stokes: Sydney).

Robinson, L. (1986) *Trees of Wolli Creek*. (Wolli Creek Preservation Society: Earlwood).

Robinson, L. (1987) *Flora of the Wolli Creek valley* (Wolli Creek Preservation Society: Earlwood).

Rodd, A.N. & Benson, D.H. (1977) Garden Island Dockyard — botanical survey. Unpub. report (copy held in the Royal Botanic Gardens Library).

Rose, A.B. (1982) A list of plant species in Ku-ring-gai Chase National Park based on *A census of trees and plants in Ku-ring-gai Chase* by O.D.Evans, 1959. With additional observations by D.F. Blaxell, T.S. Barratt & A.B. Rose, 1969, revised 1982 (NSW National Parks & Wildlife Service: Sydney).

Sanders, J. (1983) Differences in vegetation on soils associated with basalt dykes in Ku-ring-gai Chase National Park. Unpub. Bachelor of Science (Honours) Thesis (School of Biological Sciences, University of Sydney).

Sanders, J., Bedward, M., Leahy, B., Robinson, M. & Sheringham, P. (1988) *Preliminary report on the vegetation of Yengo National Park and Parr State Recreation Area*. (National Parks & Wildlife Service: Sydney).

Sheringham, P.R. & Sanders, J.(1993) *Vegetation survey of Garigal National Park & surrounding Crown Lands*. (National Parks & Wildlife Service: Sydney).

Siddiqi, M.Y., Carolin, R.C. & Anderson, D.J. (1972) Studies in the ecology of coastal heath in New South Wales. I. Vegetation structure. *Proceedings of the Linnean Society of New South Wales* 97: 211–224.

Siddiqi, M.Y., Carolin, R.C. (1976a) Studies in the ecology of coastal heath in New South Wales. II. The effects of water supply and phosphorus uptake on the growth of *Banksia serratifolia, B. aspleniifolia* and *B. ericifolia*. *Proceedings of the Linnean Society of New South Wales* 101: 38–52.

Siddiqi, M.Y., Carolin, R.C. & Myerscough, P.J. (1976b) Studies in the ecology of coastal heath in New South Wales. III. Regrowth of vegetation after fire. *Proceedings of the Linnean Society of New South Wales* 101: 53–63.

Smith, P. & Smith, J. (1990) Vegetation and fauna of Berowra Valley Bushland Park (report prepared for Hornsby Shire Council).

Smith, P. & Smith, J. (1993) *Angophora Reserve and Hudson Park: Plan of Management* (Pittwater Municipal Council).

South Turramurra Environment Protection (1980) A plan of management for South Turramurra bushland (South Turramurra Evironment Protection: Turramurra).

Specht, R.L. (1970) Vegetation, in *The Australian Environment* (G.W. Leeper Ed., 4th Edition). (CSIRO–Melbourne University Press: Melbourne).

Strom, B.(ed.) (1986) *Bouddi Peninsula study* (Association for Environmental Education NSW: Killcare Heights).

Tench, Watkin (1979) *Sydney's first four years: being a reprint of A Narrative of the Expedition to Botany Bay and A Complete Account of the Settlement at Port Jackson* (Library of Australian History: Sydney).

Thomas, J. & Benson, D.H. (1985a) Vegetation survey of Ku-ring-gai Chase National Park. Unpub. report (copy held in Royal Botanic Gardens Library).

Thomas, J. & Benson, D.H. (1985b) Vegetation survey of Muogamarra Nature Reserve. Unpub. report, updated 1991 (copy held in Royal Botanic Gardens Library).

Thorogood, C.A. (1985) Changes in the distribution of mangroves in the Port Jackson–Parramatta River estuary from 1930 to 1985. *Wetlands (Australia)* 5(2): 91–96.

Upper Middle Harbour Conservation Committee (1974) *Bantry Bay: the case for conservation*. (Upper Middle Harbour Conservation Committee: Killarney Heights).

Walker, P.H. (1960) *A soil survey of the County of Cumberland, Sydney region, New South Wales*. Bulletin No: 2, Soil Survey Unit, New South Wales Department of Agriculture.

Webb, J. (1981) Vegetation of Spectacle island, Hawkesbury River, New South Wales. *Cunninghamia* 1(1): 115–119.

Wilson, E. (ed.) (1986) *Discovering the Domain*. (Hale & Iremonger: Sydney).

Woolls, W. (1891) *Plants indigenous and naturalised in the neighbourhood of Sydney*. (Government Printer: Sydney).

Worgan, G.B. (1978) *Journal of a First Fleet surgeon*. Publication No 16, The William Dixson Foundation. (The Library Council of New South Wales in association with Library of Australian History: Sydney).

Workers' Educational Association Plant Ecology Group (1959) List of native plants (recorded in the Lake Parramatta Reserve). *Australian Wild Life* 3: 12–14.

Manuscript received 31 January 1994
Manuscript accepted 14 September 1994

Proc. Ecol. Soc. Aust. 1990 — 16:201-213

(human impact)

Proc. Ecol. Soc. Aust. 1990 — 16:115-127

Sydney's vegetation 1788-1988: utilization, degradation and rehabilitation

D. H. BENSON and J. HOWELL

National Herbarium of New South Wales, Royal Botanic Gardens, Mrs Macquarie's Road, Sydney, N.S.W. 2000, Australia

Abstract

Sydney, the site of the first European colonization in Australia, is fortunate in having so much infertile soil, supporting vegetation that is rich in species. Much of this has been preserved to provide an enviable urban setting of major national parks, and with bushland remnants conspicuous in many suburban areas. However, during 200 years, European settlement has removed most of the indigenous vegetation from the more fertile soils and destroyed or modified many wetlands and sand dune complexes.

The vegetation of 1788, inferred from geological, climatic, historical and present-day distributional information, has been described and grouped into eight major vegetation types. For each type, the impact of European settlement is outlined, and the remaining area estimated. Poorly conserved types have been identified. In bushland on soils of low fertility, the indigenous understorey is disappearing despite the preservation of canopy dominants, as weed invasion follows nutrient enrichment of drainage lines, and fire regimes change. Management strategies are being developed for individual sites, reflecting growing public concern to conserve remaining bushland in urban areas.

Introduction

Sydney (33°50'S; 151°00'E), the largest city on the eastern coast of Australia, was colonized by convicts, soldiers and administrators of the First Fleet in 1788, and has Australia's longest history of continuous European settlement. This chapter deals with the indigenous vegetation of the Sydney area, defined by the County of Cumberland, an area of almost 370 000 ha bounded to the north and west by the Nepean-Hawkesbury River and extending southwards to Bulli, north of Wollongong. This area represented the limit of the early colonial administration, and now contains most of Sydney's 3.5 million people. Its clearly-defined physiographic features represent the results of 280 million years of erosion, deposition, uplift and gentle subsidence associated with tectonic forces, occasional volcanic events and fluctuating sea levels. Its shape is that of a shallow saucer formed largely of two types of Triassic sedimentary rocks — shales and sandstones (Herbert & Helby 1980). The central part of the saucer is the Cumberland Plain where shales of the Wianamatta Group provide gently undulating to hilly country with an altitudinal range of 20-100 m a.s.l. This country extends westward from Parramatta to the Blue Mountains just beyond the Nepean-Hawkesbury River, and from Richmond in the north to Picton in the south. Between Windsor and Castlereagh are the main occurrences of Tertiary gravels, sands, silts and clays, deposited by an ancestral Nepean-Hawkesbury River system (Gobert 1978). Along the present Nepean-Hawkesbury River and its major tributaries, South, Rickabys and Eastern Creeks, are alluvial deposits of Quaternary age. The Georges River valley also has smaller areas of both Tertiary and Quarternary alluvials.

The eastern half of the saucer is formed by sandstones, principally of the Hawkesbury Sandstone. From an altitude of 20-50 m around Sydney Harbour, the Hornsby Plateau rises to over 250 m in the north before dropping to the Hawkesbury River. In the south the Woronora Plateau rises to over 200 m. Remnant Wianamatta Shale cappings persist on ridge-lines of the Hornsby Plateau, and over much of the flatter terrain between Sydney Harbour and the Georges River, but are less extensive south of the Georges River.

Quaternary sand deposits of mixed marine and aeolian origin are found around Botany Bay. These have been partly shaped by sea level fluctuations

Proc. Ecol. Soc. Aust. 1990 — 16:201-213

that are believed to have placed the sea 140 m below its present level as recently as 22 000 years ago (Chappell 1982). At this time the coastline would appear to have been up to 40 km east of Sydney. Occasional narrow basalt dykes and *ca* 30 small diatremes of volcanic breccia form only a minor part of Sydney's geology.

Climate in the Sydney area is subtropical (Gentilli 1972), with local conditions influenced by distance from the coast. Rainfall follows a decreasing gradient from the coast to the Cumberland Plain, temperature extremes become more pronounced and there is an increasing incidence of frost. Mean maximum temperatures increase from less than 26°C along the coast to over 29°C on the Cumberland Plain, while mean minima drop from 7-8°C at Sydney to 2-4° on the Cumberland Plain. Average annual rainfall decreases from 1 444 mm at Pymble, through 911 mm at Parramatta, generally less than 800 mm across the Cumberland Plain to a low of 683 mm at Menangle near Camden (Bureau of Meteorology 1979).

Major vegetation types

Native vegetation remains over about a third of the County of Cumberland. The vegetation existing at the time of European settlement has been deduced from present distributions, climatic and geological patterns and historical records. Some early writings need interpretation. For example, Watkin Tench sounded somewhat overwhelmed by new surroundings in 1789, when he described the woodlands of the Cumberland Plain as "the trackless immeasurable desert" (Tench 1979). However, Peter Cunningham's 1827 description relates vegetation to soils and gives a picture that is clearly recognizable.

"In Cumberland, the land immediately bordering upon the coast is of a light, barren, sandy nature, thinly besprinkled with stunted bushes; while from 10 to 15 miles interiorly, it consists of a poor clayey or ironstone soil, thickly covered with our usual evergreen forest timber and underwood. Beyond this commences a fine timbered country, perfectly clear of bush, through which you might, generally speaking, drive a gig in all directions, without any impediment in the shape of rocks, scrubs or close forest. This description of country commences immediately beyond Parramatta on one hand, and Liverpool on the other; stretching in length south easterly obliquely towards the sea, about 40 miles and varying in breadth near 20. The soil upon the immediate banks of the rivers is generally rich flooded alluvial, but in the forests partakes commonly of a poor clayey or ironstone nature, yet bearing tolerable crops, even without manure, at the outset." (Cunningham 1827).

Our field survey and mapping work, conducted since an earlier treatment of this topic (Burrell 1972), has identified at least 31 plant communities, differentiated by structural and floristic criteria. For convenience we have grouped these plant communities into eight major vegetation types, and given each a vernacular name. The postulated distribution of these types in 1788 is shown in Figure 1.

Blue Gum High Forest

Blue Gum High Forest is tall open-forest or wet sclerophyll forest dominated by *Eucalyptus saligna* and *E. pilularis*. Previously the dominants were probably over 40 m tall; there are trees 30 m tall in tiny remnants now. Other tree species included *Angophora costata*, *E. paniculata*, *E. globoidea*, *Syncarpia glomulifera* and *Allocasuarina torulosa*.

Blue Gum High Forest was found on the more easterly Wianamatta Shale where rainfall exceeds 1100 mm, along the central spine of the North Shore from Crows Nest to Hornsby and further west from Castle Hill to Eastwood. In well-drained situations the understorey had shrubs up to 2 m, together with grasses and herbs. In moister parts, along drainage lines, a ground cover of ferns was conspicuous beneath small trees of *Pittosporum undulatum* and *Glochidion ferdinandi*, and shrubs including *Breynia oblongifolia* and *Polyscias sambucifolia*. Trees that also occur in rainforest, *Ceratopetalum apetalum* and *Acmena smithii*, also grew along some creeks, but true rainforest appears to have occurred on the shale only around Brush Farm at Eastwood.

Turpentine-Ironbark Forest

Turpentine-Ironbark Forest grew on Wianamatta Shale country with a lower average rainfall (about 900-1100 mm) and/or shallower soil near boundaries with the underlying Hawkesbury Sandstone.

On the northern side of the Parramatta River, Turpentine-Ironbark Forest grew from Ryde westwards to Parramatta and from there discontinuously north to Castle Hill and beyond. On the south side of the harbour it probably began around Glebe-Newtown and extended westward to Parramatta and Fairfield.

This forest was not as tall as Blue Gum High Forest, its trees would probably have been 20-30 m tall, with *Syncarpia glomulifera*, *E. paniculata*, *E. globoidea*, *E. resinifera* and *Allocasuarina torulosa* the main species, growing above dense understorey which included *Pittosporum undulatum*, *Acacia* species and a variety of peas and climbers.

West of Auburn, rainfall decreases, the clay soils have increasing amounts of ironstone gravels, and drier country trees became components of this forest — *E. moluccana*, *E. longifolia* and *E. fibrosa*. The understorey here ranged from dense scrub up to 3 m high to open and grassy with scattered shrubs, with *Melaleuca* species in drainage lines.

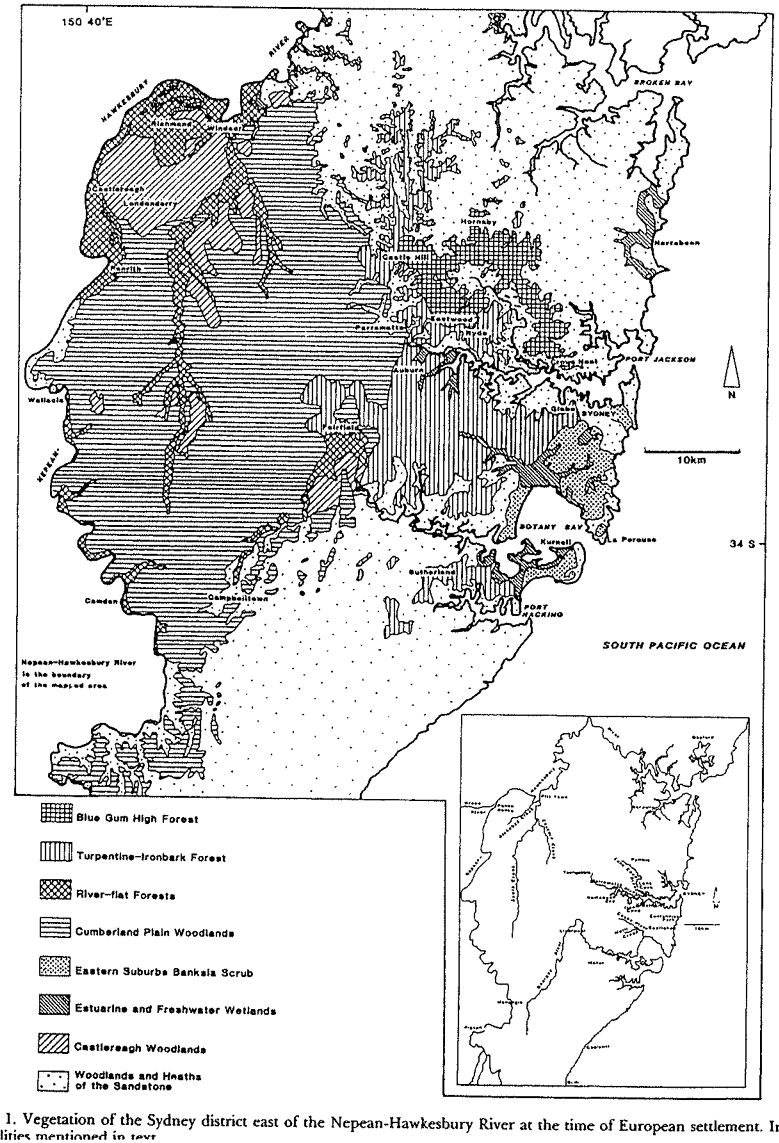


FIG. 1. Vegetation of the Sydney district east of the Nepean-Hawkesbury River at the time of European settlement. Inset: Localities mentioned in text

River-flat Forests

River-flat Forests occupied some of the most fertile soil in the district — alluvium along the Nepean-Hawkesbury River and its major tributaries, South Creek and Eastern Creek, and smaller areas along the Georges River. Dominant species in these tall open-forests downstream from Penrith were *Eucalyptus tereticornis* and *Angophora subvelutina*. In the account of his 1791 expedition, John Hunter described River-flat Forest near Richmond as "fine, straight timber", growing above a dense understorey including shrubs, "long sedges" [*Gahnia* spp., *Lomandra longifolia*], "nettles" [*Urtica incisa*] and "a weed resembling ivy" [*Smilax australis* or *Dioscorea transversa*] (Hunter 1793). Species composition is difficult to describe with certainty, because it was rapidly cleared.

Upstream from the junction with the Grose River, the species dominants changed to *A. subvelutina* and *E. amplifolia*, with *E. elata* common as far downstream as Wallacia. The rare *E. benthamii* occurred occasionally down to the Grose River junction, and further upstream *E. viminalis* and *E. botryoides/saligna* intergrade grew around Camden. Along the river's length, *Casuarina cunninghamiana* and occasional *Tristaniopsis laurina* lined the banks, and limited numbers of *Toona australis* and *Melia azedarach* grew near Penrith. There were localized occurrences of *E. bauerana* and *E. bosistoana* on both the Georges River and the Nepean. Along smaller Cumberland Plain creeks *A. floribunda* appears to have replaced *A. subvelutina*. Paperbarks, *Melaleuca linariifolia*, *M. decora* and *M. styphelioides*, with a ground cover of *Juncus* spp. or sedges, were found in backswamps and periodically waterlogged depressions associated with the alluvial forests.

Cumberland Plain Woodlands

Woodlands originally occupied the bulk of the Cumberland Plain and about 30% of the Sydney district. They extended westward from Parramatta to the Nepean-Hawkesbury River, north to Richmond and Windsor, and south to Camden and Campbelltown. They occupied the driest part of Sydney, where rainfall is approximately 700-900 mm per annum, and soils are deep clays developed from shales of the Wianamatta Group — from the Bringelly Shale on the Plain itself and from the Ashfield Shale on the margins. In 1788 Governor Phillip described this country west of Parramatta as "singularly fine, level or rising in small hills of a very pleasing and picturesque appearance. The soil excellent, except in a few small spots where it was stony. The trees growing at a distance of from 20 to 40 feet [6-12 m] from each other, and in general entirely free from brushwood" (Phillip 1789).

Two tree species are most common across the Cumberland Plain, *E. moluccana* which tends to grow on rises, and *E. tereticornis* which is more often found on lower hillslopes and depressions. Ironbarks (*E. crebra* and *E. fibrosa*) accompany these on hilly country, and *E. eugenioides* and *E. longifolia* occur sporadically. Near creeks or on poorly-drained sites *E. amplifolia*, *E. bauerana*, *Angophora floribunda*, *Casuarina glauca* or *Melaleuca decora* may be found.

The relative abundance of shrubs and grasses at the time of settlement is now impossible to determine. The early writers describe "forest land" with a general lack of underwood, though indicating that there were locally denser patches. Today the understorey may be shrubby or grassy depending more on relatively recent grazing intensity and disturbance. The main shrub species is *Bursaria spinosa* and the most common grass is *Themeda australis*.

Eastern Suburbs Banksia Scrub

The aeolian sands between Centennial Park and Botany Bay supported sclerophyllous heath, scrub and low forest, with considerable local floristic variation, now regrettably lost. The name Banksia Scrub reflects the importance of *Banksia aemula*, an indicator of old leached sands, which occurs at its southern limit at La Perouse. Other common shrub species were *Monotoca elliptica*, *Eriostemon australasius*, *Ricinocarpos pinifolius* and *Xanthorrhoea resinosa*, together with *Angophora costata* generally growing as a mallee or small tree. Similar scrub and woodland was found on the sand dunes of Kurnell on the southern side of Botany Bay but *Banksia aemula* is absent here.

Freshwater and Estuarine Wetlands

Freshwater wetlands occurred in backswamps on the floodplain of the Nepean-Hawkesbury River. Expansive billabongs and lagoons with permanent water had emergent reeds and rushes, including *Eleocharis sphacelata*, *Triglochin procera*, *Philydrum lanuginosum* and, depending on conditions, *Phragmites australis* or *Typha* spp. Ephemeral swampy waterlogged sites were characterized by rushes, most commonly *Juncus usitatus*, together with some herbs (e.g., *Persicaria* spp.), bands of paperbark shrubland with *Melaleuca linariifolia* or *M. styphelioides*, and swamp woodland of *Eucalyptus robusta* on the drier edges, though still subject to flooding.

Freshwater wetlands were also associated with the Eastern Suburbs sand dunes; small swamps occurred in the swales, and larger expanses of open water along major drainage lines formed the Lachlan Swamps now in Centennial Park, and the Botany Swamps at Eastlakes. Here, tall emergent ...s, pa...y *El...* *spha...* and

Proc. Ecol. Soc. Aust. 1990 — 16:201-213

shorter sedges, including *Baumea articulata*, *B. rubiginosa* and *Juncus* spp., grew in and around standing water. Shrub species of surrounding waterlogged soil included *Melaleuca quinquenervia*, *Viminaria juncea*, *Callistemon citrinus* and *C. linearis*.

In estuarine wetlands, mangroves mainly of *Avicennia marina* with some *Aegiceras corniculatum* were conspicuous in 1788. Saltmarshes with *Sarcocornia quinqueflora* and *Suaeda australis* were quite extensive, meadows of *Juncus kraussii* with grasses *Sporobolus* and *Zoysia* occurred on rarely-flooded sites, and landward to these beyond normal tidal influence could be found swamp oak woodland with *Casuarina glauca* and occasionally *Melaleuca ericifolia* with a ground layer of *Baumea juncea* and *Juncus kraussii*.

Castlereagh Woodlands

Woodlands with distinctive shrubby understoreys grew on the Tertiary clay, silt, sand and gravel deposits centred on Castlereagh and Londonderry, with smaller areas along South Creek and Eastern Creek. These areas are mainly flat with shallow meandering drainage lines, and species composition appears to be determined by localized soil type. Soils are sands or clays, often containing ironstone gravels or large river stones, and poor in nutrients.

On the gravelly soils grow ironbarks, mainly *E. fibrosa* but also some *E. crebra* and *E. sideroxylon*. On sandy soil these are replaced by *E. sclerophylla* and *Angophora bakeri*. Changes in understorey shrubs and ground covers accompany changes in soil type and dominant species. Along poorly-drained watercourses and depressions grow *Melaleuca decora* and *E. parramattensis*, with grasses, herbs, and some now uncommon herbaceous species, e.g. *Isotoma fluviatilis*.

Woodlands and Heaths of the Sandstone

The rugged sandstone topography supports, as it did in 1788, a number of different plant communities determined by topography, drainage, and soils.

Ridge-tops and upper slopes support woodland with *Eucalyptus haemastoma*, *E. gummifera* and *Angophora costata* the most common co-dominants, and *E. racemosa*, *E. punctata*, *E. sieberi* and *E. oblonga* common in localized patches where there is some shale or ironstone influence. Where soil is particularly shallow there is scrubby heath with dense thickets of *Angophora hispida*, *Banksia ericifolia*, *Allocasuarina distyla* and *Hakea teretifolia*. Where drainage is impeded, the shrub layer diminishes and sedges predominate. On sandstone rock platforms low shrubs and moss mats grow in shallow pockets of soil. Mallees (*E. luehmanniana*, *E. multicaulis*, *E. obtusiflora*) are found sporadically on shallow sandy soils on or below ridge lines and may ... iated ... ·page

On hillslopes, *E. piperita*, *Angophora costata*, *Allocasuarina littoralis* and some *E. gummifera* dominate open-forest in the exposed sites, while in sheltered situations *Syncarpia glomulifera* and the small trees *Elaeocarpus reticulatus*, *Ceratopetalum gummiferum* and *Pittosporum undulatum* become common. All ridge-top and hillslope communities include the well-known species-rich sclerophyllous shrub layer, except where very moist conditions favour mesic species and ferns.

Small trees and shrubs of *Callicoma serratifolia*, *Tristaniopsis laurina*, *Lomatia myricoides*, *Stenocarpus salignus* and *Austromyrtus tenuifolia*, together with ferns, are found along creeks. Where gully soil is enriched by fertile downwashed soil, trees and understorey shrubs such as *Syncarpia glomulifera*, *Eucalyptus pilularis*, *Polyscias sambucifolia* and vines normally associated with Turpentine-Ironbark Forest may grow. Further enrichment provides conditions suitable for rainforest-type species such as *Acmena smithii*, *Ceratopetalum apetalum*, *Acacia elata*, *Smilax australis* and ferns.

Coastal headland and dune vegetation, *Eucalyptus maculata* communities around Broken Bay and tall open-forest and rainforest south of Port Hacking on the Narrabeen Group shales and sandstones, and upland swamps of the Woronora Plateau, have been grouped with vegetation of the sandstone.

Aboriginal occupation and plant use

At the time of European settlement, Aborigines were concentrated in two parts of the Sydney district, the floodplain and the coast, and used a range of plants for food, shelter, canoes, tools, weapons, containers and medicines. For the Dharug people on the floodplain of the Nepean-Hawkesbury River, significant plant foods included vine tubers of the River-flat Forests, and bulbs and tubers of orchids, lilies and swamp plants of the Cumberland Plain Woodlands (Kohen 1984). Small game supplemented these plant food staples.

Along the coast, three peoples, Kuring-gai north of Port Jackson, coastal Dharug (Eora) between Port Jackson and Botany Bay, and Dharawal south of Botany Bay, lived on a diet rich in fish and shellfish. This diet was supplemented with small fleshy fruits and (mainly Proteaceous) flowers rich in nectar from the Eastern Suburbs Banksia Scrub and the sandstone heaths and woodlands, larger fleshy fruits of mesic plants in the moist sandstone gullies, and stems and rhizomes of freshwater wetlands reeds and rushes. From the forests, *Macrozamia* seeds and fern rhizomes, once detoxified, provided carbohydrate (Lampert & Sanders 1973; Poiner 1976; Ross 1976; Kohen & Lampert 1987).

Plants used in significant amounts for other purposes were species of *Xanthorrhoea*, for spear shafts and adhesive resin, *Livistona australis* for ... and fi... eral sh... id tree ... re including *Brachychiton populneus*, *Hibiscus heterophyllus* and species of *Ficus* and *Pimelea*, and *Casuarina cunninghamiana* for bark canoes.

It is difficult to tell whether Aboriginal harvesting affected plant distributions. Current distributions seem to be explainable in terms of environmental factors, but the early European clearing of fertile river flats and Cumberland Plain soils would have obliterated any patterns there. Aboriginal use of fire however, would have affected the vegetation, the different types being subjected to differing burning patterns. For example, in the grassy Cumberland Plain woodlands, fires may have been used as often as every five years, to stimulate underground food resources and grass for game. On the less productive woodlands of the Hawkesbury Sandstone, areas may have remained unburnt for perhaps 20-30 years.

Plant resources used by Aborigines and known to increase after fire are *Macrozamia communis*, for which an eight-fold increase in seed production following a hot fire has been recorded (Beaton 1982), and *Xanthorrhoea australis* in which burning has caused earlier flowering, and doubled the incidence of inflorescence production (Gill & Ingwersen 1976).

Patterns of European Utilization

A few months after the First Fleet anchored in Sydney Cove in January 1788, Surgeon Worgan summarized the settlers' activities: "the principal Business has been the clearing of Land, cutting, Grubbing and burning down Trees, sawing up Timber & Plank for Building, ... " (Worgan 1978). Clearing the land was to become a national obsession for the next century and a typical achievement is shown in John Lewin's view of the Government Farm at Castle Hill around 1806 (Fig. 2). By 1822 Governor Brisbane had clearing operations well organized, boasting that "in order to accomplish the first process towards improvement I have a Thousand men employed in clearing the Country of its excess of Forest Timber and Brushwood" (Brisbane to Buchan 1822).

Although some clearing was necessary to provide agricultural and grazing lands, many of the early colonists had an over-zealous antagonism to the bush. Louisa Meredith complained in 1839: "The system of 'clearing' here, by the total destruction of every native tree and shrub, gives a more bare, raw, and ugly appearance to a new place. In

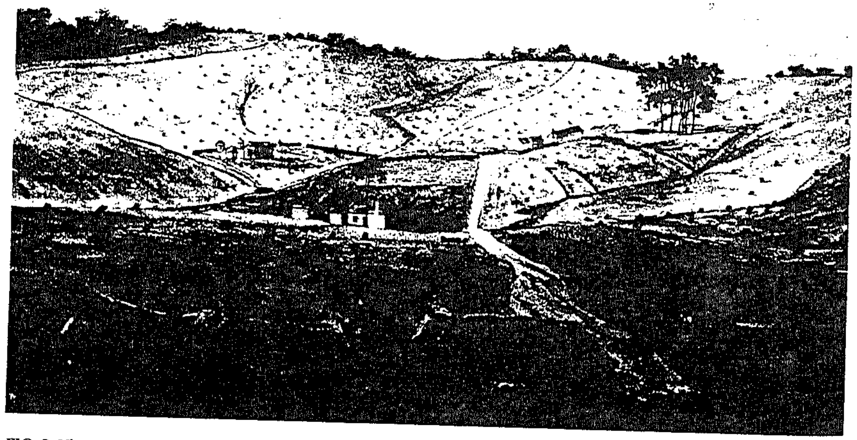


FIG. 2. View of the Government Farm at Castle Hill, about 1806, attributed to John Lewin. (Courtesy of the Mitchell Library, State Library of New South Wales).

Proc. Ecol. Soc. Aust. 1990 — 16:201-213

England we plant groves and woods, and think our country residences unfinished and incomplete without them; but here the exact contrary is the case, and unless a settler can see an expanse of bare, naked, unvaried, shadeless, dry, dusty land spread all round him, he fancies his dwelling 'wild and uncivilized' " (Meredith 1844).

Clearing of vegetation took place at different rates and different times in the various vegetation types around Sydney in response to changing needs and population size.

In broad terms the vegetation gave way to agriculture for the first 100 years, and to suburban growth during the second. The decreasing area of Sydney's different vegetation types between 1788 and 1988 is shown schematically in Figure 3.

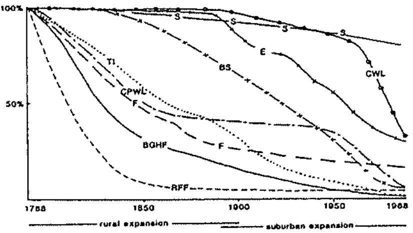


FIG. 3. Schematic diagram illustrating progressive loss of Sydney's vegetation types as a result of changing land use over 200 years. BGHF: Blue Gum High Forest, BS: Eastern Suburbs Banksia Scrub, CPWL: Cumberland Plain Woodlands, CWL: Castlereagh Woodlands, E: Estuarine Wetlands, F: Freshwater Wetlands, RFF: River-flat Forests, TI: Turpentine-Ironbark Forest, S: Woodlands and Heaths of the Sandstone.

River-flat Forests

River-flat Forests were on the first sites sought for agricultural activities, as they occupied some of the most fertile soil in the colony. Clearing the flats along the Nepean-Hawkesbury River commenced soon after 1789, and by 1826 James Atkinson was able to write "The greater part of the alluvial lands upon the Hawkesbury and Nepean have been cleared and are under cultivation" (Atkinson 1826).

The forests' demise is confirmed in early paintings; for example, John Lewin's "A View of the River Hawkesbury, N.S.Wales", of 1805, Figure 4, shows one lone, tall *Angophora subvelutina* and a few shrubs and *Casuarina* trees amongst cleared land. As early as 1803 Governor King issued a General Order against destroying trees on river banks (King to Hobart 1804) but in 1825 Judge Barron Field could still criticize the practice of clearing right to the river banks (Field 1825, reprinted in Mackaness 1965). River-flat Forests along the Hawkesbury's tributaries and on the Georges River were similarly cleared.

Cumberland Plain Woodlands

These woodlands, growing on deep clay soils, proved very attractive to the early settlers, and by 1821 the major portion of the Cumberland Plain had been allocated in land grants (Proudfoot 1987). Vegetation loss was not as rapid or as complete as for the River-flat Forests as much of the land was used for grazing. However, other areas were cleared for wheat-growing. The Government Farm at Toongabbie was established in 1791 originally for this purpose, and for a time Campbelltown was known as "the granary of the colony". Wheat-growing continued until the mid-ninteenth century, by which time wheat rusts had arrived and spread, and the new railway over the Blue Mountains opened up wheat-growing areas west of the Great Dividing Range.

The remaining Cumberland Plain Woodland has suffered gradual attrition. Completion of railway lines to Richmond and Penrith in the 1860s gave impetus to new sawmills, and extractive industries, which cleared vegetation to quarry sand, clay, gravel and blue metal to service the growing city. From the 1880s to 1960s, as land close to the city increased in value, traditional uses changed and large estates were fragmented. Some parts of previously-cleared land were used for more intensive agriculture, while on other parts there was intermittent regrowth of vegetation. From the 1970s, following Sydney's post World War II population boom, suburban expansion and hobby farming has spread across the Cumberland Plain and pressures on the few remaining areas of natural vegetation have escalated once more.

Floodplain Freshwater Wetlands

Freshwater wetlands of the Nepean-Hawkesbury floodplain were drained to provide land for grazing and agriculture. Their utilization and loss parallel the decline of the River-flat Forests.

Blue Gum High Forest

Blue Gum High Forest contained impressive trees up to 40 m tall, and the early settlers soon set about cutting these. Bush sawpits were operating on the North Shore in the early 1800s, and by 1810 Governor Macquarie reported timber "getting scarce" near the Government sawpit 10 km up the Lane Cove River. When the taller straighter trees had been removed for use in construction work (buildings, bridges, wharves, etc.), the smaller trees were cut to provide billets for navy vessels and firewood for Sydney's residents. She-oaks, species of *Casuarina* and *Allocasuarina*, were cut for shingles; in 1813, for example, Governor Macquarie instructed the Government sawpit at Lane Cove to supply 4 000 shingles each week per three-man gang, and 600 six-foot palings per week per three-man

Proc. Ecol. Soc. Aust. 1990 — 16:201-213

FIG. 4. A view of the Hawkesbury River in about 1805, by John Lewin, showing the floodplain forest had been almost completely cleared by this date. (Courtesy of the Dixson Galleries, State Library of New South Wales).

gang. Each two-man team of sawyers was to saw 450 ft (150 m) of timber each week, in addition (Russell 1970). Hardwood paling fences were a very early Sydney suburban feature.

On the North Shore, the bulk of the Blue Gum High Forest had been cleared by the 1860s, and the land used for orchards. Suburbs had spread up the North Shore ridge by 1920.

Turpentine-Ironbark Forest

Turpentine-Ironbark Forest occupied country with lower rainfall than the Blue Gum High Forest. Its principal timbers were certainly useful in the early colonial days. *Syncarpia glomulifera* was invaluable for wharf and jetty pilings, *Eucalyptus paniculata* and other ironbarks were used extensively as fence posts, *E. resinifera* yielded timber prized for its strength and durability (Maiden 1889). Although cleared less purposefully than the Blue Gum High Forest, it has now been replaced by housing and little remains.

Eastern Suburbs Banksia Scrub

The Eastern Suburbs Banksia Scrub country was of little use for agricultural purposes, and its disappearance came about mainly because of its ... nity to ... . The ... lity of ... ater in its swamps and aquifers led to the development of industries such as soap-making, tanning and wool-washing. Residential expansion in the late nineteenth century and early twentieth resulted in a steady decrease in the area of scrub. On the northern side of Botany Bay the few small areas now remaining are the subject of housing proposals.

On the southern side of Botany Bay, the Kurnell sand dune vegetation deteriorated through burning, clearing and grazing from the 1860s. Sand extraction on a major scale commenced in the 1940s, and in the 1950s a large area of dunes and swamps was flattened for an oil refinery. Large-scale sand extraction continues and use by off-road vehicles has become a problem.

Eastern Suburbs Freshwater Wetlands

The major freshwater wetlands associated with the Eastern Suburbs Banksia Scrub survived until the 1870s when the central swamps were dammed to supply Sydney's water. The system of freshwater lakes formed still exists today, in Centennial Park and Eastlakes Golf Course, but with permanent high water levels and grassy banks, supports relatively few of the original species. There are also heavy weed ... ations, ... teratio ... major r ... ks.

Estuarine Wetlands

Most Estuarine Wetlands survived into the twentieth century though small areas of shallow shoreline around Sydney Harbour were gradually filled and tidied up as Sydney developed. In Homebush Bay there was some modification of wetlands by salt evaporation works in the 1800s, and in the 1880s seawalls were built in preparation for filling, but it wasn't until after World War II that extensive wetlands of Sydney Harbour and Parramatta River were filled, particularly from Iron Cove to Homebush Bay and Parramatta. Filling has severely reduced the extent of both mangrove and saltmarsh communities, though some new opportunities for mangrove colonization have been provided by erosion and sedimentation along the Lane Cove River (McLoughlin 1985).

Wetlands of the Cooks River estuary were destroyed by the construction of Sydney Airport in the 1930s, and later the river was re-routed and turned into a canal, its neatened banks became ovals, golf courses and smaller parks. Much of the swampy creek line to the south was converted to market gardens, and transport corridors threaten tiny remnants along the tributary Wolli Creek.

In Botany Bay, mangroves were burnt to provide alkaline ash (barilla) for soap-making, from 1810 to 1850 (Bird 1981). *Casuarina glauca* was cut by oyster farmers in the late 1880s and early 1900s. The estuarine wetlands on the southern shore were conserved as Towra Point Nature Reserve in the 1970s, after being threatened with destruction for Sydney's second airport (Australian Littoral Society 1978). Its boundaries are inadequate, and in 1986 these wetlands narrowly escaped having a toxic chemical industry built on adjoining land.

Castlereagh Woodlands

The Castlereagh Woodlands survived destruction for a long period because their poor soils were not suitable for agriculture. In recent times however, woodland has been cleared during sand and clay extraction and the characteristic vegetation of the Agnes Banks sand deposits (Benson 1981) has almost been destroyed by mining. This vegetation is unusual because of its affinities with coastal plant communities 50-60 km away.

Woodlands and Heaths of the Sandstone

Finally, the vegetation of the sandstone areas has survived best in terms of the area remaining, because of low fertility soils and rugged terrain. Sydney's large national parks, Ku-ring-gai Chase, Marramarra, Heathcote and Royal, together with Muogamarra Nature Reserve and several large State Recreational Areas contain extensive sandstone communities. Smaller areas, generally a ... reek ... emain ... the ... s.

Though the sandstone around Sydney Harbour was occupied by housing last century, the stepped terrace housing of the period being suitable for the steeper slopes of Balmain and Paddington, it was not until after World War II that newer house design and construction capabilities led to the clearing and development of extensive sandstone areas. Provision of services through sandstone areas is still expensive, and engineers generally prefer softer bedrock for new housing development.

Conserving our remaining vegetation

Sydney's rich and diverse flora is spread between at least eight vegetation units but our conservation areas, particularly the major national parks, are almost all on the areas of Hawkesbury Sandstone. In earlier times such areas were seen as suitable for reserves for public recreation as they were scenically diverse yet could not be used for agriculture and were poor in minerals (except for coal). Conservation of the vegetation of the other units, most of which have now been almost totally cleared or degraded, is inadequate (Table 1), and deteriorating. Proposals for residential development, extractive industries and transport corridors threaten most unprotected vegetation remnants and it is inevitable that despite a great deal of effort, many will be lost.

A few examples

At Agnes Banks, near Richmond, about 450 ha of Pleistocene-Pliocene sand overlie Tertiary clays and silts. Although included in our broad Castlereagh Woodlands type, distinctive plant communities with coastal affinities grow on these sands, despite being 55 km inland in an area with only two-thirds of the average coastal rainfall. This vegetation is of great scientific interest because of information it contains about relationships between plant distributions and geomorphological events, including sea level fluctuations, in the Quaternary. Forster *et al.* (1977) included it in a list of areas of botanical conservation interest; detailed description and analysis of the five communities appears in Benson (1981). Despite initial proposals for reservation in 1968, about 70% of this vegetation has been removed by sand mining, and a nature reserve and Permanent Conservation Order protect about 9%.

Near Pitt Town, the Longneck Lagoon Wildlife Refuge and Field Studies Centre conserves one of the few remaining floodplain freshwater wetlands. Much of the catchment is Crown land with some of the best remaining areas of Cumberland Plain Woodland. This needs to be added to the conserved area. Until it is, it will remain vulnerable to proposals for residential or other development.

At Menangle in the south-west, the best remaining stand of the River-flat Forest which once ... the N ... ccurs ... ormer ... n

Proc. Ecol. Soc. Aust. 1990 — *16:201-213*

TABLE 1. Areas of vegetation types within the County of Cumberland in 1788, and percentages remaining in 1980.

Vegetation types	1788 area (ha)	1988 % remaining
Blue Gum High Forest	11 000	0.9
Turpentine-Ironbark Forest	35 000	0.5
River-flat Forests	19 000	3
Cumberland Plain Woodlands	107 000	6
Eastern Suburbs Banksia Scrub	8 000	3.5*
Estuarine and	6 000	29
Freshwater Wetlands	3 000	18
	9 000	25
Castlereagh Woodlands	19 000	32
Woodlands and Heaths of the Sandstone	162 000	85
County of Cumberland	370 000	

* Of the original 7 000 ha of Eastern Suburbs Banksia Scrub between Bondi and Botany Bay, only 0.2% remains. Most remaining vegetation of this type is found on the Kurnell Peninsula. This is structurally similar but lacks *Banksia aemula.*

Park Estate, the historic property of the Macarthur family. The Department of Agriculture now manages this land and is trying to conserve the forest; however, pre-existing mining leases cover the vegetated area, and the sand and soil company's application to mine has been the subject of a Commission of Inquiry. Elsewhere remnants of this forest occur in narrow bands subject to attrition at the edges, often with only the canopy trees remaining from the former forest.

North of Botany Bay, about 10 ha of Eastern Suburbs Banksia Scrub remain, but even some of this is currently the subject of housing proposals.

Problems in managing conserved areas

Even where bushland is intended to be preserved, deterioration continues through the insidious polluting effects of urban run-off, weed invasion and changes to the fire regimes.

Soil nutrient enrichment and weed invasion

Weed invasion of natural communities follows disturbance that leads to alteration in the resource base (Fox & Fox 1986). In suburban bushland two situations are particularly susceptible to weed invasion; edges, where adjacent clearing increases the light and open space resource, usually next to sources of weed propagules; and drainage lines, where urban run-off increases soil nutrient and moisture levels, favouring growth of weeds and mesic native species over scleromorphic native species.

Increased soil phosphorus content has been shown to increase the weed component of the flora (Clements 1983) and weed growth is particularly conspicuous along creeks and drainage lines below disturbed areas. Urban stormwater run-off typically moves about 1 kg ha^{-1} per year of phosphorous (Harley Wright, pers. comm.), and in northern Sydney, soil phosphorous levels have been found to be increased twofold at suburban boundaries, threefold in creek lines, and eight times below stormwater outlets (Leishman 1986). Contributors are garden fertilizers, dumped refuse, sewer discharges, and, significantly, pet excrement. Pets may add 3-10 kg ha^{-1} per year of phosphorus to suburban areas (Wright, pers. comm.). Reduction of nutrient input requires improved design of stormwater drainage systems, as advocated by Bliss *et al.* (1983).

Weed propagules are dispersed into bushland in stormwater, dumped garden refuse, by fruit-eating birds and wind, and soon take advantage of any nutrient-enriched conditions. Weed-invaded bushland is readily apparent; many creeklines in and around Sydney have become overgrown tangles where *Ligustrum*, exotic *Rubus*, *Lonicera japonica*, *Cardiospermum grandiflorum* and *Ipomoea indica* have replaced the native creekside vegetation.

Changing fire regimes

Fire regimes have undoubtedly changed in the last 200 years. Currently in bushland there may be wildfires that are less frequent and more intense than in the past, or prescribed burns that are more frequent and less intense. Other areas may remain unburnt. Frequent fires can cause local disappearances of obligate seeders, changing floristic composition in favour of resprouters (Siddiqi *et al.* 1976; Bradstock & Myerscough 1981; Nieuwenhuis 1987). In woodland on the Hawkesbury Sandstone, intervals free of fire of at least 9-10 years are needed to prevent loss of obligate seeding species (Benson 1985). Even resprouters can lose vigour if burnt too often.

Fires of low intensity may fail to stimulate germination of hard-seeded species (e.g., Floyd 1976) or release of seeds stored in woody fruits (Bradstock & Myerscough 1981) even though adults are killed. Achieving periodic hot fires in small suburban reserves is, for obvious reasons, a major difficulty. Hot fires would be desirable to reduce the understorey dominance of *Pittosporum undulatum* in a number of reserves where fire has long been excluded. However, these reserves are generally too small and too close to suburban dwellings to make hot fires acceptable, and hand thinning needs to be used as a second best alternative where fire is impossible.

Fire exclusion may cause floristic change. The small tree *Pittosporum undulatum* is susceptible to fire, and in its absence forms a dense canopy in some sandstone and shale reserves (see Adamson & Fox 1981; Clark & McLoughlin 1986). Growth and germination of other understorey species, and regeneration of canopy dominants are prevented.

Maintenance and rehabilitation

Although there is increasing awareness of the consequences of nutrient enrichment, weed invasion and altered fire regimes, bushland managers can find it hard to translate a bewildering collection of individual pieces of information, some seemingly contradictory, into an effective management plan for a specific location (Saunders *et al.* 1987). A generalized scheme of interactions between nutrients, weeds and fire for bushland on sandstone and shale in Sydney is shown in Figure 5. This gives a broad overview, designed to show the ways individual factors will interact, allowing prediction of outcomes from various combinations of conditions and actions. Soil fertility determines different sequences of events for vegetation on sandstone and shale.

To a certain extent, each site must be considered individually in the light of its past history of interacting factors. Some examples of burning and weeding programmes designed for specific areas are presented by Fox (1988).

In practice, there can be conflicts; for example, between keeping conditions suitable for recruitment of rare native species by exposing soil, and preventing weed colonization by encouraging a ground cover of ferns. Such conflicts need to be recognized, and resolved either by obtaining more management resources, or by choosing the most desirable realistic goal. However, it is important that bushland managers do not feel daunted if there are gaps in our knowledge and events cannot be predicted with certainty. It is important in such cases to try various actions to find what works for a particular situation. Managers will almost always have to make decisions with incomplete information, but they should use their activities as experiments to build up the information available iteratively (Hopkins & Saunders 1987).

Conclusion

By accidents of geology and history, Sydney is fortunate to retain much indigenous vegetation close to the city. However, for the same reasons, this vegetation is not representative of the range of types previously found there. Most remaining vegetation is on the sandstone, and for five of Sydney's eight vegetation types little remains.

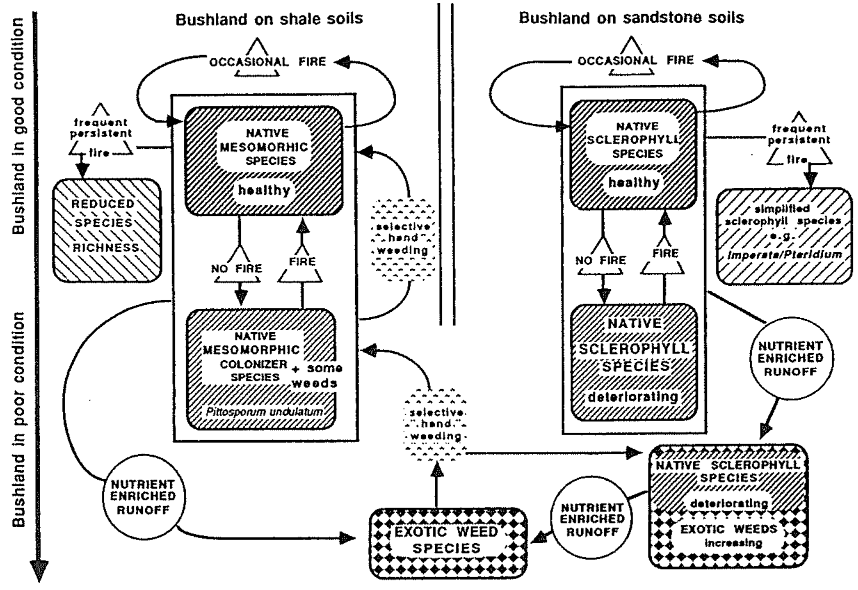


FIG. 5. Diagram illustrating interactions between vegetation, nutrients, weeds and fire in bushland on sandstone and shale

Proc. Ecol. Soc. Aust. 1990 — 16:201-213

Similarly, it is the species of the sandstone that are generally well conserved while species of other habitats survive as fragmented populations. Research is particularly needed on recruitment and maintenance of populations of uncommon species. Without adequate reservation and careful management, these fragmented populations are vulnerable to continuing attrition and possible extinction.

Research has provided guidelines for predicting management problems related to altered fire regimes and nutrient status in the large proportion of Sydney's remaining vegetation on low nutrient sandstone soils. Implementation of the results of this research by land managers, is now the main challenge in the retention of natural vegetation. For example, adequate protection of the catchments for reserves is the best long-term solution, to avoid weed invasion of gullies. However, new subdivisions are planned without regard to these factors, and bushland in suburbs such as Berowra and Menai will succumb to weed invasion in due course like the older suburbs that were developed before the consequences were evident. Planning may be more costly initially, but will allow our natural vegetation to survive and provide pleasure and value for many centuries. The deterioration of bush in new subdivisions cannot be blamed on our lack of knowledge.

For bushland in older areas, local solutions, perhaps simple or innovative, are needed to mitigate problems. The interface between bushland and housing is an important area where ecology, education and reserve management need to be brought together.

Acknowledgements

We thank Peter Mitchell and Jim Kohen for providing information, Lyn McDougall and Jeanette Stannard for their help with diagrams, and Sue McCahon, Angela Murray and Angela Benn for typing.

References

Adamson D. A. & Fox M. D. (1981) Change in Australasian vegetation since European settlement. In: *A History of Australasian Vegetation* (ed. J. M. B. Smith) pp. 109-46. McGraw-Hill, Sydney.

Atkinson J. (1826) *An Account of the State of Agriculture and Grazing in New South Wales.* Cross, London.

Australian Littoral Society (1978). *An Investigation of Management Options for Towra Point, Botany Bay.* Commonwealth of Australia.

Beaton J. M. (1982) Fire and water: aspects of Australian Aboriginal management of Cycads. *Archaeol. in Oceania* **17**, 51-8.

Benson D. H. (1981) Vegetation of the Agnes Banks sand deposit, Richmond, New South Wales. *Cunninghamia* **1**, 35-57.

Benson D. H. (1985) Maturation periods for fire-sensitive shrub species in Hawkesbury Sandstone vegetation. *[illegible]ingham* [illegible]-49.

Bird J. F. (1981) Barilla production in Australia. In: *Plants and Man in Australia* (eds D. J. Carr and S. G. M. Carr) pp. 274-80. Academic Press, Sydney.

Bliss P. J., Riley S. J. & Adamson D. (1983) Towards rational guidelines for urban stormwater disposal into flora preservation areas. *The Shire and Municipal Record* **76**, 181-5, 191.

Bradstock R. & Myerscough P. J. (1981) Fire effects on seed release and the emergence and establishment of seedlings of *Banksia ericifolia* L. f. *Aust. J. Bot.* **29**, 521-31.

Brisbane to Buchan (1822) *Historical Records of Australia, Series 1*, **10**, 723.

Bureau of Meteorology (1979) *Climatic Survey, Sydney, Region 5, New South Wales.* Department of Science and the Environment, Canberra.

Burrell J. P. (1972) Vegetation of the Sydney area: 1788 and 1961. In: *The City as a Life System?* (ed. H. A. Nix). *Proc. Ecol. Soc. Aust.* **7**, 71-8.

Chappell J. (1982) Sea levels and sediments: some features of the context of coastal archaeological sites in the tropics. *Archaeol. in Oceania* **17**, 69-78.

Clark S. S. & McLoughlin L. C. (1986) Historical and biological evidence for fire regimes in the Sydney region prior to the arrival of Europeans: implications for future bushland management. *Australian Geographer* **17**, 101-12.

Clements A. (1983) Suburban development and the resultant changes in the vegetation of the bushland of the northern Sydney region. *Aust. J. Ecol.* **8**, 307-19.

Cunningham P. (1827) *Two Years in New South Wales.* Colburn, London.

Field B. (1825) Journal of an Excursion Across the Blue Mountains of New South Wales, October, 1822. Appendix to *Geographical Memoirs on New South Wales*, John Murray.

Floyd A. G. (1976) Effect of burning on regeneration from seeds in wet sclerophyll forest. *Aust. For.* **39**, 210-20.

Forster G. R., Campbell D., Benson D. & Moore R. M. (1977) *Vegetation and soils of the western region of Sydney.* Technical Memorandum 77/10, CSIRO Division of Land Use Research, Canberra.

Fox M. D. (1988) The ecological status of alien plant species. In: *Weeds on public land — an action plan for today.* Weed Science Society of Victoria Inc. and the School of Environmental Science, Monash University, Melbourne.

Fox M. D. & Fox B. J. (1986) The susceptibility of natural communities to invasion. In: *Ecology of Biological Invasions: An Australian Perspective* (eds R. H. Groves & J. J. Burdon) pp. 57-66. Australian Academy of Science, Canberra.

Gentilli J. (1972) *Australian Climate Patterns.* Nelson, Melbourne.

Gill A. M. & Ingwersen F. (1976) Growth of *Xanthorrhoea australis* R. Br. in relation to fire. *J. Appl. Ecol.* **13**, 195-203.

Gobert V. (1978) Proposed nomenclature for the Cainozoic sediments of the Penrith-Windsor area. *Quarterly Notes of the Geological Survey of N.S.W.* **32**, 1-9.

Herbert C. & Helby R. (eds) (1980) *A Guide to the Sydney Basin.* Bulletin No. 26, Geological Survey of New South Wales. Department of Mineral Resources, Sydney.

Hopkins A. J. M. & Saunders D. A. (1987) Ecological studies as the basis for management. In: *Nature Conservation: The Role of Remnants of Native Vegetation* (eds D. A. Saunders, G. W. Arnold, A. A. Burbidge & A. J. M. Hopkins). pp. 15-28. Surrey Beatty, Chipping Norton.

Hunter J. (1793) *Historical Journal of the transactions at Port Jackson and Norfolk Island with the discoveries which have been made in New South Wales and in the Southern Ocean since the publications of Phillip's voyage.* John Stockdale, [illegible]don.

King to Hobart (1804) *Historical Records of Australia, Series 1*, **5**, 67.

Kohen J. L. (1984) Computer analysis of Aboriginal-plant interactions on the Cumberland Plain. In: *Technology in the 80's* (ed. J. L. Kohen). Proceedings of a Regional Conference on Science Technology. ANZAAS-AIST, Macquarie University, Sydney.

Kohen J. L. & Lampert R. (1987) Hunters and Fishers in the Sydney Region. In: *Australians to 1788* (eds D. J. Mulvaney & P. J. White) pp. 342-65. Fairfax, Syme and Weldon Associates, Broadway.

Lampert R. J. & Sanders F. (1973) Plants and men on the Beecroft Peninsula, New South Wales. *Mankind* **9**, 96-108.

Leishman M. (1986) The Distribution of Soil Phosphorus within Urban Bushland in the area of Ku-ring-gai, Sydney. B.Sc. (Hons.) Report, School of Biological Sciences, Macquarie University.

Mackaness G. (ed) (1965) *Fourteen Journeys Over the Blue Mountains of New South Wales 1813-1841.* Horwitz-Grahame, Sydney.

McLoughlin L. (1985) *The middle Lane Cove River: a history and a future.* Monograph No. 1, Centre for Environmental and Urban Studies, Macquarie University.

Maiden J. H. (1889) *The Useful Native Plants of Australia.* Facsimile edition (1975), Compendium, Melbourne.

Meredith L. A. (1844) *Notes and Sketches of New South Wales during a residence in that colony from 1839 to 1844.* Facsimile edition (1973), Penguin Books, Harmondsworth, England.

Nieuwenhuis A. (1987). The effect of fire frequency on the sclerophyll vegetation of the West Head, New South Wales. *Aust. J. Ecol.* **12**, 373-85.

Phillip A. (1789). *Voyage of Governor Phillip to Botany Bay with an account of the establishment of the colonies of Port Jackson and Norfolk Island; compiled from authentic papers.* John Stockdale, London.

Poiner G. (1976). The process of the year among Aborigines of the central and south coast of New South Wales. *Arch. & Phys. Anthrop. in Oceania.* **11**, 186-206.

Proudfoot H. (1987). *Exploring Sydney's West.* Kangaroo Press, Kenthurst.

Ross A. (1976). Inter-tribal Contacts — What the First Fleet Saw. BA (Hons.) Thesis, Department of Anthropology, University of Sydney.

Russell E. (1970). *Lane Cove 1788, 1895, 1970 — A North Shore History.* The Council of the Municipality of Lane Cove, Lane Cove.

Saunders D. A., Arnold G. W., Burbidge A. A. & Hopkins A. J. M. (eds) (1987). *Nature Conservation: The Role of Remnants of Native Vegetation.* Surrey Beatty, Chipping Norton.

Siddiqi M. Y., Carolin R. C. & Myerscough P. J. (1976). Studies in the ecology of coastal heath in New South Wales, III, Regrowth of vegetation after fire. *Proc. Linn. Soc. NSW.* **101**, 53-63.

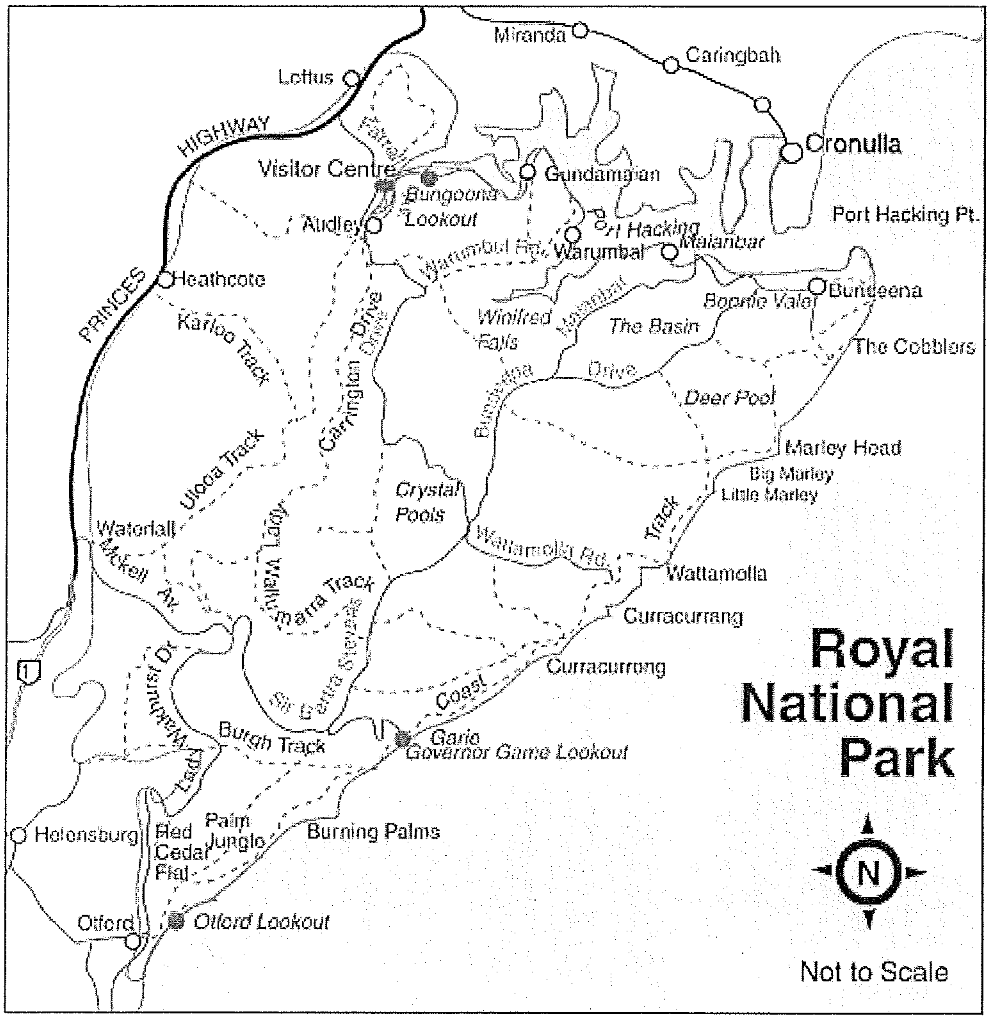
Tench W. (1979). *Sydney's First Four Years.* Library of Australian History in association with the Royal Australian Historical Society, Sydney.

Worgan G. B. (1978). *Journal of a First Fleet Surgeon.* Publication Number 16, The William Dixson Foundation. The Library Council of New South Wales in association with Library of Australian History, Sydney.

DAY 1.

Royal National Park is described at:
http://www.environment.nsw.gov.au/NationalParks/parkHome.aspx?id=N0030

Established in 1879, Royal National Park is the world's second oldest national park - after Yellowstone in the USA. Only 32 km from Sydney, the Royal packs incredible natural diversity into a relatively small area. It offers riverside picnics, great surf beaches, clifftop heathland walks, rainforest cycle tracks, and much more.



Nice images of the Sea Cliff Bridge are found at:
http://www.flickr.com/photos/tags/seacliffbridge/interesting/show/

The township of Robertson is described at:
http://www.highlandsnsw.com.au/towns/robertson.html

Clues to the 'burning question': Pre-European fire in the Sydney coastal region from sedimentary charcoal and palynology

By Scott D. Mooney, Kate L. Radford and Gary Hancock

This article was prepared by Scott Mooney while employed as a Lecturer in the School of Geography, at the University of NSW (Sydney, NSW 2052, Australia. Tel: 61-2-9385 -4389. Email: s.mooney@unsw.edu.au). In collaboration with Kate Radford, a former Honours student (Environmental Science, UNSW) and Gary Hancock from CSIRO (Division of Land and Water, Black Mountain Laboratories, Canberra). This work forms a part of a larger project by Scott Mooney on the fire history of the Sydney Basin.

Summary The concentration and influx of charcoal in a ^{210}Pb-dated sediment core were used to investigate the recent fire history of Jibbon Lagoon in Royal National Park, NSW. Fire events of the recent (historic) past were compared to this record in an attempt to test its sensitivity. Recent fire events were not always reflected in the charcoal results. Nonetheless it can be concluded that since about AD 1930 the area has been characterized by a relatively high frequency of fires. The analysed sediments of the pre-European period contained a low concentration of charcoal, and only one large conflagration appears to have occurred in approximately the last 1600 years. How Aboriginal people used fire in this landscape is still uncertain. However, it is possible that they did not regularly burn the landscape, or if they did, it was in such a way that the delivery of charcoal to the lagoon was minimal. This study thus suggests that the idea of the ubiquitous use of fire by Aboriginal people should be further, and critically, analysed.

Key words *^{210}Pb, charcoal analysis, fire, Royal National Park.*

Introduction

There are several issues of contention regarding the recent history of fire in Australia. This debate has recently been revisited by Flannery's (1994) book *The Future Eaters*, which popularized the decades-old debate concerning Aboriginal use of fire (e.g. Cleland 1957; Tindale 1959; Jones 1969; Hallam 1975; Horton 1982; Kohen 1996).

In the Sydney region and elsewhere, Flannery (1994; p. 218) claimed that regular burning of the Australian landscape by Aboriginal people resulted in an 'open, fire-maintained woodland' (Flannery 1994; p. 382). This suggests that the Aboriginal influence on the fire regime was so extreme that the vegetation encountered by European settlers was a cultural artifact resulting from thousands of years of manipulation by Aborigines. This interpretation relies heavily on evidence gleaned from writings of early settlers, especially in the Sydney area, which may be misinterpreted and/or exaggerated (Williams & Gill 1995; Benson & Redpath 1997).

Despite an obvious lack of consensus regarding the impact of the Aboriginal use of fire (e.g. Horton 1982; Clark 1983; Head 1989; Bowman 1998), Flannery (1994), Ryan *et al.* (1995) and Langton (1998) have proposed that Aboriginal burning practices be applied in the modern setting for conservation reasons. They suggest that the introduction of low intensity, high frequency fire will return the landscape to a condition that was maintained by the Aborigines.

The way in which fire regimes changed with the coming of European settlers is another issue surrounded in contention (Head 1989). Nonetheless, generalizations abound in the literature (Recher & Christensen 1981; Pyne 1992; Flannery 1994; Kirkpatrick 1994; Kohen 1995). For example, the lifting of the Aboriginal-imposed fire regime is often cited as resulting in a build up of fuel and a subsequent increase in the intensity of fires. In other areas the burning of land for agricultural purposes perhaps saw changes to fire frequency.

Partially as a result of extensive fires in 1939, a policy of fire suppression followed (Luke & McArthur 1978; Recher & Christensen 1981; Pyne 1992; Flannery 1994). In recent times suppression of fire has given way to hazard reduction burning, which generally constitutes low intensity fires at predetermined intervals, perhaps out of the normal fire season (McLoughlin 1998). Even with these practices in place large-scale wildfires are still a component of the fire regime.

It is notable that these views concerning both pre- and post-European use of fire are apparently not well based in scientific study. When palaeoecological studies are examined (Horton 1982; Clark 1983; Head 1989; Benson & Redpath 1997; Bowman 1998) it is generally concluded that they say nothing objectively about the issues. This is however, a result of methodological problems, which have largely been overcome in overseas studies.

The most common method for the reconstruction of fire history has been to analyse charcoal particles found in sediments (Clark 1982; Patterson *et al.* 1987; MacDonald *et al.* 1991). In Australia the 'point count method' (PCM), described by Clark (1982), is the most common way of determining the amount of charcoal present in lake or swamp sediments. This method is favoured as it is reportedly fast

(Clark 1982) and can be applied to slides prepared for palynology.

There are a number of limitations associated with the PCM and most researchers acknowledge that it results in a coarse fire history. The major problem is the size of the charcoal particles quantified, which are typically less than 50 μm in diameter (Clark & Royall 1995), but may range up to the size of the sieve used in the pollen preparation. Theoretical studies by Clark (1988a) suggest that charcoal of this size can potentially be carried long distances by strong convection currents during wildfires. Analysis of fine charcoal particles therefore provides an extra-regional record of fire, but may yield only limited inferences about site-specific fire regimes.

Larger charcoal particles (> 50 μm in length) are easier to identify, and if they do enter suspension they will travel much shorter distances than charcoal quantified using the PCM. As such it should result in a more localized record of fire (Clark 1988a,b, 1990a; Tinner *et al.* 1998). Such macroscopic charcoal in sediment was first analysed by Clark (1988b) and has since been used by MacDonald *et al.* (1991), Clark & Royall (1995), Millspaugh & Whitlock (1995), Long *et al.* (1998) and Tinner *et al.* (1998). Notably, to our best knowledge, no Australian study has used macroscopic charcoal to date, with the exception of Martin (1994) who counted only charcoal > 120 μm in maximum diameter.

Knowledge of the past provides a firmer basis for understanding the present (e.g. Clark 1990b; Foster *et al.* 1990). The study of macroscopic charcoal holds great promise for site-specific studies of fire history, and could be applied to issues addressing Aboriginal use of fire, and in conjunction with palynology, to ecological studies such as the examination of fire and vegetation relationships (Sander & Gee 1990). Knowledge of fire regimes of the past may also be desirable for the scientific management of National Parks and other conservation reserves.

Aims

This study aims to reconstruct the fire history of the Jibbon Lagoon catchment in Royal National Park before and after European settlement. Notably, the present study differs from previous palaeoecological studies in the Sydney region (e.g. Kodela & Dodson 1988; Johnson 1994; Martin 1994) by analysing macroscopic charcoal from contiguous samples and by better constraining the recent sediment chronology through the application of ^{210}Pb dating.

Furthermore, this study attempts to test the methodology by relating the charcoal record to the recent history of fire at the study site. Sedimentary charcoal is most commonly validated using dendrochronological studies, however, in Australia, few trees are suitable (Ogden 1978; Dunwiddie & LaMarche 1980; but see Green *et al.* 1988). As an alternative, several studies have compared sedimentary charcoal records with historic records of fire (Long *et al.* 1998; Tinner *et al.* 1998), but care is needed as historical sources have their own limitations and biases (Williams & Gill 1995).

Site description

Jibbon Lagoon is located approximately 20 km south of the Sydney CBD (Fig. 1) in the northeastern corner of Royal National Park (34°5' S, 151°9' E). The lagoon is fresh water despite it occupying a deflation hollow below sea level. It is separated from Port Hacking by a longitudinal sand dune, the formation of which has been linked to the post-glacial marine transgression 6000–10 000 years ago (National Parks and Wildlife Service 1994).

The bedrock underlying the lagoon consists of Triassic Hawkesbury Sandstone (Wright 1996). The main feature of the catchment is a moderately steep hill to the southwest of the lagoon that leads to the township of Bundeena. There are no streams flowing into the lagoon; precipitation and runoff from the surrounding catchment are the only surficial flows of water. The soils immediately surrounding the lagoon consist of unconsolidated sand dunes or skeletal sandy loams. They are considered to be highly erodible (National Parks and Wildlife Service 1994).

The Jibbon area experiences a temperate coastal climate (Bureau of Meteorology 1999) with a mean daily temperature of 13–22°C and a mean annual rainfall of 1106 mm. The natural fire season is spring or summer (Luke & McArthur 1978; McLoughlin 1998).

Jibbon Lagoon has areas dominated by emergent Tall Spike Rush (*Eleocharis sphacelata*) and is surrounded by a closed sedgeland assemblage (Goldstein 1976). The catchment of the lagoon is dominated by heath, Sydney Red Gum (*Angophora costata*) dune forest and a *Cupaniopsis* littoral closed forest assemblage consisting of Tuckeroo (*Cupaniopsis anacardioides*) and Bangalay (*Eucalyptus botryoides*) (Chalson 1983) between the lagoon and Jibbon Beach. Common species in the catchment include Old Man Banksia (*Banksia serrata*), Coast Banksia (*B. integrifolia*), Scrub She-oak (*Allocasuarina distyla*), Coastal Tea-tree (*Leptospermum laevigatum*) and Coast Wattle (*Acacia longifolia* ssp. *sophorae*).

It is thought that Aboriginal people from the Dharawal language group occupied Royal National Park for at least 7500 years prior to European settlement (Megaw 1969; Goldstein 1976; Flood 1990; Wright 1996). Middens containing remnants of marine organisms implies that they relied heavily on the marine environment for resources (Goldstein 1976). An important rock-engraving site occurs in the Jibbon area, indicating unequivocally that Aborigines occupied the area (Flood 1990; National Parks and Wildlife Service 1994).

After European settlement the Dharawal people were rapidly displaced, although the timing of the abandonment of traditional lifestyles is uncertain. Carter (1969) places it in the early 19th Century. Details of their use of fire are not well known.

The European history of the study area began as a large property known as Yarmouth Estate. This was subdivided in 1898 to form the township of Bundeena (Pettigrew & Lyons 1979). As Bundeena is in close proximity to Jibbon Lagoon (Fig. 1), the Lagoon and its catchment have undoubtedly been subject to European impacts.

Methods

The recent fire history of the study site was derived from the National Parks and Wildlife Royal National Park GIS, which

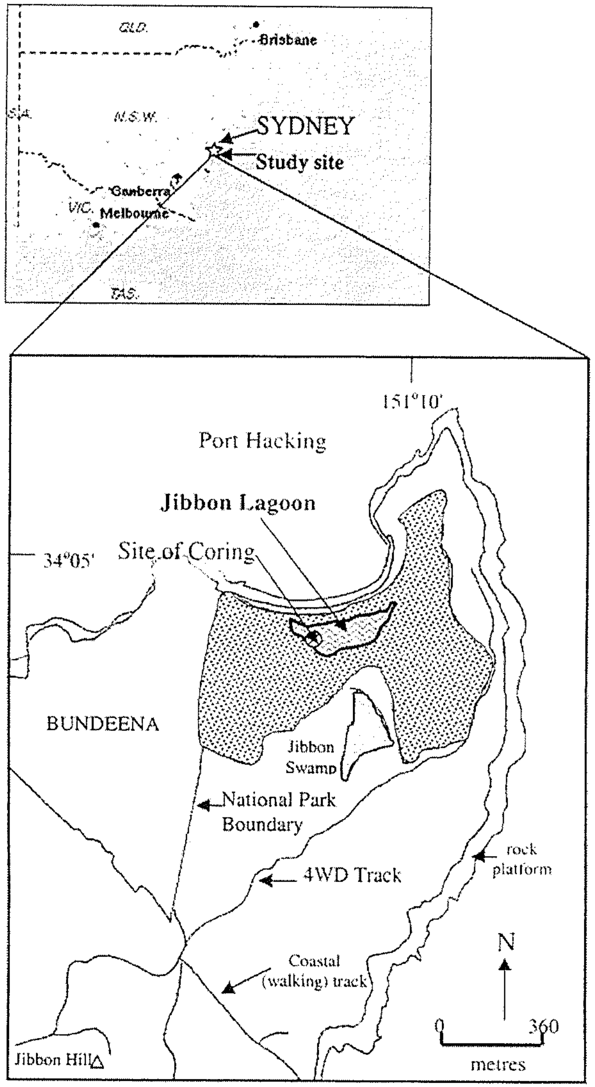


Figure 1. The location of the study site. The inset shows the location of the coring operation.

maps fire events from 1968 to the present. The occurrence of fires prior to this date was obtained from Keith (1995; p. 202) who analysed aerial photographs back to 1942 from a site to the southwest of the lagoon (Jibbon Hill). Although this site is in an adjacent catchment to that of Jibbon Lagoon it was assumed that the fires would have impacted upon the Jibbon area.

A total of nine sediment cores were removed from the lagoon (Fig. 1). These were removed from a site 6.0 m from the southwestern shore, where the water depth was 1.2 m. This site was chosen as it is adjacent to a steep slope, where it was thought that the delivery of charcoal would be best. The sediment cores were described using a modified Troels-Smith method (Kershaw 1997) and the longest core retrieved (Core 3) was chosen for further analysis.

The charcoal content of the sediment was assessed in three size classes. Larger sized particles, here referred to as macro-charcoal, were analysed using a modification of the wet-sieving method described by Long *et al.* (1998), resulting in size fractions of 125–250 μm and greater than 250 μm. Previous studies have found charcoal particles > 125 μm within a 10-km radius of a recent fire (Millspaugh & Whitlock 1995; Long *et al.* 1998) and the > 250 μm size fraction was analysed in an attempt to produce an extremely local record. The amount of sand present in each of the macro-charcoal subsamples was also estimated using an ordinal scale.

Pollen slides were produced following standard palynological techniques (Faegri & Iverson 1975; Moore *et al.* 1991). Charcoal was quantified on these slides using the PCM of Clark (1982). This charcoal is predominantly finer, compared to the macro-charcoal, and is here referred to as micro-charcoal. Charcoal was recognized as black, opaque, angular particles that were often shiny, following criteria similar to Clark (1982), Patterson *et al.* (1987) and Clark (1988b).

The concentration of *Pinus* and *Banksia* pollen grains was also determined on the palynology slides. The pollen of the exotic genus *Pinus* was quantified as it has been used in previous studies as an

approximation of the arrival of Europeans in an area (Kodela & Mackillop 1988). *Banksia* pollen was quantified as the dominant species found in the Jibbon area are negatively affected by high fire frequency (Keith 1995; Keith & Tozer 1997). For example, Heath-leaved Banksia (*B. ericifolia*) is fire sensitive and the soil seed bank may be affected if the fire interval is less than 5 years and Old Man Banksia is only fire tolerant upon maturity (Keith & Tozer 1997).

Loss-on-ignition (LOI) was determined at intervals similar to those for macro-charcoal analysis but only to a depth of 28 cm. The bulk density and water content of the fresh sediment and (volumetric) dry weight of the samples was also determined during the LOI process and as such was also only determined to a depth of 28 cm.

Lead-210 dating was chosen as the most appropriate method for determining an accurate chronology (Oldfield 1977; Robbins 1978). In brief, ^{210}Pb occurs naturally in lake sediments as an isotope of the ^{238}U decay series. Some of this ^{210}Pb is produced by the ^{238}U series nuclides in the sediments, and some is produced in the atmosphere by decay of gaseous ^{222}Rn, and is subsequently deposited as unsupported fallout ^{210}Pb. It is the unsupported fallout ^{210}Pb, equivalent to the ^{210}Pb activity in 'excess' of the sediment ^{226}Ra activity, that is used for dating.

The assumptions required for dating are that a lake has received a constant input of unsupported ^{210}Pb, the ^{210}Pb has had a constant residence time in the lake and there has been no significant migration of ^{210}Pb in the sediment column (Oldfield 1977). If these assumptions are fulfilled unsupported ^{210}Pb activity will decline down the sediment profile in accordance with its natural radioactive decay (Oldfield 1977). This declining activity allows the derivation of dates for the different depths of sediment.

The charcoal methods described above provide data as concentrations. Concentration data are limited, however, as these may be influenced by any change in the input of extraneous materials. A trace of charcoal unencumbered by any variations in the organic content of the sediment, for example, or in the rate of sedimentation, was especially required for the uppermost section where the historic record of fire allows testing of the data.

Hence, the concentration data were re-calculated as an influx (the number of charcoal particles per cm per year). This involved re-expressing the macro-charcoal data per gram of material not ignited in the LOI procedure and then multiplying the result by the rate of sediment accumulation (in g/cm per y). This re-calculation of the data was only possible in the upper section of the core, corresponding to the ^{210}Pb analyses.

Results

Recent fire history

Investigations into the documented fire history of the Jibbon area resulted in a large number of fires (Table 1). In particular, the fires in 1930, 1942, 1946, 1955, 1964, 1976, 1988 and 1994 were considered 'signature' fires to be examined against the sedimentary charcoal record.

Sediment chronology

An initial assessment of the chronology of sedimentation can be made from the first appearance of *Pinus* at a depth of 13 cm in core 3. The presence of this pollen is indicative that this sediment postdates European settlement (Kodela & Mackillop 1988).

A log-linear plot of excess ^{210}Pb against depth is shown in Fig. 2. Depth is expressed as cumulative mass (g/cm^2 per y) to eliminate variations in porosity and ashed weight is used to eliminate variations in organic content. Given the non-linearity of the plot in Fig. 2, and non-monotonic decrease in ^{210}Pb activity, the constant rate of supply (CRS) dating model is the most appropriate (Oldfield & Appleby 1984). With this model, the age of sediment at depth x is given by

$$t_x = \frac{1}{\lambda} \ln \frac{A_0}{A_x}$$

where A_0 is the total excess ^{210}Pb sediment inventory, and A_x is the excess ^{210}Pb inventory below depth x. This equation has been used to generate a plot of age against depth, shown in Fig. 3. The plot suggests that the sediments of the European period were confined to the upper 19 cm, as 19 cm yielded a ^{210}Pb date of 158 ± 11 years before 1999, approximating the time Aborigines left the Jibbon area and Europeans arrived.

Also shown in Fig. 3 is a plot of the sediment accumulation against depth. The plots show that below 17 cm a period of low sediment accumulation is indicated (0.02 g/cm per y equivalent to 0.04 cm/y). This depth corresponds to an age of about

Table 1. Historic fires in the vicinity of Jibbon Lagoon, Royal National Park, 1930–1999. The 'signature' fires are in bold

Year	Notes	Source
1930	Large and intense	Keith (*pers. comm.*)
1942	Large and intense	Keith (1995)
1946	Large and intense	Keith (1995)
1955	Relatively smaller fire	Keith (1995)
1959	Relatively smaller fire	Keith (1995)
1960	Relatively smaller fire	Keith (1995)
1964	Large and intense	Keith (1995)
1968/69	Included a fire next to the lagoon	NPWS GIS
1972/73	Between the lagoon and Bundeena, possibly hazard reduction burn	NPWS GIS
1974/75	To the south of Bundeena, not in lagoon catchment	NPWS GIS
1976	Extensive and high intensity	NPWS GIS
1984/85	Included next to lagoon, but likely low intensity hazard reduction fire	NPWS GIS
1986/87	To the south of Bundeena, not in lagoon catchment	NPWS GIS
1987/88	Burnt in immediate vicinity of the lagoon, but probably low intensity	NPWS GIS
1988	Extensive and high intensity (October)	NPWS GIS
1994	Extensive and high intensity (January)	NPWS GIS

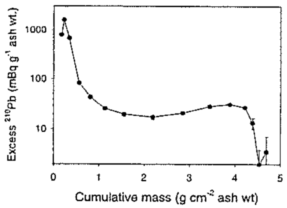


Figure 2. Excess ^{210}Pb against depth, expressed as cumulative mass.

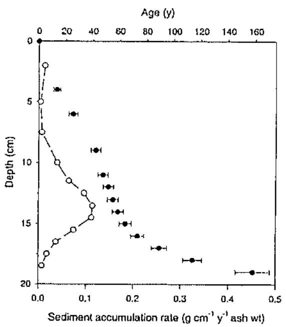


Figure 3. Sediment age against depth (closed circles, top horizontal axis) and the rate of sediment accumulation (open circles, bottom axis). Age is in years before AD 1999.

90 years (~1910). Above 17 cm, the accumulation accelerates, reaching a value almost an order of magnitude higher (0.30 cm/y) in the period 1940–1960. Recent accumulation rates appear to have declined significantly, approaching those prior to 1910. No radiocarbon dating of the sediment from Jibbon has been made, but if the sediment accumulation rate of the lowermost section of the ^{210}Pb analysis is assumed typical of pre-European accumulation rates the age of the lowermost analysed sediments is approximated at *ca* 1600 years.

Based on the ^{210}Pb chronology, the first appearance of *Pinus* at 13 cm indicates an age of just 55 years (1945). The implications of this age are discussed in the next section.

Sediment stratigraphy

The sediment recovered from Jibbon Lagoon was relatively homogenous organic lake mud. The top 10.5 cm was fibrous with unhumified herbaceous material that was highly elastic. The material from 10.5 cm to 16 cm was only slightly more humified and sand was visible but not abundant. From 16 cm to 56 cm the sediment contained a higher proportion of clay with very little sand and 56 cm to 63 cm was sandy, inelastic and had a high proportion of fine detritus present.

The results of the LOI analyses, bulk density, water content and dry weight determinations also reflect the physical make up of the sediment. The results of these analyses are shown in Fig. 4.

The LOI values are very high in the top 9 cm of the core, they decrease to low values between 10 cm and 18 cm, and increase to fairly high values again until 28 cm depth where the analysis stopped. The bulk density of the sediment was elevated between 10 cm and 18 cm and at the base of the core (Fig. 4). There is also a slight rise in the bulk density between 21 cm and 30 cm. The water content of the analysed sediment column was relatively consistent except for two slight decreases at 16 cm and 22 cm (Fig. 4). The dry weight of the sediment is low at the top of the profile, high between 12 cm and 18 cm and moderate between 18 cm and 28 cm (Fig. 4).

The amount of sand present changes throughout the analysed sediment profile and is similar for the 125–250 μm and > 250 μm size fractions (Fig. 4). The top 23 cm of the core is characterized by a higher abundance of sand. This decreases to being constantly present but not abundant between 23 cm and 48 cm with one small increase between 29 and 31 cm. Between 48 cm and the base of the analysed core there is a dramatic increase in the amount of sand.

Charcoal and other analyses

The concentration of macro-charcoal was found to be relatively high between 9 cm and 18 cm and between 47 cm and 49 cm (Fig. 5). This is consistent for both the 125–250 μm and > 250 μm size fractions. There is also a slight increase in the concentration of the 125–250 μm macroscopic charcoal size fraction between 24 cm and 33.5 cm. Apart from this there is little difference between the 125–250 μm and > 250 μm size fractions.

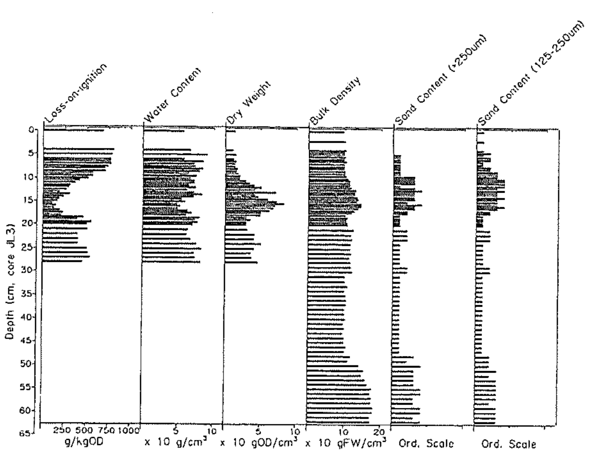


Figure 4. Physical parameters quantified.

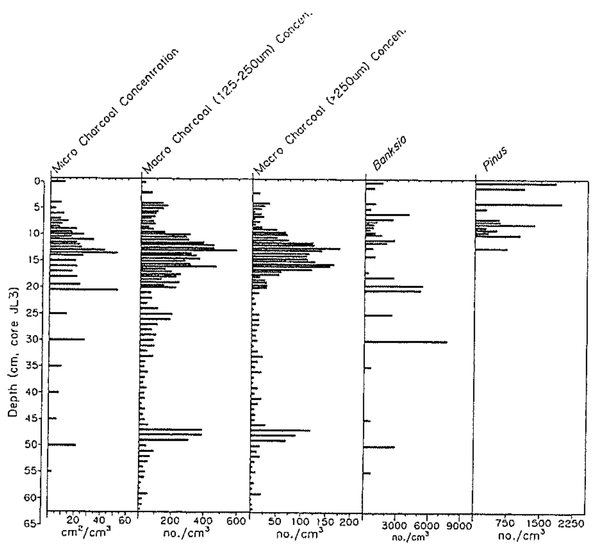


Figure 5. The results of all charcoal size fractions quantified expressed as concentrations together with the results of the palynology.

The micro-charcoal concentration results are similar to the macro-charcoal results (Fig. 5), revealing higher concentrations centred on a depth of 14 cm. Microscopic charcoal was quantified at a coarse resolution below 20 cm depth but it appears there is an increase at 48 cm. There also appears to be a peak in microcharcoal at 30 cm, corresponding to a slight increase in concentration of the 125–250 μm macro-charcoal size fraction.

The influx of macro-charcoal could only be calculated in the upper section of the core, corresponding to the ^{210}Pb analyses. Both the 125–250 μm and > 250 μm size fractions show that the delivery of charcoal was low in the top 8.5 cm of the core, high in the section from 9 cm to 15 cm and then low again from 15 cm to 19 cm (Fig. 6).

Some general relationships are apparent between the analysed variables. For example, high LOI results correspond with high water content values and lower bulk density, dry weight, sand content and (macro- and micro-) charcoal values. Notably, the peaks in macro- and microcharcoal concentration centred on 14 cm correspond with increases in the amount of sand present in the sediment (Figs 4, 5). An increase in the abundance of sand between 20 cm and 30 cm also corresponds with slight increases in the concentration of macro-charcoal in the 125–250 μm size fraction.

The concentration of *Banksia* pollen fluctuates throughout the profile (Fig. 5) in an often inverse relationship with charcoal. In the pre-European period *Banksia* is present at all analysed depths except 40 cm. It also appears to decrease following increases in macro-charcoal concentrations.

Discussion

Battarbee (1991) has suggested that lake sediments allow quasi-experimental procedures whereby the influence of known perturbations in the catchment, such as a

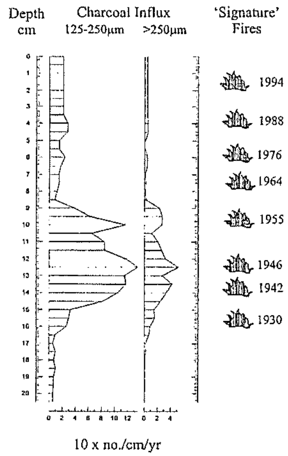


Figure 6. The influx of charcoal in the upper section of the analysed sediment core.

well documented fire can be compared to the sedimentary record. One of the aims of this research was to test the methodology by comparing recent fires with their sedimentary expression.

It was hoped that the fire events of the recent European period at Jibbon Lagoon would be reflected as distinct peaks in the charcoal record. For example, it was expected that the upper section of the sediment core would contain abundant charcoal due to the two very large fires of October 1988 and January 1994. In this section, however, both the concentration and influx of charcoal were relatively low (Figs 5, 6).

Despite this, several peaks in the charcoal record do occur at a depth that approximates the timing of earlier historic fires. For example, the ^{210}Pb analyses suggest that 1930 is represented just below the depth of 15 cm, when the influx of charcoal increases dramatically. Similarly, the influx of charcoal apparently reflects the signature fires of 1942, 1946, 1955 and perhaps 1976.

It is uncertain why some fires appear as peaks in the charcoal record when others, and notably the two most recent fires

(1988, 1994), do not. It is often explained that the delivery of charcoal to sediments is dependent on post-fire rainfall events, and hence the sedimentary record may better reflect fire and rainfall, however, this cannot be invoked here as rainfall followed both fires.

Alternatively, Whitlock & Millspaugh (1996) and Tinner *et al.* (1998) have demonstrated a time lag between a fire event and the deposition of charcoal in a lake. It is also conceivable that this time lag could vary, perhaps depending on factors such as whether the littoral vegetation was lost or not. The overall impression from the study by Whitlock & Millspaugh (1996) is that charcoal deposition is complex, with considerable movement between littoral areas and deeper water. They also noted that 'it is conceivable that past fire events could be missed in shallow water if winds were particularly strong and cores were taken on the upwind shore' (Whitlock & Millspaugh 1996; p. 13).

This inconsistent nature of the expression of fire in the sedimentary record of charcoal suggests some caution in any interpretation. Nonetheless, there are other suggestions that the charcoal data do provide a measure of past fire. This includes the increases in the amount of sand present in the sediment coincident with increases in charcoal. Furthermore, Keith (1995) has reported that *Banksia* thicket was unknown in the heathland to the west of Jibbon Hill prior to 1960 and that since that time this has expanded or contracted in relation to the occurrence of fire. This suggests that fire has changed in this landscape since about 1960, which is a conclusion that can also be drawn from the charcoal influx data. This also may explain the weak negative relationship between *Banksia* pollen and the charcoal data.

This suggests that if all indicators are interpreted in concert some general conclusions regarding the nature of fire in the Jibbon area can be drawn.

Post-European fire

There is a very noticeable difference in charcoal values between the European and pre-European periods at Jibbon Lagoon (Fig. 5). During the pre-European period there were consistently low concentrations of macro-charcoal with only one apparent large local fire event at 47–49 cm, resulting in charcoal delivery above these low levels. The European period, in contrast, is characterized by high concentrations and influx rates of macro-charcoal. Even in the most recent period of hazard reduction burning, the charcoal record suggests that the fire regime does not mimic the pre-European pattern.

The early European period (below about 17 cm or before *ca* 1907) contained the lowest influx of charcoal of the European period. This is likely to reflect the absence of fire, an interpretation supported by the relatively high representation of *Banksia* pollen. This time may hence have been a period of little human influence in the Jibbon Lagoon catchment, representing the period between the decline of Aborigines in the Sydney region and the subsequent post-European impacts.

The influx of charcoal is very high in the section of the core corresponding to *ca* 1934–1957 (9 cm to 15 cm, Fig. 6). It is likely that this charcoal reflects an overall increase in fire activity, including the two large fire events of the 1940s, a conclusion supported by the decline in the representation of *Banksia* pollen. This period covers the depression years and WWII, during which time military training occurred in the catchment. The expansion of Bundeena also occurred during this period (Pettigrew & Lyons 1979). It is possible that this increased human influence provided ignition sources, perhaps coupled with generally dry conditions in NSW during the 1940s (CSIRO 2000).

This period of increased charcoal influx of 1934–1957 also corresponds to a period of increased sedimentation (Figs 3, 6). This suggests that the increase in fire activity in the catchment is largely responsible for the post-European increased rate of sedimentation in Jibbon Lagoon. This also seems sensible, as the lagoon catchment is still largely in a naturally vegetated state.

Aboriginal fire

The charcoal analyses indicate consistently low concentrations of macroscopic charcoal during the pre-European period. Two charcoal peaks are evident in the concentration of charcoal of the 125–250 μm size fraction, at 25–26 cm and 47–49 cm, with only the latter mirrored in the > 250 μm size fraction. This suggests that only one fire comparable in size to the conflagrations of the recent European period has occurred in the catchment of Jibbon Lagoon in the time represented by the analysed sediment column. This timeframe can be approximated, using the sedimentation rate of the lowermost section of the ^{210}Pb analyses, to be *ca* 1600 years.

The generally low abundance of charcoal in the pre-European period may reflect the rarity or absence of fire as secondary charcoal may be washed into a lake even during long fire-free intervals (Millspaugh & Whitlock 1995). It is also conceivable that Aboriginal people used small patch burning, such that the vegetation surrounding any burnt patch impeded the transport of charcoal to the lagoon. Nonetheless, the persistence of obligate seeding shrubs in the catchment provides evidence that fire was not of such high frequency to cause their local extinction.

The rationale for the broadacre use of fire by the Dharawal people in the Jibbon Lagoon catchment must also be considered. For example, the heath and *Angophora* woodland of the catchment is unlikely to have furnished many useful plant foods (Benson & Howell 1990) and palatable grass species are relatively rare. Those terrestrial monocots with underground storage organs (e.g. Iridaceae, Liliaceae, Hypoxidaceae, Orchidaceae), which are often stimulated by fire, are a possible exception, as they may have acted as a supply of starch. Nonetheless, there may hence have been little advantage to manipulating the vegetation using fire, as is implied by Jones's (1969) 'Fire-Stick Farming' hypothesis.

Notably, Martin (1994), in a similar environmental setting to Jibbon Lagoon, previously suggested that a dependence on seafood may have resulted in little broadacre use of fire. Recher *et al.* (1993; p. 12) have also suggested that sandstone vegetation was unlikely to be burnt other than along corridors for transport, which in this environment is possible along the beach.

Comparison to previous studies

The finding that there has been a noticeable increase in fire activity since the arrival of Europeans at Jibbon contradicts the findings of other studies carried out in the Sydney Basin (Kodela & Dodson 1988; Johnson 1994; Martin 1994; Dodson *et al.* 1995). Nonetheless, a post-European increase in charcoal and presumably fire has been recorded before, by Boon & Dodson (1992) at Lake Curlip in east Gippsland, Victoria, by Gell *et al.* (1993) at a site on the Delegate River, also in southeastern Victoria and by Kodela (1996; p. 105) on the Robertson Plateau, NSW.

In contrast to the present study, and in a similar vegetation community in Ku-ring-gai Chase National Park, Kodela & Dodson (1988) found very low charcoal concentrations in the European period compared with the pre-European period. They hence concluded that after European settlement there was a reduction in fire activity possibly due to the displacement of the Aborigines and their burning practices.

Martin (1994) used the pollen contained in a swamp on the Kurnell peninsula, near Sydney, to infer the vegetation history from about 8000 years ago, to the present. Only charcoal greater than 120 μm in maximum dimension was tallied, and this was expressed as a ratio of charcoal to the dryland pollen. Although not discussed by Martin (1994) this charcoal quotient was generally low after the first record of exotic pollen, but comparable to the pre-European period.

Johnson (1994) also investigated sites on the Kurnell Peninsula using a variety of palaeoenvironmental analyses including palynology. Charcoal was quantified using the PCM, but re-expressed as an influx, using low-resolution chronological control. In the period when exotic pollen was present the charcoal influx was moderate.

Dodson *et al.* (1995) investigated a small area of peatland in Sydney's eastern suburbs. Again charcoal was counted using the PCM and expressed as charcoal influxes, based on coarse-resolution dating. Charcoal values were low in the European period, but as the site is now surrounded by urban development the absence of fire in the modern environment is not unexpected.

There are a number of reasons for the differences between the current study and previous Sydney palaeoenvironmental studies. Previous studies examined micro- rather than macro-charcoal and at a coarser resolution than this study. The problems associated with the PCM have been widely recognized (Clark 1983; Patterson *et al.* 1987; MacDonald *et al.* 1991) and, as discussed above, probably reflect fires at a regional or larger scale (Clark 1988a).

Perhaps of greatest concern is the temporal control of previous studies. No study to date in the Sydney Basin has utilized ^{210}Pb dating, but rather they rely on the presence of *Pinus* pollen in the sediment as a proxy boundary between the pre- and post-European periods (e.g. Kodela & Mackillop 1988). In the present study *Pinus* pollen is not present in the sediment until a depth of 13 cm, which is about 55 years before present (Fig. 3). It is thus possible that *Pinus* pollen in sedimentary profiles better indicates the establishment of large-scale pine plantations, which occurred in the early to mid-20th Century (Nimmo 1988), rather than small numbers of garden plants introduced by European settlers. Alternatively the date may represent the expansion of Bundeena. Such a conclusion would, if validated, significantly affect the conclusions of other researchers.

Johnson (1994), for example, assumed *Pinus* indicated the start of the European period and found that there was low fire activity in the European period and high fire activity toward the end of the pre-European period. A reassessment of his data shows that if the historic boundary was placed a few centimetres closer to the base of the core, then the period of high fire activity that he places in the pre-European period and attributes to Aboriginal burning would actually be in the European period.

Aside from methodological differences it is possible that the differences between the studies reflect different use of fire by different groups of Aborigines. It appears that the Jibbon area may have been the northernmost extension of one group (Goldstein 1976) and as such they may have had a different approach to burning than the Aborigines at the other study sites. Site specific histories may also be apparent due to the use of different vegetation communities in different ways (Head 1989; Benson & Redpath 1997). This is also a conclusion Bowman (1998; p. 400) made after a review of post-European changes to fire: 'clearly the ecological context of pollen cores requires considerable thought'.

It is also likely that other specific features are of importance, further suggesting that extrapolation from single sites should be used with considerable caution. For example, this study is located close to the township of Bundeena, and this human presence is likely to have led to increased ignition sources and the application of fire either intentionally or accidentally.

Conclusions

It will require further study of the Jibbon Lagoon sedimentary environment before any conclusions regarding the fire history of the catchment can be made with some degree of certainty. In particular, the methods used herein applied to a sediment core from an area not colonized by aquatic vegetation and perhaps in a downwind area of the lake may prove instructive. Whitlock and Millspaugh (1996) have demonstrated, for example, that at least initially, charcoal was more than 10 times more abundant on the downwind side of a lake. They also recommended that the deepest part of a lake is the best site for coring, suggesting further work at the site.

The possibility of applying knowledge of Aboriginal burning practices to the modern setting has been proposed by a number of people (e.g. Flannery 1994; Ryan *et al.* 1995; Langton 1998). In reality it is difficult to do this as our knowledge is limited and apparently biased with preconceived ideas about the past. This is perhaps exacerbated by unresolved problems with charcoal methodology.

Here, for example, there appears to be an inconsistent relationship between fire and charcoal in the sediment. It is, however, only through the testing of such methodology that we will answer several contentious issues. Until this occurs the claims of people such as Flannery (1994) espousing widespread, regular low intensity burns to return the landscape to a previous state must be viewed with some caution.

As concluded by Bowman (1998) the management of our conservation estate must have the clear aim of conserving extant biodiversity, meaning that the lessons of the past may not be entirely relevant given that conditions are now different. Nonetheless, knowledge of pre-European fire history may help to ensure that management decisions are made in a well-informed manner.

It is likely that fire regimes would have varied spatially across the range of environments and with different Aboriginal groups in Australia. The use of fire may also have varied temporally with changes in population and climate (Head 1989). This study suggests that Aboriginal burning in the heath and *Angophora* woodland that dominates the Jibbon Lagoon catchment was relatively rare or consisted of small patch burning. In contrast, fire in the European period, particularly from the 1930s to *ca* 1960 was frequent. This study thus supports the view held by Clark (1983; p. 32) that 'the frequency and areal extent of Aboriginal burning may well have been overestimated and European burning underestimated'.

Method details

Core retrieval and sampling

A total of nine sediment cores were removed from the lagoon. Six of the cores were approximately 1 m and procured using 50 mm diameter PVC. The other cores were taken to a depth of 90 cm using a Russian D-section corer (Jowsey 1966). The cores were kept in a vertical position and refrigerated at all times until they were analysed.

The PVC cores were split, photographed and described using a modified Troels-Smith method (Kershaw 1997). Core 3 was subsampled at 0.5 cm contiguous intervals to a depth of 20 cm, with the exception of the top 4 cm due to the dominance of vegetative material, and below 20 cm it was subsampled at 1 cm intervals.

Charcoal and palynology

Macro-charcoal was analysed using a modification of the wet-sieving method described by Long *et al*. (1998), resulting in size fractions of 125–250 μm and greater than 250 μm. Sediment of a known volume was placed into 10 mL of 5% sodium hexametaphosphate for a minimum of 24 h and then washed through two nested sieves (mesh sizes 125 and 250 μm) with the aid of gentle brushing. The contents of the sieves were washed into Petri-dishes and placed on a 1-cm^2 grid to assist in counting the number of charcoal particles under a dissecting microscope. Initially all particles of charcoal were counted, however, this was laborious, and hence only the charcoal in 10 random squares for each sample was counted. This number was then multiplied by the total number of squares to be comparable with the total count.

Pollen slides were produced using 1 cm^3 of sediment taken at half cm intervals with the exception of the 0–7 cm interval. Known quantities of the exotic pollen grain *Alnus* were added to the subsamples, and then they underwent an alkali treatment, filtering through a 150 μm sieve, acetolysis and dehydration through an alcohol series before the residue was mounted in silicone oil.

Micro-charcoal was quantified using PCM (Clark 1982). At least 150 random fields of view were examined, and in each field of view 11 points were applied. The concentration of *Alnus*, *Pinus* and *Banksia* pollen grains was also determined on these slides. The concentration and influx of micro-charcoal in the sediment was determined using the method described by Clark (1982).

Other analyses on the sediment

Loss-on-ignition was calculated as a percentage of the oven-dry mass (Bengtsson & Enell 1986). For this, 1 cm^3 of sediment was subsampled using a cut syringe, and the mass was determined initially (bulk density), after 12 h in an oven at 105°C (giving the volumetric dry weight) and after 2 h in a muffle furnace at 550°C (giving LOI).

Sediment chronology

Activities of Lead-210 (via its ^{210}Po daughter) and ^{226}Ra were measured in oven-dried samples using radiochemical separation procedures and alpha particle spectrometry (Martin & Hancock 1992). The chemical yield was determined using ^{209}Po and ^{225}Ra yield tracers. The sediment samples were from contiguous 1 cm intervals from 0 to 19 cm in depth. The results of the upper 11 cm were combined into 0–4 cm, 4–6 cm 6–9 cm and 9–11 cm intervals, the remaining samples remained as individual results.

Acknowlegements

National Parks and Wildlife Service kindly granted permission to work in Royal National Park. Tanya Leishman provided assistance in the field and Chris Myers and Dorothy Yu advised in the lab. Chris Togher, Ross Bradstock, David Keith, Mark Tozer and Jennifer Beane (all NSW NPWS) provided information. Nick Skelton offered suggestions for this work and David Keith, Ross Bradstock, Phil Kodela and John Benson kindly commented on earlier drafts. The Faculty of Science and Technology, UNSW, provided funding for this project through a Special Research Grant.

References

Battarbee R. W. (1991) Recent Palaeolimnology and Diatom-Based Environmental Reconstruction. In: *Quaternary Landscapes* (eds L. C. K. Shane and E. J. Cushing), pp. 129–174. Belhaven Press, London.

Bengtsson L. and Enell M. (1986) Chemical analysis. In: *Handbook of Holocene Palaeoecology and Palaeohydrology* (ed. B. E. Berglund), pp. 423–451. Wiley and Sons, UK.

Benson D. and Howell J. (1990) *Taken for Granted — the Bushland of Sydney and its Suburbs*. Kangaroo Press, Kenthurst.

Benson J. S. and Redpath P. A. (1997) The nature of pre-European native vegetation in south-eastern Australia: a critique of Ryan, D. G., Ryan, J. R. and Starr, B. J. (1995) *The Australian Landscape — Observations of Explorers and Early Settlers Cunninghamia* **5**, 285–328.

Boon S. and Dodson J. R. (1992) Environmental response to landuse at Lake Curlip, East Gippsland, Victoria. *Australian Geographic Studies* **30**, 207–222.

Bowman D. M. J. S. (1998) Tansley Review no. 101: The impact of Aboriginal landscape burning on the Australian biota. *New Phytologist* **140**, 385–410.

Bureau of Meteorology (1999) Bureau of Meteorology Website, Climate Averages. www.bom.gov.au/climate/averages/tables/cw_066037.shtml

Carter N. (1969) A 'paradise lost' — the Kurnell Peninsula since 1770. *Australian Natural History* **16**, 276–280.

Chalson J. (1983) Palynology and Palaeoecology of Jibbon Swamp, Royal National Park [Unpublished Honours Thesis]. University of New South Wales.

Clark J. S. (1988a) Particle motion and the theory of charcoal analysis: source area, transport, deposition, and sampling. *Quaternary Research* **30**, 67–80.

Clark J. S. (1988b) Stratigraphic charcoal analysis on petrographic thin sections: application to fire history in Northwestern Minnesota. *Quaternary Research* **30**, 81–91.

Clark J. S. (1990) Fire and climate change during the last 750yr in Northwestern Minnesota. *Ecological Monographs* **60**, 135–159.

Clark J. S. and Royall P. D. (1995) Particle-size evidence for source areas of charcoal accumulation in late Holocene sediments of Eastern North American lakes. *Quaternary Research* **43**, 80–89.

Clark R. L. (1982) Point count estimation of charcoal in pollen preparations and thin sections of sediment. *Pollen et Spores* **24**, 523–535.

Clark R. L. (1983) Pollen and charcoal evidence for the effects of Aboriginal burning on the vegetation of Australia. *Archaeology in Oceania* **18**, 32–37.

Clark R. L. (1990) Ecological history for environmental management. *Proceedings of the Ecological Society (Australian)* **16**, 1–21.

Cleland J. B. (1957) Our natives and the vegetation of Southern Australia. *Mankind* **5**, 149–115.

CSIRO (2000) Australian Rainfall Trends. CSIRO Atmospheric Rainfall Trends. http://www.dar.csiro.au/res/cm/rainfall_trends.htm

Dodson J. R., Chant J. and Daly J. (1995) Human impact recorded in an urban wetland's sediments in Sydney. *Australia Man and Culture in Oceania* **11**, 113–124.

Dunwiddie P. W. and LaMarche V. C. (1980) Dendrochronological characteristics of some native Australian trees. *Australian Forester* **43**, 124–135.

Faegri K. and Iverson J. (1975) *Textbook of Pollen Analysis*. Blackwell Science, Oxford.

Flannery T. (1994) *The Future Eaters*. Reed Books, Victoria.

Flood J. (1990) *The Riches of Ancient Australia*. University of Queensland Press, St Lucia.

Foster D. R., Schoonmaker P. K. and Pickett S. T. A. (1990) Insights from paleoecology to community ecology. *TREE* **5**, 119–122.

Gell P. A., Stuart I. M. and Smith J. D. (1993) The response of vegetation to changing fire regimes and human activity in East Gippsland, Victoria, Australia. *The Holocene* **3**, 150–160.

Goldstein W. (1976) *Royal National Park*. Environmental Education and Wildlife Extension Section of the National Parks and Wildlife Service, Sydney.

Green D., Singh G., Polach H., Moss D., Banks J. and Geissler E. A. (1988) A fine-resolution palaeoecology and palaeoclimatology from south-eastern Australia. *Journal of Ecology* **76**, 790–806.

Hallam S. J. (1975) *Fire and Hearth — a Study of Aboriginal Usage and European Usurpation in South-Western Australia*. Australian Institute of Aboriginal Studies, Canberra.

Head L. (1989) Prehistoric Aboriginal impacts on Australian vegetation: an assessment of the evidence. *Australian Geographer* **20**, 37–46.

Horton D. R. (1982) The burning question: Aborigines, fire and Australian ecosystems. *Mankind* **13**, 237–251.

Johnson A. G. (1994) Late Holocene environmental change on Kurnell Peninsula, NSW. *Proceedings of the Linnean Society of New South Wales* **114**, 119–132.

Jones R. (1969) Fire-stick farming. *Australian Natural History* **16**, 224–228.

Jowsey P. C. (1966) An improved peat sampler. *New Phytologist* **65**, 245–248.

Keith D. A. (1995) Mosaics in Sydney heathland vegetation: the roles of fire, competition and soils. *CALMScience* **(Suppl. 4)**, 199–206.

Keith D. A. and Tozer M. G. (1997) Experimental design and resource requirements for monitoring flora in relation to fire. In: *Proceedings of Bushfire '97 — Darwin 8–10 July* (eds McKaige, B. J., Williams, R. J. and Waggitt, W. M.). pp. 274–279.CSIRO Tropical Ecosystems Research Centre, Darwin.

Kershaw A. P. (1997) A modification of the Troels-Smith system of sediment description and portrayal. *Quaternary Australasia* **15**, 63–68.

Kirkpatrick J. (1994) *A Continent Transformed — Human Impact on the Natural Vegetation of Australia*. Oxford University Press, Melbourne.

Kodela P. G. (1996) The vegetation of the Robertson Plateau, New South Wales: historical and contemporary issues [Unpublished PhD Thesis] School of Geography, University of New South Wales, Sydney.

Kodela P. G. and Dodson J. R. (1988) A late Holocene vegetation and fire record from Ku-ring-gai Chase National Park, New South Wales. *Proceedings of the Linnean Society of New South Wales* **110**, 317–325.

Kodela P. G. and Mackillop R. D. (1988) Weed pollen, a geomorphological application (introduced pollen taxa as indicators of post-European sediments). *Palynological and Palaeobotanical Association of Australia Newsletter* **17**, 4–6.

Kohen J. L. (1995) *Aboriginal Environmental Impacts*. University of New South Wales Press, Sydney.

Kohen J. L. (1996) Aboriginal use of fire in South-eastern Australia. *Proceedings of the Linnean Society of New South Wales* **116**, 19–26.

Langton M. (1998) Burning Questions — Emerging Environmental Issues for Indigenous Peoples in Northern Australia. Centre for Indigenous Natural and Cultural Resource Management Northern. Territory University, Darwin.

Long C. J., Whitlock C., Bartlein P. J. and Millspaugh S. H. (1998) A 9000-year fire history from the Oregon Coast Range, based on a high-resolution charcoal study. *Canadian Journal of Forestry Research* **28**, 774–787.

Luke R. H. and McArthur A. G. (1978) *Bushfires in Australia*. Australian Government Publishing Service, Canberra.

MacDonald G. M., Larsen C. P. S., Szeicz J. M. and Moser K. A. (1991) The reconstruction of boreal forest fire history from lake sediments: a comparison of charcoal, pollen, sedimentological, and geochemical indices. *Quaternary Science Reviews* **10**, 53–71.

Martin A. R. H. (1994) Kurnell Fen: an eastern Australian coastal wetland, its Holocene vegetation, relevant to sea-level change and Aboriginal land use. *Review of Palaeobotany and Palynology* **80**, 311–332.

Martin P. and Hancock G. J. (1992) Routine analysis of naturally occurring radionuclides in environmental samples by alpha-particle spectrometry. Research Report 7, Supervising Scientist for the Alligator Rivers Region. AGPS, Canberra.

McLoughlin L. C. (1998) Season of burning in the Sydney region: The historical records compared with prescribed burning. *Australian Journal of Ecology* **23**, 393–404.

Megaw J. V. S. (1969) Captain Cook and the Australian Aborigine. *Australian Natural History* **16**, 255–260.

Millspaugh S. H. and Whitlock C. (1995) A 750-year fire history based on lake sediment records in central Yellowstone National Park, USA. *The Holocene* **5**, 283–292.

Moore P. D., Webb J. A. and Collinson M. E. (1991). *Pollen Analysis*. Blackwell Science, London.

Nimmo B. (1988) Planting Radiata Pine in New South Wales. *Forest and Timber* **24**, 20–25.

National Parks and Wildlife Service (1994) *Royal National Park, Heathcote National Park and Garawarra State Recreation Area Draft Plan of Management*. National Parks and Wildlife Service, Sydney.

Ogden J. (1978) On the dendrochronological potential of Australian trees. *Australian Journal of Ecology* **3**, 339–356.

Oldfield F. (1977) Lakes and their drainage basins as units of sediment-based ecological study. *Progress in Physical Geography* **1**, 460–505.

Oldfield F. and Appleby P. G. (1984) Empirical testing of ^{210}Pb-dating models for lake sediments. In: *Lake Sediments and Environmental History* (eds E. Y. Haworth and J. W. G. Lund), pp. 93–124. Leicester University Press, Leicester.

Patterson W. A., Edwards K. J. and Maguire D. J. (1987) Microscopic charcoal as a fossil indicator of fire. *Quaternary Science Reviews* **6**, 3–23.

Pettigrew C. and Lyons M. (1979) Royal National Park: a history. In: *Australia's 100 Years of National Parks* (ed. W. Goldstein), pp. 15–30. National Parks and Wildlife Service, Sydney.

Pyne S. J. (1992) *Burning Bush — a Fire History of Australia*. Allen & Unwin, Sydney.

Recher H. F. and Christensen P. E. (1981) Fire and the evolution of the Australian biota. In: *Ecological Biogeography of Australia* (ed. A. Keast). Dr W. Junk, The Hague.

Recher H. F., Hutchings P. A. and Rosen S. (1993) The biota of the Hawkesbury-Nepean catchment: reconstruction and restoration. *Australian Zoologist* **29**, 3–41.

Robbins J. A. (1978) Geochemical and geophysical applications of radioactive lead. In: *The Biogeochemistry of Lead in the Environment, Part A* (ed. J. O. Nriagu), pp. 285–393. Elsevier Scientific, Amsterdam.

Ryan D. G., Ryan J. E. and Starr B. J. (1995) *The Australian Landscape — Observations of Explorers and Early Settlers*. Murrumbidgee Catchment Management Committee, Wagga Wagga.

Sander P. M. and Gee C. T. (1990) Fossil charcoal: techniques and applications. *Review of Palaeobotany and Palynology* **63**, 269–279.

Tindale N. B. (1959) Ecology of the primitive Aboriginal man in Australia. In: *Biogeography and Ecology in Australia* (eds A. Keast, R. L. Crocker and C. S. Christian), pp. 36–51. Dr W. Junk, The Hague.

Tinner W., Conedera M., Ammann B., *et al.* (1998) Pollen and charcoal in lake sediments compared with historically documented forest fires in Southern Switzerland since AD 1920. *The Holocene* **8**, 31–42.

Whitlock C. and Millspaugh S. H. (1996) Testing the assumptions of fire history studies: an examination of modern charcoal accumulation in Yellowstone National Park, USA. *The Holocene* **6**, 7–15.

Williams J. E. and Gill A. M. (1995) *Forest Issues 1: The Impact of Fire Regimes on Native Forests in Eastern New South Wales*. NSW National Parks and Wildlife Service, Hurstville.

Wright P. C. (1996) Royal National Park and Garawarra State Recreation Area. In: *The NPA Guide to the National Parks of Southern New South Wales (Including State Recreation Areas)*, pp. 87–98. National Parks Association of NSW Inc., Sydney.

The Holocene 18,3 (2008) pp. 437–447

Implications of a 14 200 year contiguous fire record for understanding human–climate relationships at Goochs Swamp, New South Wales, Australia

M.P. Black,[1] S.D. Mooney[1]* and V. Attenbrow[2]

([1]School of Biological, Earth & Environmental Sciences, University of New South Wales, Sydney, New South Wales 2052, Australia; [2]Australian Museum, Anthropology Unit, Research Branch, Australian Museum, 6 College Street, Sydney, New South Wales 2010, Australia)

A HOLOCENE SPECIAL ISSUE

Abstract: This paper interprets macroscopic charcoal (>250 μm), humification and loss-on-ignition over the last ~14 200 cal. BP from Goochs Swamp, located to the west of Sydney in the Greater Blue Mountains World Heritage Area. This study aimed to investigate relationships between humans, climate and fire through time, primarily by comparison of these palaeoenvironmental indices with archaeological evidence from the region. Climatic forcing can explain all periods of change in the history of fire at Goochs Swamp: fire activity was variable during the Lateglacial–Holocene transition, low during the relatively stable climate of the early Holocene, and high but variable after the onset of modern El Niño from the mid Holocene. Although the dominant control on fire in this environment during the Holocene appears to be climate, fluctuations in the late Holocene may reflect anthropogenic fire or human responses to climate change. The archaeological record of the Blue Mountains and other parts of the Sydney Basin illustrates that Aboriginal people altered subsistence, resource and land-use patterns in the late Holocene. We propose that these cultural measures were adopted to overcome new risks as the frequency of ENSO events increased, and the natural fire regime and resource reliability changed. These strategies perhaps included a more systematic use of fire. The most parsimonious interpretation of the evidence for changes in fire activity at Goochs Swamp in the light of nearby archaeological evidence is that Aboriginal people used fire within a changing climatic framework.

Key words: Holocene, Aboriginal impacts, fire, climate, Sydney Basin, human–environment interaction, New South Wales, Australia.

Introduction

This study is part of a broader research project that is investigating relationships between humans, climate and fire through time, primarily by comparison of palaeoenvironmental indices with regional archaeological evidence. Such an approach was advocated by Bowman (1998), who highlighted that palaeoecological and archaeological information used together may lead to a better understanding of fire history in Australia. Our study reconstructs fire activity at Goochs Swamp, located in the Blue Mountains of eastern Australia, using charcoal and other palaeoecological analyses of the accumulating sediment. This fire history is then compared with regional climate proxies and data from a nearby excavated archaeological site, with the aim of better resolving issues concerning controls on fire activity during the Holocene.

Black and Mooney (2006) and Black *et al.* (2007) suggested that climate was the dominant factor controlling past fire activity at Goochs Swamp. This interpretation conflicts with the dominant paradigm in Australia, which depicts Aboriginal people as strongly controlling prehistoric fire activity. Here the 14 200 cal. BP charcoal record from Goochs Swamp has been revised using high resolution, contiguous analyses of charcoal and it is compared with regional archaeological trends to further investigate any anthropogenic influences. The aim here is to further elucidate the relationship between fire, climate and humans in this landscape and, in so doing, comment on the wider implications for the 'intensification hypothesis' in Australia.

Interpretation of any palaeoenvironmental fire record is often difficult as either climate (directly or via vegetation) or human activity may be responsible for change. In Australia it is commonly considered that fire was used by Aboriginal people to acquire resources or to manipulate and thereby increase the availability of resources (Jones, 1969; Nicholson, 1981; Gott, 2005). The word 'farming' was deliberately used by Jones (1969) to imply that Aboriginal people actively managed the land and were not totally reliant on what nature produced (cf. Elkin, 1954). It has

*Author for correspondence (e-mail: s.mooney@unsw.edu.au)

© 2008 SAGE Publications 10.1177/0959683607087933

been argued that this use of fire led to vegetation change and other environmental impacts (eg, Hughes and Sullivan, 1981; Singh *et al.*, 1981; Kershaw, 1986; Flannery, 1994; Miller *et al.*, 2005). In opposition, Clark (1983), Horton (1982, 2000) and Benson and Redpath (1997) argued that Aboriginal use of fire had only a minor role in shaping Australia's ecosystems.

In Australia prehistoric fire regimes are typically and uncritically related to human activity. It has thus been suggested that Aboriginal fire regimes could be used for the contemporary management of various Australian ecosystems (eg, Rolls, 1981; Flannery, 1994; Ryan *et al.*, 1995). Gill (1977) argued that frequent low-intensity fires were applied by Aboriginal people in some Australian ecosystems but that this was not applicable across the entire continent. Clark and McLoughlin (1986) and Baker (1997) suggested that Aboriginal people variously used fire in different vegetation types depending on what resources they were extracting. Head (1989) also noted that there is a common assumption that Aboriginal people had a single ongoing impact, thereby potentially ignoring climatic, demographic and cultural changes. This followed Mulvaney's (1971: 378) challenge to the fallacy of an 'unchanging land and people' and those who viewed Aboriginal socio-economic and demographic changes as seemingly insignificant (eg, Birdsell, 1953).

Climate change since the last glacial maximum

The last glacial maximum (LGM) in Australasia is generally dated between about 17 000 and 24 000 cal. BP (Kershaw *et al.*, 1991; DeDeckker, 2001; Barrows *et al.*, 2002). Sea levels during the LGM were lower by ~135 m (Chappell and Shackleton, 1986; Yokoyama *et al.*, 2001) resulting in Australia being about one-third larger than it is today (Markgraf *et al.*, 1992). There is substantial evidence of dry or shallow lakes (Bowler, 1981; Nanson *et al.*, 1992; Harrison and Dodson, 1993), expanded dunefields (Wasson *et al.*, 1988), an increased flux of dust into the Tasman (Hesse, 1994) and marked changes in pollen records (eg, Colhoun *et al.*, 1982; Singh and Geissler, 1985; Kershaw, 1986; Hope, 1994; McKenzie and Kershaw, 2000; Moss and Kershaw, 2000; Hopf *et al.*, 2000; Sweller and Martin, 2001) during the LGM in southeastern Australia.

The transition from the lateglacial Pleistocene to the Holocene included a number of climatic oscillations that have been recorded in various palaeoenvironmental archives from both the Northern and Southern Hemispheres. This has included, most famously in the Northern Hemisphere, the Bölling/Alleröd interstadial (~14 700–12 900 cal. BP); the Younger Dryas (YD) stadial (~12 900–11 600 cal. BP); and the warm preboreal after ~11 600 cal. BP (chronology based on the Greenland ice core GISP2). Research from the Southern Hemisphere has identified two overlapping cooling events: the Antarctic Cold Reversal (ACR) from ~14 000 to 12 500 cal. BP (Jouzel *et al.*, 2001) and the Oceanic Cold Reversal (OCR) from ~13 200 to 12 500 cal. BP (Stenni *et al.*, 2001). Based on palynological and geomorphological evidence from a number of sites throughout New Zealand, Turney *et al.* (2003: 223) described an initial cooling period during the first half of the period 14 000–11 500 cal. BP followed by a sustained warming, with the latter event closely corresponding with the Northern Hemisphere YD event.

The early Holocene appears to be a period of climatic stability in southeastern Australia, perhaps related to reduced seasonality. The early to mid Holocene includes a period of maximum effective precipitation, and perhaps increased warmth (McGlone *et al.*, 1996) between about 7000 and 5000 cal. BP (Bowler *et al.*, 1976; Shulmeister, 1999; Kershaw *et al.*, 2002). This Holocene Climatic Optimum saw the expansion of wet sclerophyll and rainforest taxa in southeastern Australia (eg, Macphail and Hope, 1985; Dodson *et al.*, 1986).

The mid Holocene has been identified as a notable period for climate change both in Australasia (Shulmeister, 1999) and elsewhere (Bond and Lotti, 1995; Steig, 1999; Rodbell *et al.*, 1999; Sandweiss *et al.*, 1999; deMenocal *et al.*, 2000). Hodell *et al.* (2001) noted an abrupt cooling of sea surface temperatures, expansion of sea ice and increased ice-rafted detritus accumulation in the Southern Ocean, between 5500 and 5000 cal. BP. In southeastern Australia 4000–2000 cal. BP was drier and perhaps cooler, and the late Holocene has seen a return to wetter conditions (Kershaw *et al.*, 2002).

Postglacial changes in Australian Aboriginal technologies

Lourandos (1980, 1983) introduced the theory of 'intensification' to Australia and suggested that the mid to late Holocene (from ~5 cal. ka) was a period of continent-wide changes in terms of technology, socio-demographics, settlement patterns, social structures and population densities. Lourandos (1983: 92) described Aboriginal occupation as less intensive and more nomadic during the late Pleistocene/early Holocene and sedentary and intensive after the mid Holocene. During the late Holocene, he argued that 'environmental manipulation strategies', particularly large-scale drainage systems, the use of fire, and harvesting and processing of food plants, were associated with increasing social complexity (Lourandos, 1983).

The theory of 'intensification' is controversial within Australian archaeology. Some are especially critical about the forms of evidence and sources used to justify the theory (Rowland, 1999; Attenbrow, 2004, but see also Bowdler, 1977; Jones, 1977; Hiscock 1994). For example, Bird and Frankel (1991: 10) described the 'cumulative directional change' in archaeological sequences used by Lourandos (1980, 1983) as a series of short-term adjustments to local conditions rather than intensification. Lourandos' 'continent-wide' intensification model implies continuous unidirectional changes but archaeological sequences do not necessarily show such trajectories (Attenbrow, 2004).

Changes in Australian Aboriginal technologies during the Holocene included variations to tool assemblages and the way stone was worked to produce tools. Lourandos (1983) associated the beginning of the 'intensification' process with the introduction of new tool forms in the late Holocene, often referred to as the 'Australian Small Tool Tradition'. Recent research has established that backed artefacts (one of the new tool forms) were produced, albeit at low rates and as yet identified in only a small number of sites, in early-Holocene contexts in the Sydney Basin (Hiscock and Attenbrow, 1998, 2004). While this indicates that these new forms did not appear suddenly, archaeological data show that they proliferated relatively quickly from 3500 BP and declined significantly in number after 1600 BP.

Site description

Goochs Swamp (33°27'116"S, 150°16'020"E, ~960 m a.s.l.) is located on the Newnes Plateau in the Blue Mountains, on the western edge of the Sydney Basin (Figure 1). The site is ~150 km west of Sydney and located within the Blue Mountains National Park, which is incorporated into the Greater Blue Mountains World Heritage Area.

Goochs Swamp is a narrow, elongate topographic feature in a low sloping headwater valley (Figure 1). It is surrounded by sandstone cliffs and steep slopes, vegetated with eucalypt woodland and open heath (Benson and Keith, 1990). The swamp is accumulating sandy organic sediments and is currently vegetated with a closed wet heath (dominated by *Baeckea*, *Epacris*, *Gleichenia*, *Grevillea*, *Gymnoschoenus*, *Leptospermum*). The timing of fieldwork (2002) and subsequent visits coincided with an extreme

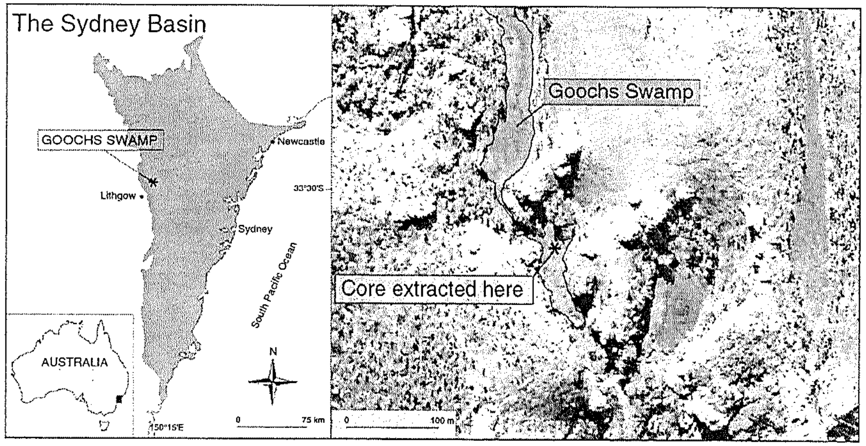


Figure 1 The location of Goochs Swamp

drought, and the water-table was at or just below ground level. Thus, while it is probable that standing vegetation may burn during a fire event, it seems less likely that any of the sediment is lost.

The climate of the Newnes Plateau is temperate with an average minimum of −1°C in July and an average maximum of 23.5°C in the hottest month, January (Commonwealth Bureau of Meteorology (BoM), 2005). The site receives an average annual rainfall of 1047 mm, which is influenced by a mild orographic effect. In the recent historical period the Blue Mountains have been notoriously fire prone with a fire season occurring from October to February (Cunningham, 1984). The Blue Mountains are also subject to ENSO-related drought, which can be associated with 'high intensity wildfires during severe fire weather' (Blue Mountains Bushfire Management Committee (BMBMC), 2000: 11). Cunningham (1984) observed that conflagration fires in the Blue Mountains during the recent historical period have been most commonly associated with El Niño-related droughts in the year following above-average rainfall (and hence fuel loads) linked to La Nina events.

The Dharug (or Daruk, Darug) and Gundungurra were the principal Aboriginal language groups occupying the Blue Mountains region at the time of British colonization, with the Wiradjuri to their west (Gollan, 1987; Kohen, 1993; Horton, 1994). There are only very limited historical descriptions of Aboriginal life and culture in the Blue Mountains, particularly the northern Blue Mountains, but it has been suggested that the Newnes Plateau was a place of interaction or a transport corridor for various Aboriginal groups (Gollan, 1987).

Ethno-historical data examined by Flood (1980) indicated a negative correlation between population size and altitude, which suggests there were relatively low population densities in the upper Blue Mountains compared with the coast and coastal plain. This is a common theme in archaeological research in the upper Blue Mountains and it is often implied that the altitude, rugged topography and limited resources meant that humans would be sensitive to climatic variations (eg, Stockton and Holland, 1974). Stockton (1970) described human occupation in the upper Blue Mountains as 'spasmodic' with only seasonal hunting trips during the milder periods of the Holocene. However, the increasing number of sites being recorded during recent fieldwork in the Blue Mountains (Stockton, 1993; Taçon *et al.*, 2006) may well change these earlier views.

The archaeological record of the Blue Mountains extends back 22 000 years (Stockton and Holland, 1974), though the evidence comes from only a few excavated sites. Of the more than 27 excavated sites, only seven provide information on artefact accumulation rates or densities from which dates and levels of occupation can be inferred (Stockton and Holland, 1974; Johnson, 1979; Attenbrow, 2004: appendix 4) (Table 1). Several sites have either a hiatus in occupation (sterile layers) or a period with low artefact accumulation rates during the late Pleistocene–early Holocene and between ~6000 and 3360 BP.

When Europeans began exploring the Blue Mountains in the early nineteenth century they reported a largely unoccupied landscape. It is uncertain if these observations are correct or if the low population resulted from earlier smallpox epidemics and other diseases (Breckell, 1993; Turbet, 2001). A road across the mountains was completed in 1815 and similarly a railway completed in 1867; this access resulted in considerable development by the late nineteenth century, however this was and is still largely confined to the ridge tops. On the Newnes Plateau, there are currently national parks, state forests and sand mines.

Methods

A Russian D-section corer (Jowsey, 1966) was used to extract a 3.55 m deep sediment core from Goochs Swamp. Core stratigraphy was quantified using a modified version of the Troels-Smith method (Kershaw, 1997) and the core was photographed. Four radiocarbon dates for bulk peat samples were obtained for the following sections of the core: 48–53, 80–90, 150–156 and 295–307 cm, and these were calibrated with CALIB v5 (Stuiver *et al.*, 2005). Macroscopic charcoal, which is thought to represent local fire events (Whitlock and Millspaugh, 1996; Long *et al.*, 1998), was analysed using image analysis (Mooney and Black, 2003). Subsamples of a known volume were taken at every 1 cm along the core and were placed in 8% sodium hypochlorite for 24 h to

Table 1 Basal dates and artefact accumulation through time for published archaeological sites located in the Blue Mountains

Site	Initial habitation	Artefact accumulation/densities	Author
Kings Tableland	22 400 ± 1000 BP	Highest at 1100 BP with a decrease from 1000 BP	Stockton and Holland (1974); Attenbrow (2004)
Springwood Creek	8563 ± 430 BP	Highest at 100–600 BP	Stockton and Holland (1974); Attenbrow (2004)
Walls Cave	12 000 ± 350 BP	Steady rate over the past 4000 BP	Stockton and Holland (1974) Attenbrow (2004)
Capertee 1 Capertee 3	7360 ± 125 BP (Capertee 3)	Decrease from 1000 BP	McCarthy (1964); Johnson (1979)
Shaws Creek K1	No radiocarbon dates	Decrease in uppermost levels	Stockton (1973)
Shaws Creek K2	14 700 ± 250 BP	Decrease in uppermost levels	Kohen *et al.* (1981, 1984)

Table 2 Radiocarbon dates and calibration for Goochs Swamp sediments

Sample depth (cm)	^{14}C date BP with 1σ error	Cal. yrs BP* (2 σ error)	Lab code
48–53	1760 ± 60	1419–1466 (4.3%) 1491–1497 (0.4%) 1509–1742 (91.4%) 1753–1785 (2.4%) 1790–1811 (1.4%)	β-169992
80–90	2450 ± 60	2333–2619 (82.2%) 2632–2708 (17.8%)	β-192605
150–156	4950 ± 130	5322–5418 (8.9%) 5440–5912 (91.1%)	β-169993
295–307	10 360 ± 140	11 646–11 667 (0.5%) 11 703–12 737 (99.5%)	β-169994

All dates were standard ^{14}C dates performed on bulk sediment samples and calibration used CALIB v5 (Stuiver *et al.*, 2005). The mid-point of the entire calibrated year range was used in age–depth model.

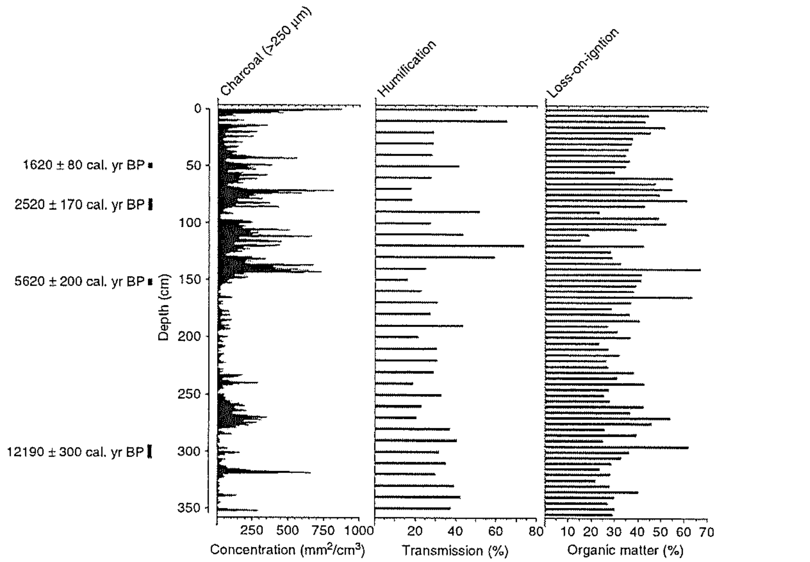


Figure 2 The results of the charcoal analyses, humification and loss-on-ignition at Goochs Swamp. Higher transmission represents lower humification

remove the pigment from organic matter and, hence, help in charcoal identification. These samples were then washed through a 250 μm sieve and the collected materials were photographed in petri dishes using a Nikon Coolpix 4500 digital camera. Charcoal concentrations (mm^2/cm^3) were calculated using image analysis software (Scion Image Beta 4.02 for Windows).

Loss-on-ignition (LOI) analysis, which is commonly used to calculate the relative proportion of organic material contained in sediments, was determined using sediment samples of a known volume and mass taken at 5 cm intervals through the sequence. The samples were oven-dried at 105°C for 24 h and combusted at 550°C for 4 h (based on Bengtsson and Enell, 1986). LOI was expressed as a percentage of combustible against the oven-dry mass of the sediment.

The humification of peat is used as an indication of the rate of accumulation over time with low values suggesting the rapid accumulation of organic material (Aaby and Tauber, 1975). Goochs Swamp sediment was analysed at every 10 cm following a modified version of Aaby (1986). Gravimetric oven-dried subsamples were placed in a 0.5% NaOH solution, boiled for an hour, diluted

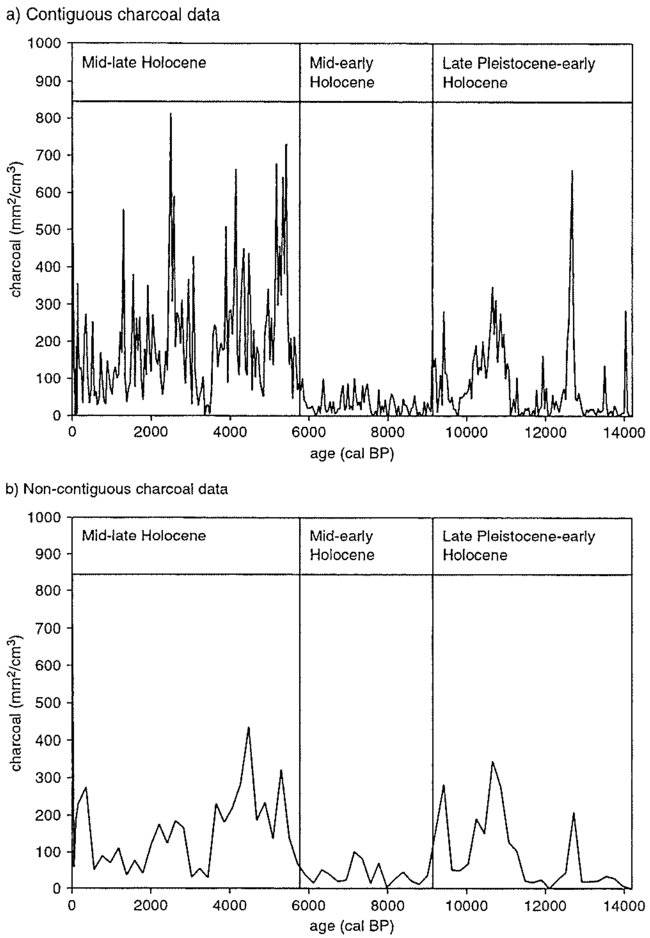


Figure 3 The non-contiguous macroscopic charcoal record from Goochs Swamp, with analyses completed every 5 cm, and the new contiguous record. Charcoal concentration (mm^2/cm^3) is expressed against time, highlighting the difference between the late Pleistocene, early to mid Holocene and the mid Holocene to the present

with water and then filtered. The degree of humification was quantified as percentage transmission in this supernatant using an EEI Colorimeter (using a 540 nm filter). Low values of transmission indicate well humified peat, which is normally interpreted as indicative of relatively dry surface conditions.

To test the hypothesis that past fire activity in the vicinity of Goochs Swamp was anthropogenic, the charcoal record was compared with the archaeological record of Capertee 3, which is the closest (~35 km away), well-described archaeological site. Discard rates of backed and non-backed artefacts at Capertee 3 (Hiscock and Attenbrow, 2004) were used for this comparison.

Results

Core stratigraphy and chronology

The Goochs Swamp sediment core was composed of humified peat with some sections of slightly higher sand or clay content. The four radiocarbon dates for Goochs Swamp (Table 2) and the first appearance of the pollen of the exotic taxon *Pinus* at 15 cm (~1870) were used to formulate an age–depth model, which was well described ($R^2 = 0.9936$) by the linear relationship:

$$y = 41.224x - 471.74$$

where x is depth in cm, y is age in cal. BP. This relationship is used for all age calculations. At this resolution of dating, it appears that the rate of sedimentation in Goochs Swamp is relatively constant (~0.025 cm/yr) and none of the analyses of the sediment sequence suggests discontinuities, indicated, for example, by abrupt or unconformable changes. Based on this age–depth relationship the analysed core (355 cm) represents ~14 200 cal. BP.

Macroscopic charcoal

The concentration of macroscopic charcoal (Figure 2) is relatively high in several sections of the core: between 0–6 cm (the late European period), 67–87 cm (~2300–3100 cal. BP), 97–150 cm (~3500–5700 cal. BP), 232–244 cm (~9100–9600 cal. BP) and 250–281 cm (~9800–11 100 cal. BP). There are low levels of charcoal between 6–13 cm (early European period), 25–40 cm (~1100–500 cal. BP), 87–97 cm (~3100–3500 cal. BP), 150–232 cm (~5700–9000 cal. BP), 287–315 cm (~11 300–12 500 cal. BP), and 325–353 cm (~12 900–14 000 cal. BP). Given the near linear rate of sedimentation in the analysed core, the concentration of charcoal is a good reflection of charcoal accumulation.

The contiguous and the previous non-contiguous charcoal records from Goochs Swamp, analysed at 5 cm increments (Black and Mooney, 2006) are presented against time in Figure 3. The timing of the changes in the contiguous charcoal records are mostly coeval with the non-contiguous record, however there are some notable differences. Between 14 200 and 9100 cal. BP there are several major peaks in the new charcoal record that are not seen in the non-contiguous record. From 9100 to 5700 cal. BP the new contiguous record shows more variability than the previous analysis and the charcoal values are much higher between 3000 and 1000 cal. BP from the contiguous record when compared with the non-contiguous record. In the non-contiguous record the highest peaks were between 5000 and 4000 cal. BP whereas the new charcoal data show the highest peaks between 5700 and 5000 cal. BP, 3000 and 2000 cal. BP, and 13 000 and 12 000 cal. BP.

The charcoal concentration/accumulation at Goochs Swamp reveals three distinctly different periods: 232–355 cm (9100–14 200, coinciding with the late Pleistocene–Holocene transition); 150–232 cm (5700–9100, reflecting the early to the mid Holocene); and 0–150 cm (from 5700 cal. BP to the present).

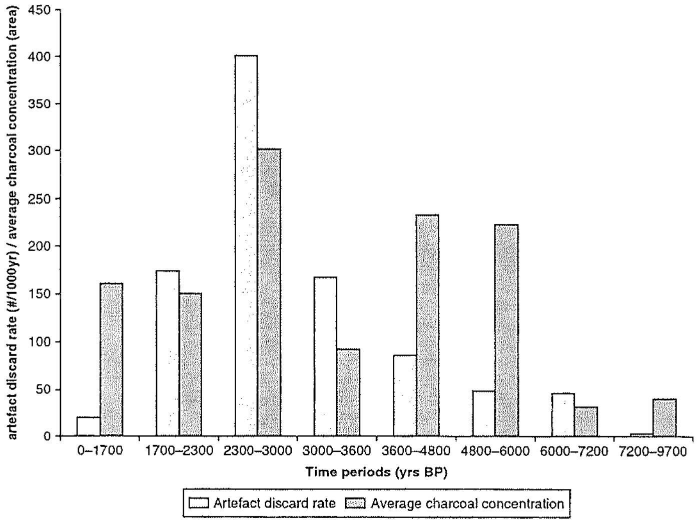


Figure 4 Artefact discard rates (Capertee 3 site) versus average charcoal concentration (Goochs Swamp) throughout the Holocene (source: archaeological data adapted from table 94 in Hiscock and Attenbrow, 2004)

The most obvious change in charcoal occurs at 150 cm (~5700 cal. BP).

Humification and loss-on-ignition

Throughout the Goochs Swamp sequence transmission levels averaged ~34% (Figure 2). There were higher transmission levels (ie, representing reduced humification) between 280 and 350 cm (~11 000 and 14 200 cal. BP) and more obviously reduced humification between 80 and 140 cm (~2800 and 5300 cal. BP) (with the exception of a drop at 100 cm), and at 0 to 10 cm (European period).

Loss-on-ignition averaged 37% throughout the sequence with a maximum value of 73% at the surface and minimum of 14% at 115 cm (~4300 cal. BP) associated with a higher sand content (Figure 2). Between 355 (~14 200 cal. BP) and 140 cm (~5300 cal. BP) LOI values remain relatively constant with the exception of peaks at 140 (~5300 cal. BP), 165 (~6300 cal. BP), 270 (~10 600 cal. BP) and 295 cm (~11 700 cal. BP) associated with woody detritus. From 140 cm (~5300 cal. BP) LOI values become more variable with troughs at 100–140 cm (~3600–5300 cal. BP) and 80–100 cm (~2800–3600 cal. BP). There are steadily increasing values from 55 cm to the surface (~1800 cal. BP to the present).

Charcoal versus archaeological indices

The average charcoal concentration at Goochs Swamp was compared with the discard rates of backed and non-backed artefacts at Capertee 3 for each corresponding time period in Figure 4. Artefact discard rates and charcoal were both relatively low in the early to mid Holocene, however the marked increase in charcoal at Goochs Swamp at ~6000 cal. BP is not matched with an increase in discard rates. Artefact numbers were high between 3600 and 1700 BP and peaked between 3000 and 2300 BP when average charcoal concentration was also at a maximum. The period ~1700 cal. BP to present has very low artefact discard rates, corresponding with relatively high levels of charcoal accumulation.

Discussion

Macroscopic charcoal persisted throughout the analysed Goochs Swamp sequence, although abundance fluctuated greatly (Figure 2). The differences between the contiguous and non-contiguous charcoal records highlight the importance of using high resolution, continuous records (Figure 3). Goochs Swamp is the second longest contiguously analysed charcoal record in Australia (Haberle's (2005) Lake Euramoo record spans 22 000 yr BP) and together these records challenge simplistic notions of pre-European fire and indicate that fire regimes are dynamic in nature. It can be inferred that fire has persisted in the environment surrounding Goochs Swamp for the last ~14 200 cal. BP, although its intensity and frequency have varied.

In Figure 5 the contiguous Goochs Swamp charcoal record, smoothed using a 41 point running average, is compared with Haberle *et al.*'s (2001) regional cumulative charcoal curve constructed by summing the 200 yr values for each of ten sites throughout Indonesia and Papua New Guinea. Haberle *et al.* (2001) described a general synchronicity between their cumulative charcoal curve and regional climate proxies, noting that charcoal increased during times of climatic instability such as during the glacial transition (~17 000–9000 cal. BP) and after the mid Holocene when ENSO events became stronger (~5000 cal. BP to present).

Haberle and Ledru (2001) found a degree of consistency in comparing charcoal records from Indonesia and Papua New Guinea with Central and South America. Haberle and Ledru (2001: 97) suggested that this broad correlation 'demonstrates that fire is promoted during periods of rapid climate change and high climate variability, regardless of the presence or absence of people'. They also noted that the strongest correlation between these charcoal records postdates 5000 yr BP, suggesting that intensification of El Niño-related variability was responsible for this synchronization, a theme expanded upon by Donders *et al.*

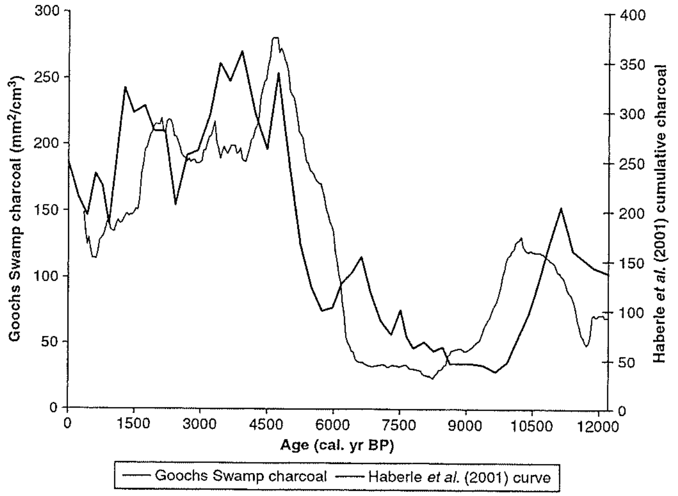


Figure 5 A comparison of the composite charcoal results from several sites in Indonesia and Papua New Guinea, from Haberle *et al.* (2001), and the results from Goochs Swamp

(2007). The strong association between the trends in these composite tropical records (Haberle and Ledru, 2001; Haberle *et al.*, 2001) and at Goochs Swamp strongly supports the hypothesis that climate had a profound influence on fire at this site.

Charcoal accumulation at Goochs Swamp suggests fire activity can be characterized in three time intervals: the late Pleistocene–early Holocene period from 14 200 to 9100 cal. BP, the early to mid Holocene (9100 to 5700 cal. BP) and the mid Holocene to the present (from 5700 cal. BP).

The late Pleistocene–early Holocene (~14 200 to 9100 cal. BP)

At Goochs Swamp the charcoal record during the late Pleistocene–early Holocene is highly variable (Figure 3). This variability includes four major peaks centred on ~14 000, ~12 660, 10 640 and ~9400 cal. BP and periods of low charcoal accumulation ~14 000–12 800, ~12 500–11 300 and ~10 100 to 9600 cal. BP. This trend is reminiscent of palaeoclimatic records of the Lateglacial–Holocene transition. However, caution is warranted given that calibration of radiocarbon dates during this period results in relatively large ranges (of ~1200 years) and that there is contradictory evidence of a 'southern' YD event (eg, Andres *et al.*, 2003; Turney *et al.*, 2003).

At Goochs Swamp it appears that the fire activity during the late Pleistocene–early Holocene was variable, but whether this was related to climatic instability is yet to be demonstrated. The pollen record from Goochs Swamp registered no significant vegetation changes during the Lateglacial–Holocene transition, though the substitution of species within genera may make any subtle vegetation change invisible in the pollen record (Black and Mooney, 2006). Clark (1983) has previously described an inability of palynology to detect subtle changes in fire-adapted Australian vegetation. In Indonesia and Papua New Guinea, Haberle *et al.* (2001) found a reversal of high charcoal values coeval with the YD and suggested that a relatively cool phase may have altered soil moisture and the vulnerability of the vegetation to fire. The degree of humification at Goochs Swamp was relatively low between ~14 200 and 11 100 cal. BP, which usually indicates relatively wetter conditions, supporting Haberle *et al.*'s (2001) interpretation.

Charcoal variability at Goochs Swamp between ~14 200 and 9100 cal. BP may possibly reflect the redistribution of people in the region, perhaps as climatic variability made it more or less favourable for human occupation. Some archaeological records from the Blue Mountains include periods of site abandonment during the late Pleistocene–early Holocene (Attenbrow, 2004).

The early to mid Holocene (9100 to 5700 cal. BP)

At Goochs Swamp charcoal accumulation is generally low in the early to mid Holocene (Figure 3), perhaps reflecting reduced fire activity. In Indonesia and Papua New Guinea Haberle *et al.* (2001) interpreted a similar period of low charcoal during the early Holocene to low fire activity and attributed this to climatic stability and reduced seasonality. If this is the case then seasonality must act synergistically with stability, as seasonality was lower at this latitude during the very late Pleistocene when fire activity was higher.

This period of reduced charcoal at Goochs Swamp overlaps the Holocene Climatic Optimum when wetter and perhaps warmer conditions may have made the upper Blue Mountains more favourable for human occupation. Chen (1986) suggested that a low and consistent charcoal record may indicate a regime of high frequency but low-intensity fires: a scenario that is consistent with often-presumed Aboriginal firing practices. More recently Whitlock and Larsen (2001) suggested that fire regimes characterized by frequent and efficient ground fires do not produce a large amount of charcoal. The scenario that low charcoal in the early Holocene represents an anthropogenic regime is not, however, supported by the archaeology of the Blue Mountains (Figure 4).

The mid to late Holocene (after 5700 cal. BP)

The charcoal record at Goochs Swamp from the mid Holocene to the present is highly variable and charcoal concentrations are generally much higher than for the preceding period. The abundance of charcoal increases abruptly at 5700 cal. BP and remains high until ~3500 cal. BP and is similarly high from 3100 cal. BP until 2300 cal. BP. These periods of increased charcoal are likely to reflect phases of relatively frequent, intense fires in the landscape, an interpretation based on the similarities of the accumulating charcoal (concentration and variability) during these periods and the recent historic past when large, intense fires have been a feature of the environment.

Kershaw *et al.* (2002) noted a significant increase in fire after the mid-Holocene in all Australian vegetation types, excluding wet forests, and this was maintained until ~2000 cal BP. Although Kershaw *et al.* (2002) considered the influence of people to explain this increase in fire activity they thought it was better explained by decreased precipitation and the onset of ENSO in the region. This is supported by approximately coeval increases in fire activity in New Zealand, which is similarly influenced by ENSO but was not colonized by people at that time (Kershaw *et al.*, 2002). Haberle *et al.* (2001) found an abrupt increase in fire activity in the uplands of New Guinea after ~6000 cal. BP, with a peak between 4500 and 1000 cal. BP and also attributed this to climatic variability.

Increased climatic variability in the circum-Pacific during the Holocene appears to be related to El Niño-Southern Oscillation (ENSO) phenomena. Rodbell *et al.* (1999) argued that ENSO progressively achieved modern characteristics by ~5000 cal. BP in central Ecuador, although in southern Ecuador, Moy *et al.* (2002) placed this earlier at ~7000 cal. BP. Sandweiss *et al.* (2001) described ENSO events in Peru after ~5800 cal. BP, albeit at a low frequency until about 3200 cal. BP. Riedinger *et al.* (2002) described an increase in the intensity and frequency of El Niño events after 3100 cal. BP in the Galapagos Islands and Clement *et al.* (2000) described an increase in ENSO events during the 3000–1000 cal. BP period.

As fire at Goochs Swamp appears to reflect climatic instability this study corroborates previous findings that the present-day ENSO influences became apparent after 5700 cal. BP. Another sustained increase in the charcoal record at Goochs Swamp after ~3100 cal. BP is roughly coeval with the increased ENSO signal described above. A more frequent and probably more intense fire regime after the mid Holocene makes sense in an ENSO-dominated climate, which allows the accumulation of biomass during the wetter La Niña events and the drying and subsequent burning of this biomass during El Niño events.

Another plausible scenario is that the mid-Holocene increase in charcoal at Goochs Swamp resulted from anthropogenic alterations to the fire regime. As an example, Martin (1994) found an increase in charcoal at 5500 cal. BP at a coastal site near Sydney, which he attributed to the use of fire by Aboriginal people. Black and Mooney (2007), Black *et al.* (2007) and Mooney *et al.* (2007) have advanced suggestions that the changes in fire activity in the late Holocene represent a complex relationship between climate forcing and human response. Turney and Hobbs (2006) have also suggested that the onset of modern ENSO activity from the mid Holocene had a significant influence on cultural change in Queensland.

Comparison of the average charcoal concentration at Goochs Swamp with the discard rates of backed and non-backed artefacts at Capertee 3 for each corresponding time period (Figure 4) implies that the mid-Holocene increase in fire activity was unrelated to people. Occupation of the Blue Mountains, at least as indicated by the relatively few excavated sites, includes a hiatus in the use of some sites during the period between 6000 and 3000 years ago when Goochs Swamp has a very high average charcoal concentration and Capertee 3 has low artefact discard rates (Figure 4). In the period between 3000 and 1700 cal. BP charcoal at Goochs Swamp and artefact discard rates show some degree of similarity, and hence fire activity during this time may reflect a combination of climate and land management practices by Aboriginal people. This interpretation obviously has a number of assumptions, including the (perhaps contentious) idea that low artefact discard rates at Capertee 3 indicate less Aboriginal activity in the area.

The archaeological record of Capertee 3, with its variations in artefact discard rates and stone artefact assemblages, illustrates that Aboriginal people began to increasingly adopt different tool forms and technological methods in the late Holocene. Combined with evidence from other parts of the Sydney Basin, this suggests that shifts in subsistence, resource and land-use patterns increased in frequency in the late Holocene; changes which are often lumped together as 'intensification' (*sensu lato* Lourandos, 1980, 1983). Hiscock (1994) argued that the increased use of the finely shaped implements of the Small Tool Tradition in the late Holocene was a response to increased risk resultant from higher mobility, use of new environments or environmental change.

Here we argue that the impetus for this change in culture and in the tool kit of the people of the Sydney region was environmental variability associated with ENSO. It is possible that these changes were adopted to overcome perceived new risks as the frequency of ENSO events increased, resulting in a hazardous natural fire regime and subsistence resource reliability changed. One response to this was perhaps a more strategic or systematic use of fire.

Conclusions

A climatic solution can be used to explain all periods of change in the fire history of the landscape surrounding Goochs Swamp: a variable fire regime being related to climatic variability associated with the late Pleistocene–Holocene transition; low fire activity associated with climatic stability and perhaps increased moisture availability during the early to mid Holocene; and the most significant change, after the mid Holocene (5700 cal. BP), with an abrupt increase in fire activity associated with ENSO-like climatic variability. The similarities between the charcoal accumulation from Goochs Swamp and similar records from tropical locations (Haberle and Ledru, 2001; Haberle *et al.*, 2001) also suggest that fire activity in the Blue Mountains was a response to regional or larger-scale climatic forcing. Although the dominant control on fire in this environment during the Holocene appears to be climate, fire in this landscape in the late Holocene may reflect anthropogenic activity. Even if this is the case, it is possible that this may have been a response by the humans to climate variability, further complicating any artificial dichotomy between 'anthropogenic' and 'natural' causation.

References

Aaby, B. 1986: Palaeoecological studies of mires. In Berglund, B.E., editor, *Handbook of Holocene palaeoecology and palaeohydrology*. John Wiley and Sons Ltd, 145–64.

Aaby, B. and **Tauber, H.** 1975: Rates of peat formation in relation to degree of humification and local environment, as shown by studies of a raised bog in Denmark. *Boreas* 4, 1–14.

Andres, M.S., Bernasconi, S.M., McKenzie, J.A. and **Rohl, U.** 2003: Southern Ocean deglacial record supports global Younger Dryas. *Earth and Planetary Science Letters* 216, 515–24.

Attenbrow, V. 2004: *What's changing: population size or land use patterns? The archaeology of Upper Mangrove Creek, Sydney Basin*. Pandanus Books.

Baker, M. 1997: *Fire and the pre-European cultural landscapes of the Hawkesbury-Nepean catchment*. Science and technology in the environmental management of the Hawkesbury-Nepean catchment, paper No. 14 (Geographic Society of NSW).

Barrows, T.T., Stone, J.O., Fifield, L.K. and **Cresswell, R.G.** 2002: The timing of the Last Glacial Maximum in Australia. *Quaternary Science Reviews* 21, 159–73.

Bengtsson, L. and **Enell, M.** 1986: Chemical analysis. In Berglund B.E., editor, *Handbook of Holocene palaeoecology and palaeohydrology*. John Wiley and Sons Ltd, 423–51.

Benson, D.H. and **Keith, D.A.** 1990: The natural vegetation of the Wallerawang 1:100,000 map sheet. *Cunninghamia* 2, 305–35.

Benson, J.S. and **Redpath, P.A.** 1997: The nature of pre-European native vegetation in south-eastern Australia: a critique of Ryan, D.G., Ryan, J.R. and Starr, B.J. (1995) 'The Australian landscape – observations of explorers and early settlers'. *Cunninghamia* 5, 285–328.

Bird, C.F.M. and **Frankel, D.** 1991: Chronology and explanation in western Victoria and south-east South Australia. *Archaeology in Oceania* 26, 1–16.

Birdsell, J.B. 1953: Some environmental and cultural factors influencing the structuring of Australian Aboriginal populations. *The American Naturalist* 87, 171–207.

Black, M. and **Mooney, S.D.** 2006: Holocene fire history from the Greater Blue Mountains World Heritage Area, New South Wales, Australia: the climate, humans and fire nexus. *Regional Environmental Change* 6, 41–51.

—— 2007: The response of Aboriginal burning practices to population levels and El Nino-Southern Oscillation events during the mid- to late-Holocene: a case study from the Sydney Basin using charcoal and pollen analysis. *Australian Geographer* 38, 37–52.

Black, M.P., Mooney, S.D. and **Haberle, S.G.** 2007: The fire, human and climate nexus in the Sydney Basin, eastern Australia. *The Holocene* 17, 465–78.

Blue Mountains Bushfire Management Committee 2000: *Bushfire risk management plan*. 14 December 2000, Blue Mountains Bushfire Management Committee.

Bond, G.C. and **Lotti, R.** 1995: Iceberg discharges into the North Atlantic on millenial time scales during the last glaciation. *Science* 267, 1005–10.

Bowdler, S. 1977: The coastal colonisation of Australia. In Allen, J., Golson, J. and Jones, R., editors, *Sunda and Sahul: prehistoric studies in southeast Asia, Malenesia and Australia*. Academic Press, 205–46.

Bowler, J.M. 1981: Australian Salt Lakes: a palaeohydrological approach. *Hydrobiologia* 82, 431–44.

Bowler, J.M., Hope, G.S., Jennings, J.N., Singh, G. and **Walker, D.** 1976: Late Quaternary climates of Australia and New Guinea. *Quaternary Research* 6, 359–94.

Bowman, D.M.J.S. 1998: Tansley Review No. 101: the impact of Aboriginal landscape burning on the Australian biota. *New Phytologist* 140, 385–410.

Breckell, M. 1993: Shades of grey: Aboriginal contact in the Blue Mountains. In Stockton, E., editor, *Blue Mountain dreaming: the Aboriginal heritage*. Three Sisters Production, 114–21.

Bureau of Meteorology 2005: Commonwealth Bureau of Meteorology Website (http://www.bom.gov.au). Department of Environment, Federal Government of Australia. Accessed May 2005.

Chappell, J. and **Shackleton, N.J.** 1986: Oxygen isotopes and sea level. *Nature* 324, 137–40.

Chen, Y. 1986: Early Holocene vegetation dynamics of Lake Warrine Basin northeastern Queensland, Australia. Unpublished PhD thesis, Australian National University, Canberra.

Clark, R.L. 1983: Pollen and charcoal evidence for the effects of Aboriginal burning on the vegetation of Australia. *Archaeology in Oceania* 18, 32–37.

Clark, S.S. and **McLoughlin, L.C.** 1986: Historical and biological evidence for fire regimes in the Sydney region prior to the arrival of Europeans: implications for future bushland management. *Australian Geographer* 17, 101–12.

Clement, A.C., Seager, R. and **Cane, M.A.** 2000: Suppression of El Niño during the mid-Holocene by changes in the Earth's orbit. *Paleoceanography* 15, 731–37.

Colhoun, E.A., van der Geer, G. and **Mook, W.G.** 1982: Stratigraphy, pollen analysis and palaeoclimatic interpretation of Pulbeena Swamp, northwestern Tasmania. *Quaternary Research* 18, 108–26.

Cunningham, C.J. 1984: Recurring natural fire hazards: a case study of the Blue Mountains, New South Wales, Australia. *Applied Geography* 4, 5–27.

DeDeckker, P. 2001: Late Quaternary cyclic aridity in tropical Australia. *Palaeogeography Palaeoclimatology Palaeoecology* 170, 1–9.

deMenocal, P., Ortiz, J., Guilderson, T., Adkins, J., Sarnthein, M., Baker, L. and **Yarusinsky, M.** 2000: Abrupt onset and termination of the African Humid Period: rapid climate responses to gradual insolation forcing. *Quaternary Science Reviews* 19, 347–61.

Dodson, J.R., Greenwood, P.W. and **Jones, R.L.** 1986: Holocene forest and wetland vegetation dynamics at Barrington Tops, New South Wales. *Journal of Biogeography* 13, 561–85.

Donders, T.H., Haberle, S.G., Hope, G., Wagner, F. and **Visscher, H.** 2007: Pollen evidence for the transition of the Eastern Australian climate system from the post-glacial to the present-day ENSO mode. *Quaternary Science Reviews* 26, 1621–37.

Elkin, A.P. 1954: *The Australian Aborigines: how to understand them*. Angus and Robertson.

Flannery, T. 1994: *The future eaters*. Reed Books.

Flood, J. 1980: *The moth hunters: Aboriginal prehistory of the Australian Alps*. Australian Institute of Aboriginal Studies.

Gill, A.M. 1977: Management of fire prone vegetation for plant species conservation in Australia. *Search* 8, 20–25.

Gollan, K. 1987: *Archaeological investigations on Newnes Plateau: a report to the National Parks and Wildlife Service*. New South Wales National Parks and Wildlife Service.

Gott, B. 2005: Aboriginal fire management in south-eastern Australia: aims and frequency. *Journal of Biogeography* 32, 1203–208.

Haberle, S.G. 2005: A 22ka pollen record from Lake Euramoo, Wet Tropics of NE Queensland, Australia. *Quaternary Research* 64, 343–56.

Haberle, S.G. and **Ledru, M.P.** 2001: Correlations among charcoal records of fires from the past 16,000 years in Indonesia, Papua New Guinea, and Central and South America. *Quaternary Research* 55, 97–104.

Haberle, S.G., Hope, G.S. and **van der Kaars, S.** 2001: Biomass burning in Indonesia and Papua New Guinea: natural and human induced fire events in the fossil record. *Palaeogeography, Palaeoclimatology, Palaeoecology* 171, 256–68.

Harrison, S. and **Dodson, J.** 1993: Climates of Australia and New Guinea since 18,000 yr B.P. In Wright, H.E., Jr, Kutzbach, J.E., Webb, T., III, Ruddiman, W.F., Street-Perrot, F.A. and Bartlein, P.J., editors, *Global climates since the Last Glacial Maximum*. University of Minnesota Press, 265–93.

Head, L. 1989: Prehistoric aboriginal impacts on Australian vegetation: an assessment of the evidence. *Australian Geographer* 20, 36–45.

Hesse, P.P. 1994: The record of continental dust from Australia in Tasman Sea sediments. *Quaternary Science Reviews* 13, 257–72.

Hiscock, P. 1994: Technological responses to risk in Holocene Australia. *Journal of World Prehistory* 8, 267–92.

Hiscock, P. and **Attenbrow, V.** 1998: Early Holocene backed artefacts from Australia. *Archaeology in Oceania* 33, 49–62.

—— 2004: A revised sequence of backed artefact production at Capertee 3. *Archaeology in Oceania* 39, 94–99.

Hodell, D.A., Kanfoush, S.L., Shemesh, A., Crosta, X., Charles, C. and **Guilderson, T.P.** 2001: Abrupt cooling of Antarctic surface waters and sea ice expansion in the South Atlantic sector of the Southern Ocean at 5000 cal yr B.P. *Quaternary Research* 56, 191–98.

Hope, G.S. 1994: Quaternary vegetation. In Hill, R., editor, *History of Australian vegetation. Cretaceous to recent*. Cambridge University Press, 368–89.

Hopf, F.V.L., Colhoun, E.A. and **Barton, C.E.** 2000: Late-glacial and Holocene record of vegetation and climate from Cynthia Bay, Lake St Clair, Tasmania. *Journal of Quaternary Science* 15, 725–32.

Horton, D.R. 1982: The burning question: Aborigines, fire and Australian ecosystems. *Mankind* 13, 237–51.

—— 1994: *The encyclopedia of Aboriginal Australia*. Aboriginal Studies Press.

—— 2000: *The pure state of nature*. Allen & Unwin.

Hughes, P.J. and **Sullivan, M.E.** 1981: Aboriginal burning and late Holocene geomorphic events in eastern NSW. *Search* 12, 277–78.

Johnson, I. 1979: The getting of data: a case study from the recent industries of Australia. Unpublished PhD thesis, Australian National University, Canberra.

Jones, R. 1969: Fire-stick farming. *Australian Natural History* 16, 224–28.

—— 1977: Sunda and Sahul: an introduction. In Allen, J., Golson, J. and Jones, R., editors, *Sunda and Sahul: Prehistoric studies in southeast Asia, Melanesia and Australia*. Academic Press, 1–9.

Jouzel, J., Masson, V., Cattani, O., Falourd, S., Stievenard, M., Stenni, B., Longinelli, A., Johnsen, S.J., Steffenssen, J.P., Petit, J.-R., Schwander, J., Souchez, R. and **Barkov, N.I.** 2001: A new 27 ky high resolution East Antarctic climate record. *Geophysical Research Letters* 28, 3199–202.

Jowsey, P.C. 1966: An improved peat sampler. *New Phytologist* 65, 245–48.

Kershaw, A.P. 1986: Climatic change and Aboriginal burning in north-east Australia during the last two glacial/interglacial cycles. *Nature* 322, 47–49.

—— 1997: A modification of the Troels-Smith system of sediment description and portrayal. *Quaternary Australasia* 15, 63–68.

Kershaw, A.P., D'Costa, D.M., McEwan Mason, J.R.C. and **Wagstaff B.E.** 1991: Palynological evidence for Quaternary vegetation and environments of mainland southeastern Australia. *Quaternary Science Reviews* 10, 391–404.

Kershaw, A.P., Clark, J.S. and **Gill, A.M.** 2002: A history of fire in Australia. In Bradstock, R., Williams, J. and Gill, A.M., editors, *Flammable Australia: the fire regimes and biodiversity of a continent*. Cambridge University Press, 3–25.

Kohen, J. 1993: *The Darug and their neighbours – the traditional Aboriginal owners of the Sydney region*. Darug Link and the Blacktown and District Historical Society.

Kohen, J., Stockton, E. and **Williams, M.** 1981: Where plain and plateau meet: recent excavations at Shaws Creek rock-shelter, eastern New South Wales. *Australian Archaeology* 13, 63–68.

—— 1984: Shaws Creek KII rock-shelter: a prehistoric occupation site in the Blue Mountains piedmont, eastern New South Wales. *Archaeology in Oceania* 19, 57–73.

Long, C.J., Whitlock, C., Bartlein, P.J. and **Millspaugh, S.H.** 1998: A 9000-year fire history from the Oregon Coast Range, based on a high-resolution charcoal study. *Canadian Journal of Forestry Research* 28, 774–87.

Lourandos, H. 1980: Change or stability? Hydraulics, hunter gatherers and population in temperate Australia. *World Archaeology* 11, 245–66.

—— 1983: Intensification: a late Pleistocene–Holocene archaeological sequence from southwestern Victoria. *Archaeology in Oceania* 18, 81–94.

Macphail, M.K. and **Hope, G.S.** 1985: Late Holocene mire development in montane southeastern Australia: a sensitive climatic indicator. *Search* 15, 344–49.

Markgraf, V., Dodson, J.R., Kershaw, A.P., McGlone, M.S. and **Nichols, N.** 1992: Evolution of late Pleistocene and Holocene climates in the circum-south Pacific land areas. *Climate Dynamics* 6, 193–211.

Martin, A.R.H. 1994: Kurnell Fen: an eastern Australian coastal wetland, its Holocene vegetation, relevant to sea-level change and aboriginal land use. *Review of Palaeobotany and Palynology* 80, 311–32.

McCarthy, F.D. 1964: The archaeology of the Capartee Valley, New South Wales. *Records of the Australian Museum* 26, 197–246.

McGlone, M., Hope, G., Chappell, J. and **Barrett, P.** 1996: Past climate change in Oceania and Antarctica. In Bouma, W.J., Pearman, G.I. and Manning, M.R., editors, *Greenhouse: coping with climate change*. CSIRO Publishing, 81–90.

McKenzie, G.M. and **Kershaw, A.P.** 2000: The last glacial cycle from Wyelangta, the Otway Region of Victoria, Australia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 155, 177–93.

Miller, G., Mangan, J., Pollard, D., Thompson, S., Felzer, B. and **Magee, J.** 2005: Sensitivity of the Australian Monsoon to insolation and vegetation: implications for human impact on continental moisture balance. *Geology* 33, 65–68.

Mooney, S. and **Black, M.** 2003: A simple and fast method for calculating the area of macroscopic charcoal isolated from sediments. *Quaternary Australasia* 21, 18–21.

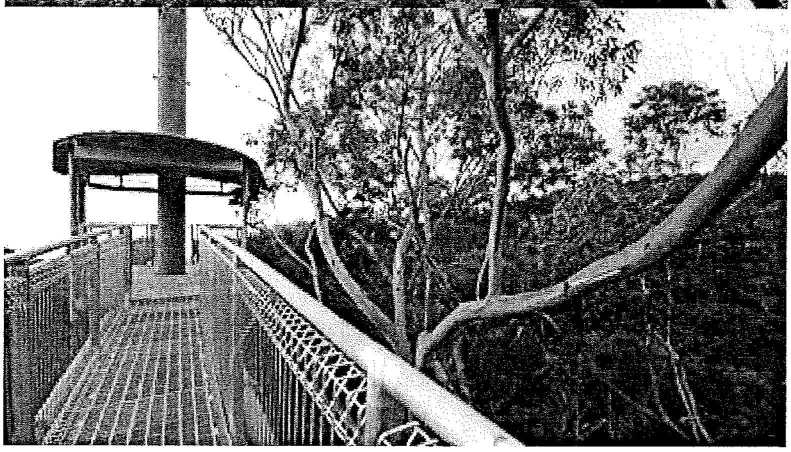
Mooney, S.D., Webb, M. and **Attenbrow, V.** 2007: A comparison of charcoal and archaeological information to address the influences on Holocene fire activity in the Sydney Basin. *Australian Geographer* 38, 177–94.
Moss, P.T. and **Kershaw, A.P.** 2000: The last glacial cycle from the humid tropics of northeastern Australia: comparison of a terrestrial and a marine record. *Palaeogeography, Palaeoclimatology, Palaeoecology* 155, 155–76.
Moy, C.M., Seltzer, G.O., Rodbell, D.T. and **Anderson, D.M.** 2002: Variability of El Niño/Southern Oscillation activity at millennial timescales during the Holocene epoch. *Nature* 420, 162–65.
Mulvaney, D.J. 1971: Aboriginal social evolution: a retrospective view. In Mulvaney, D.J. and Golson, J., editors, *Aboriginal man and environment in Australia*. Australian National University Press, 368–80.
Nanson, G.C., Price, D.M. and **Short, S.** 1992: Wetting and drying of Australia over the past 300 ka. *Geology* 20, 791–94.
Nicholson, P.H. 1981: Fire and the Australian Aborigine. In Gill, A.M., Groves, R.H. and Noble, I.R., editors, *Fire and the Australian biota*. Australian Academy of Science, 23–54.
Riedinger, M.A., Steinitz-Kannan, M., Last, W.M. and **Brenner, M.** 2002: A ~6100 ^{14}C yr record of El Niño activity from the Galapagos Islands. *Journal of Paleolimnology* 27, 1–7.
Rodbell, D.T., Seltzer, G.O., Anderson, D.M., Abbott, M.B., Enfield, D.B. and **Newman, J.H.** 1999: An ~15,000 year record of El Niño-driven alleviation in southwestern Ecuador. *Science* 283, 516–20.
Rolls, E. 1981: *A million wild acres*. Penguin Books.
Rowland, M.J. 1999: Holocene environmental variability: have its impacts been underestimated in Australian prehistory? *The Artefact* 22, 11–48.
Ryan, D.G., Ryan, J.E. and **Starr, B.J.** 1995: *The Australian landscape – observations of explorers and early settlers*. Murrumbidgee Catchment Management Committee.
Sandweiss, D.H., Maasch, K.A. and **Anderson, D.G.** 1999: Transitions in the mid-Holocene. *Science* 283, 499–500.
Sandweiss, D.H., Maasch, K.A. Burger, R.L., Richardson, J.B., III, Rollins, H.B. and **Clement, A.** 2001: Variation in Holocene El Niño frequencies: climate records and cultural consequences in ancient Peru. *Geology* 29, 603–606.
Shulmeister, J. 1999: Australasian evidence for mid-Holocene climate change implies precessional control of Walker Circulation in the Pacific. *Quaternary International* 57/58, 81–91.
Singh, G. and **Geissler, E.A.** 1985: Late Cainozoic history of vegetation, fire, lake levels and climate, at Lake George, New South Wales, Australia. *Philosophical Transactions of the Royal Society of London B* 311, 379–477.
Singh, G., Kershaw, A.P. and **Clark, R.** 1981: Quaternary vegetation and fire history in Australia. In Gill, A.M., Groves, R.H. and Noble, I.R., editors, *Fire and the Australian biota*. Australian Academy of Science, 23–76.
Steig, E.J. 1999: Paleoclimate: mid-Holocene climate change. *Science* 286, 1485–87.
Stenni, B., Masson-Delmotte, V., Johnsen, S., Jouzel, J., Longinelli, A., Monnin, E., Rothlisberger, R. and **Selmo, E.** 2001: An oceanic cold reversal during the last deglaciation. *Science* 293, 2074–77.
Stockton, E.D. 1970: An archaeological survey of the Blue Mountains. *Mankind* 7, 295–301.
—— 1993: Archaeology of the Blue Mountains. In Stockton, E., editor, *Blue Mountains dreaming*. Three Sisters Publication, 23–52.
Stockton, E.D. and **Holland, W.** 1974: Cultural sites and their environment in the Blue Mountains. *Archaeology and Physical Anthropology in Oceania* 9, 36–65.
Stuiver, M., Reimer, P.J. and **Reimer, R.W.** 2005: CALIB 5.0. Retrieved December 2005 from http://calib.qub.ac.uk/calib/
Sweller, S. and **Martin, H.A.** 2001: A 40,000 year vegetation history and climatic interpretations of Burraga Swamp, Barrington Tops, New South Wales. *Quaternary International* 83–85, 233–44.
Taçon, P.S.C., Kelleher, M., Brennan, W., Hooper, S. and **Pross, D.** 2006: Wollemi petroglyphs, N.S.W., Australia: an unusual assemblage with rare motifs. *Rock Art Research* 23, 227–38.
Turbet, P. 2001: *The Aborigines of the Sydney district before 1788*. Kangaroo Press.
Turney, C.S.M. and **Hobbs, D.** 2006: ENSO influence on Holocene Aboriginal populations in Queensland, Australia. *Journal of Archaeological Science* 33, 1744–48.
Turney, C.S.M., McGlone, M.S. and **Wilmshurst, J.M.** 2003: Asynchronous climate change between New Zealand and the North Atlantic during the last deglaciation. *Geology* 31, 223–26.
Wasson, R.J., Fitchett, K., Mackey, B. and **Hyde, R.** 1988: Large-scale patterns of dune type, spacing and orientation in the Australian continental dunefield. *Australian Geography* 19, 89–104.
Whitlock, C. and **Larsen, C.** 2001: Charcoal as a fire proxy. In Smol, J.P., Birks, H.J.J. and Last, W.M., editors, *Tracking environmental change using lake sediments*. Kluwer Academic Publishers, 75–95.
Whitlock, C. and **Millspaugh, S.H.** 1996: Testing the assumptions of fire-history studies: an examination of modern charcoal accumulation in Yellowstone National Park, USA. *The Holocene* 6, 7–15.
Yokoyama, Y., Purcell, A., Lambeck, K. and **Johnston, P.** 2001: Shoreline reconstruction around Australia during the Last Glacial maximum and Lake Glacial States. *Quaternary International* 83–85, 9–18.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

DAY 2.

An excellent site describing Wingecarribee Swamp is:
http://www.uow.edu.au/arts/sts/sbeder/wingecarribee/value/ecosystem.html

The Illawarra Fly Treetop Walk is a 500 metre long, 25 metre high elevated tree top walk along the picturesque Illawarra escarpment. It is described at:
http://www.illawarrafly.com/



Barren Grounds Nature Reserve (time permitting)
The BGNR is between Robertson and Kiama (on the Jamberoo Pass Road 16km south-east of Robertson). The Reserve is a heathland plateau and famous also for birds.

Wetlands Ecology and Management 11: 37–49, 2003.
© 2003 Kluwer Academic Publishers. Printed in the Netherlands.

Sphagnum in peatlands of Australasia: Their distribution, utilisation and management

J. Whinam[1], G.S. Hope[2], B.R. Clarkson[3], R.P. Buxton[3], P.A. Alspach[4] & P. Adam[5]
[1]*Author for correspondence: Department of Primary Industries, Water and Environment, GPO Box 44A, Hobart, Tasmania 7001, Australia;* [2]*Research School of Pacific & Asian Studies, Australian National University;* [3]*Landcare Research New Zealand Ltd;* [4]*The Horticulture and Food Research Institute of New Zealand Ltd;* [5]*School of Biological Sciences, University of New South Wales*

Received 14 March 2001; accepted in revised form 20 December 2001

Key words: Australia, moss harvesting, New Guinea, New Zealand, peat industry, peat mining, restoration, sustainability

Abstract

In comparison to the northern hemisphere, *Sphagnum* peatlands are an unusual and infrequent component of the Australasian landscape. Most peatlands in Australasia are primarily composed of either Restionaceous or Cyperaceous peats. *Sphagnum* peatlands in Australia and Papua New Guinea/Irian Jaya (now West Papua) are largely located in montane and alpine environments, but also occur down to sea level in New Zealand and as moss patches on some subantarctic islands. Fire is a major determinant of the characteristics of peatlands in Australasia. Peatland management in Australasia is hindered by the need for increased understanding of peatland processes to enable a sustainable balance of conservation of a small resource with localised utilisation. The management focus in Australasia has largely been on ensuring ecologically sustainable *Sphagnum* moss harvesting, with limited peat mining. We have found that general recovery of *Sphagnum* after moss harvesting can be enhanced by harvesting larger peatlands, and by leaving one-third of the acrotelm to regenerate. The largest upland peat swamp in mainland Australia, Wingecarribee Swamp, suffered a major collapse in 1998 following peat mining. Environmental and management consequences of this collapse have major ramifications for rehabilitation options. *Sphagnum* peatlands in Australasia are likely to be adversely affected by drainage, burning, grazing, trampling, global warming and peat mining.

Introduction

In comparison with peatlands in the northern hemisphere, Australasian peatlands dominated by *Sphagnum* are generally small in area, restricted in distribution, and have relatively few species. Most Australasian peatlands are instead dominated by Restionaceae, Cyperaceae, and Epacridaceae species, but *Sphagnum* is frequently an important component. There has been no comprehensive assessment of peatlands in Australia or New Zealand, but a general description of Australasian mires is provided in Campbell (1983). *Sphagnum* moss can also occur as a small but distinct component of other plant communities, such as in tropical mountains of New Guinea. *S. cristatum* is the most common species in both Australia and New Zealand, and is the main species harvested.

The most common resource from Australasian *Sphagnum* peatlands is *Sphagnum* moss harvested for the horticulture industry. At present all commercial *Sphagnum* moss harvesting is restricted to Australia and New Zealand and is from wild populations in natural peatlands. Small experimental trials of growing *S. cristatum* in tunnelhouse environments were initiated in New Zealand (Smale et al., 1995), but cancelled due to withdrawal of research funding.

Historically, many areas of *Sphagnum* peatland have been drained and fertilised for farmland or destroyed by peat mining, particularly in New Zealand,

although a few extensive deposits up to several thousands of hectares still remain (Davoren, 1978). Current threats to the long-term survival of *Sphagnum* peatlands include draining for agriculture, frequent burning, peat mining and *Sphagnum* moss harvesting. A major threat to peatlands in Western Australia is groundwater abstraction (P. Horwitz, personal communication). In general, *Sphagnum* peatlands in Australasia have not been subjected to the same extent of broadscale mining operations reported in the northern hemisphere (e.g. Lappalainen, 1996; Rochefort, 2001).

Peatland management in Australasia is not unified but is mainly driven by the need to protect/reserve representative examples of the full range of natural biodiversity. For example, less than 10% of the original area of wetlands now remains throughout New Zealand (Newsome, 1987), making conservation of all remaining wetlands significant. In New Zealand, peatlands have an additional conservation value in that they have revealed, and still contain, many significant cultural artefacts from early Maori settlement. In both Australia and New Zealand, peatlands in lowland areas are particularly threatened, with most having been drained for farmland or subjected to frequent burning. These lowland peatlands are targeted for protection and restoration in New Zealand.

The aim of this paper is to present a brief overview of the currently known Australasian peatlands containing *Sphagnum*, specifically Australia, New Zealand, New Guinea, and some subantarctic islands. Descriptions of the current *Sphagnum* moss harvesting and peat mining industries are presented. Methods to manage harvesting impacts and issues encountered in peatland restoration are outlined. The major environmental problems and management issues that can be encountered as a result of peat collapse following mining are given in a case study of Wingecarribee swamp.

Sphagnum species distribution

In Tasmania 10 species of *Sphagnum* have been recorded in the literature (Dalton et al., 1991) but in a taxonomic revision (Seppelt, 2000) only 6 taxa (including one new species; Seppelt and Crum, 1999) are recognised (Table 1). Another species, formerly known as *Sphagnum leucobryoides*, has been transferred to a new monotypic Order, Family and Genus as *Ambuchanania* (Crum and Seppelt, 1999). Away from the eastern states on mainland Australia, only *Sphagnum novo-zelandicum* is represented in South Australia (Crocker and Eardly, 1939) and in a few localities in southwestern Western Australia (Smith, 1969; Figure 1). Under the provisions of the New South Wales Threatened Species Conservation Act one particular *Sphagnum* community (Ben Halls Gap National Park *Sphagnum* Moss Cool Temperate Rainforest) has been designated an Endangered Ecological Community. There are two communities with *Sphagnum* listed in Victoria under the Victorian Flora and Fauna Guarantee Act – Alpine Bog and Montane Swamp Complex.

Nine species of *Sphagnum* are recognised from New Zealand (Fife, 1996), five of which are common to Australia (Table 1). The diversity of *Sphagnum* species in the Chatham Islands and the Australasian subantarctic Islands (Auckland Islands, Campbell Island, Macquarie Island) is low. Only *S. falcatulum* is known from Macquarie Island, *S. australe* and *S. novo-zelandicum* from Campbell Island, *S. australe* and *S. falcatulum* from the Auckland Islands (Vitt, 1979), and *S. australe*, *S. cristatum* and *S. falcatulum* from the Chatham Islands (Table 1). In Australasia, only *S. falcatulum* and *S. fuscovinosum* appear to be specifically aquatic. There is less evidence of extensive patterned mires (Campbell, 1983; Kirkpatrick and Gibson, 1984; Whinam and Kirkpatrick, 1994; Mark et al., 1995) and of the hummock/hollow partitioning of *Sphagnum* species in Australasia (Millington, 1954; Ashton and Hargreaves, 1983) than reported in the northern hemisphere.

In the Malesian tropics approximately thirteen species have been described (Eddy, 1977, 1988; Table 1), and most are probably more widely distributed than currently documented as very few ecological surveys have been made. New Guinea is a tropical centre of diversity for *Sphagnum*, having twelve of these species, with only *S. luzonense* not occurring there. Endemic or near endemic species recorded from New Guinea include *S. antarense*, found at 2200 m in the Star Mountains and on mountains in Sulawesi, *S. efibrillosum*, from the Mt Albert Edward summit plateau at 3650 m and *S. novo-guineense* which occurs in central New Guinea and on adjacent islands. *S. sericeum* and *S. junghuhnianum* var *semiporosum* are known from stream edges and waterfall spray zones in grassland and montane forest near Lake Habbema in the Snow Mountains as well as Mt Dayman and Goodenough Island in eastern Papua. They occur in open mist forests at mid-altitudes along seepages

Figure 1. *Sphagnum* occurence and *Sphagnum*-dominated communities in Australasia. Chatham Island is enlarged as an inset.

(Bartram, 1942, 1957). Other Malesian or southern species in New Guinea are *S. perichaetiale* and *S. cuspidatum*, both occuring in the montane and subalpine zones above 2000 m, as well as the curious lax *S. cuspidatum* ssp. *subrecurvum*, which is found at low altitudes in Borneo, Malaya and Sumatra as well as New Guinea. *Sphagnum* species of mostly boreal distribution occur in the mountains of New Guinea – *S. subsecundum*, *S. cuspidatulum* and *S. compactum*. *S. compactum* is related to a species with an African – Malesian distribution, *S. strictum* ssp. *pappeanum* (Eddy, 1988).

In the Pacific, six *Sphagnum* species are restricted to the higher mountains (above 500 m). On New Caledonia *S. cristatum* also occurs in the austral temperate region and *S. cuspidatum* is also found in the Malesian tropics and boreal regions. *S. novo-caledoniae* is endemic to the high rainfall ultramafic area. Three endemic species occur further east; *S. palustre* on Viti Levu (Fiji) and Oahu (Hawaii), *S. seemannii* on Tavieuni (Fiji) and Samoa and *S. reichardtii* on Viti Levu.

Table 1. Distribution of *Sphagnum* species in Australasia. Australia (Aus, Mainland Australia; Tas, Tasmania), New Zealand (NZ, New Zealand; Chat, the Chatham Islands), Subantarctic Pacific islands (AI, Auckland; An, Antipodes; C, Campbell; M, Macquarie), Pacific (NG, New Guinea; VFJ, Viti Levu, Fiji; TaFJ, Tavieuni, Fiji; NCal, New Caledonia; HAW, Hawaii; Sam, Samoa), and Malesia (Sul, Sulawesi, Indonesia; BM, Borneo, Malaya; M, Malesia; WM, Western Malesia). Based on Streimann and Curnow (1989), Fife (1996), Seppelt (2000) and A. Touw (unpublished data).

Species	Australia	New Zealand	Subantarctic islands	Pacific	Malesia (other than New Guinea)
S. australe	Aus, Tas	NZ, Chat	AI, An, C		
S. antarense				NG	Sul
S. compactum		NZ		NG	M
S. cristatum	Aus, Tas	NZ, Chat		NCal	
S. cuspidatulum				NG	M
S. cuspidatum				NG, NCal	M
S. cuspidatum ssp. *subrecurvum*				NG.	BM
S. efibrillosum				NG	
S. falcatulum	Aus, Tas	NZ, Chat	AI, An, M		
S. fuscovinosum	Tas				
S. junghuhnianum var *semiporosum*				NG	
S. luzonense					WM
S. novo-caledoniae				NCal	
S. novo-guineense				NG	
S. novo-zelandicum	Aus, Tas	NZ	C		
S. palustre				VFJ, HAW	
S. perichaetiale (incl. *S. beccarii*)	Aus	NZ		NG	M
S. reichardtii				VFJ	
S. seemannii				TFJ, Sam	
S. sericeum				NG	M
S. simplex		NZ			
S. strictum ssp. *pappeanum*				NG	M
S. squarrosum		NZ			
S. subnitens		NZ			
S. subsecundum				NG	M

Distribution of *Sphagnum* peatlands

Australasia – generalities

Sphagnum peatlands, for the purposes of this paper, are defined as having *Sphagnum* species as the dominant peat forming vegetation and where the peatland area is greater than 1000 m^2 to form a distinct ecosystem. They occur in Australia most frequently between 600 to 1000 m altitude. In New Zealand they mostly occur from 1500 m down to sea level, with the proportion of *Sphagnum* in the vegetation generally increasing from north to south and with increasing altitude. They tend to be mostly minerotrophic in Australia and ombrotrophic in New Zealand. In New Zealand, *S. australe* commonly forms small bogs and moss beds under beech (*Nothofagus menziesii* and *N. solandri* var *cliffortioides*) forest canopies, yielding dominance to *S. cristatum* as light levels increase. *S. cristatum* covers extensive areas in wet heath and bog communities and may be regionally important as in eastern Fiordland (Burrows and Dobson, 1972; Mark et al., 1979) and south Westland (Dickinson and Mark, 1994). In New Guinea, *Sphagnum* occurs in wet hollows in montane forest, and along stream banks and lake edges above 3000 m, in minerotrophic and some ombrotrophic situations. Although a common element, *Sphagnum* is rarely dominant anywhere in Malesia, New Guinea or the Pacific (Hope, 1980).

The major geomorphic types of *Sphagnum* peatlands in Australasia include: kettle holes and moraine-dammed valleys of the depositional zone; glaciofluvial outwash or colluvial valley fill deposits; riparian or lacustrine environments; horizontally-bedded sandstone shelves; karst sinkholes (Whinam and Buxton, 1997).

The major floristic types include: snowpatch, subalpine coniferous; sedgelands; shrublands (including New Zealand pakihi wet heath; Mew, 1983); rainforest; grassy tussock and aquatic. Descriptions of *Sphagnum* communities in New Zealand are included in Wardle (1991) and for Tasmania in Whinam et al. (1989, 2001). On mainland Australia *Sphagnum* is most common as a component of shrub bogs dominated by epacrids and restionaceous species (Costin, 1954; Millington, 1954; Ashton and Hargreaves, 1983; Hope and Southern, 1983; Kershaw et al., 1997; Clarke and Martin, 1999). It occurs mainly on humic peats and deep accumulations of *Sphagnum* peat are unknown, suggesting that it is always a subsidiary taxon in Holocene mire communities.

Australia

Australia is predominantly arid or semiarid. Most of the continent is of low relief. Although there are very extensive wetlands in inland Australia, these are intermittent and the prolonged dry periods are not conducive to peat formation. The majority of permanent wetlands occur in the coastal zone, the Eastern Highlands and Tasmania (Australian Nature Conservation Agency, 1996). One of the major factors limiting the development of *Sphagnum* peatlands in Australia is moisture availability, in particular evapotranspiration in the driest month. While rainfall may be less important in peatlands that receive significant catchment runoff, the generally small size of the peatlands affects their sensitivity to hydrologic changes. In Tasmanian *Sphagnum* peatlands, the mean annual temperature ranges between 5.7 and 8.6 °C, the mean maximum temperature of the warmest month ranges from 16.2 to 19.5 °C. Mean annual precipitation varies at these Tasmanian sites between 1540 and 2020 mm and that of the driest month ranges between 70 and 100 mm. Despite topographic and climatic suitability, large *Sphagnum* peatlands do not occur on the siliceous substrate in south-western Tasmania. The Cyperaceous peatlands that dominate south-western Tasmania have lower values for total N, total P and percentage organic matter than those recorded for *Sphagnum* peatlands in Tasmania and the northern hemisphere (Whinam, 1990), suggesting that the combination of poor nutrient status and fire history have prevented the widespread growth of *Sphagnum* (Whinam et al., 1989). Similarly it is not prominent in the sandstone habitats of the Blue Mountains of New South Wales. This is in contrast with Northern Hemisphere and New Zealand data, which suggest that *Sphagnum* occupies nutrient-poor habitats (Clymo and Hayward, 1982), but reflects the lower nutrient status and fire history of south-western Tasmania (Bowman et al., 1986), which favours moorlands dominated by buttongrass (*Gymnoschoenus sphaerocephalus*). The total area of *Sphagnum* peatlands in Tasmania, estimated by using colour aerial photographs and vegetation mapping data for parts of the Tasmanian World Heritage Area (Parks and Wildlife Service, unpublished data) and ground confirmation, is approximately 1300 ha (J. Whinam, unpublished data).

In Victoria, peatlands are most extensive and hummocks better developed at altitudes above 900 m. At this altitude, the mean annual temperature ranges from 6.5 to 10.4 °C, the mean maximum temperature of the warmest month ranges from 19.0 to 23.1 °C and the mean annual precipitation ranges from 1570 to 1600 mm, with the mean annual precipitation of the driest month being around 75 mm (McKenzie, 1997).

Even in the high rainfall, well-vegetated regions, dry periods occur and bushfires are frequent. Fire can have serious impacts on peatlands (Kershaw and Bohte, 1997; Horwitz et al., 1998), causing substantial losses of substrate, although in many cases fire may burn surface vegetation without igniting the underlying peat (e.g. Clarkson, 1997). At a local scale *Sphagnum* may decline, even to local extinction, during drought periods. For example at a small hanging swamp on top of a seacliff in Sydney (Bridgman et al., 1995), small amounts of *Sphagnum* persisted until the late 1970s but disappeared during a drought in 1980–1981.

Extensively distributed, but normally shallow, peat deposits are occasionally found in the coastal lowlands, often in dune swales, both on the east coast and in the south-west of Western Australia (Horwitz et al., 1998). The vegetation on these sedgeland deposits is dominated mainly by Restionaceae species where rainfall exceeds 1000 mm yr^{-1} and Cyperaceae species elsewhere or wet heath, but forested wetlands (dominated by *Melaleuca* spp., *Eucalyptus* spp. and *Casuarina* spp.) also occur. Peat deposits are scattered across the sandstone plateaux around Sydney, New South Wales, along creek lines and in shallow depressions (e.g., Kodela and Dodson, 1989).

Peat swamps are found in the uplands and highlands of eastern Australia, for example in Victoria (Kershaw et al., 1997), the New South Wales

(N.S.W.)/Australian Capital Territory (A.C.T.) Alps (Hope and Southern, 1983), Barrington Tops (Dodson et al., 1986) and the New England region (Millington, 1954). *Sphagnum* may be a major component of the vegetation of some of these upland swamps. In some Australian states good data exist – for example, moorlands (Jarman et al., 1988) and *Sphagnum* peatlands (Whinam et al., 1989) in Tasmania and peatlands in Victoria (Kershaw et al., 1997). For other states coverage is still incomplete. Hancock (1998) provides an estimate of the peat resources in Australia, but his figures are misleading, as they over-estimate the resource considerably, by including extensive floodplain *Phragmites* swamps as peatlands.

New Zealand

The surface area for all peatlands in New Zealand (including farmland, forestry, etc.) is at least 2100 km^2 (derived from Newsome 1991). Much of the 270,000 ha of swamp (including bogs) and 97,000 ha of pakihi vegetation is peatlands (Hunter and Blaschke, 1986). Annual rainfall at *Sphagnum* sites in New Zealand, ranges from 1100 to >10,000 mm, with that of the driest month ranging between 60 and 190 mm. Mean annual temperature at these sites ranges from 3.5 to 13.4 °C, and mean maximum temperature ranges between 11.5 and 28.3 °C (Mark et al., 1995).

On the gley podzols of Westland, New Zealand, *Sphagnum* peatland communities have been favoured by activities associated with logging (e.g. tramways). Here, *Sphagnum* occupies a transitional phase to closed shrubland and forest that would ultimately reduce its abundance. Although forest clearance has led to *Sphagnum* abundance in the first instance, it is the disturbance associated with continued harvesting of *Sphagnum* moss (e.g. rise in water table caused by impeded drainage) that appears to be maintaining *Sphagnum* dominance. These cut-over forests are now some of the major sites of commercial *Sphagnum* harvesting on the South Island. On the North Island several *Sphagnum* bogs have similarly been induced or increased by forest logging, particularly in upland areas with high rainfall, e.g., Mamaku Ranges west of Rotorua. *Sphagnum* is also common along track margins and other disturbed areas (Mew, 1983).

Pacific

In the Pacific *Sphagnum* occurs in mountain areas on the windward slopes in shrub-rich peatlands, as these locations experience high orographic rainfall (Mueller-Dombois and Fosberg, 1998).

New Guinea and Malesia

In New Guinea and Malesia there are montane swamp forests which often have *Sphagnum* species around tree bases. Mires are common along the outer flanks of the main mountain cordillera that extends along the island, and also on outlying ranges and mountainous islands. Above 2700 m mosaics of subalpine grassland and sedge mires are common, and above 3400 m on most mountains' soils are peaty and mire taxa invade the grasslands to form cushion bogs. New Guinea is humid, with precipitation throughout the year in the mountains and rainfall totals from 2500 to >10,000 mm. Temperatures range from 20 °C at 1400 m to about 6 °C at the tree-line at 3900 m, and a snowline at 4620 m. Terrestrial mosses are particularly common in the mist zone forests and bogs between 2000–3500 m (Hope, 1996). Conditions are not as moist in south-east Asia but mountain plateaux and streamlines support sedge swamps. Large ombrotrophic peat swamp forests occur in the lowlands of Sumatera and Borneo (Reiley and Page, 1997).

In montane New Guinea, *Sphagnum* occurs in openings in forests that are beset by low-lying cloud for most days. The forest is often microphyll or nanophyll, with an open canopy formed by *Nothofagus, Elaeocarpus, Pittosporum, Rapanea* and *Syzygium* species. The ground is a tangle of scrambling orchids, with the trees draped in mosses and hepatics. *Sphagnum* grows in forest openings around wet hollows and is encouraged by forest clearing. At higher altitudes *Sphagnum* occurs around ponds and along stream banks in tree fern dominated riparian communities. Conifers such as *Phyllocladus hypophyllus* and *Dacrycarpus compactus* are common as remnant low forest. *Sphagnum* is rarely dominant but may form mats with hepatics around wet fens or tarns and occurs with cushions of *Astelia, Carpha, Oeobolus, Centrolepis, Rhododendron, Potentilla, Plantago, Eriocaulon* and other cushion mosses (Hope, 1980; Gibson and Hope, 1986). The western half of the island has less seasonality and less fertile substrates and seems richer in *Sphagnum* than the volcanic soils of most of the Papua New Guinea highlands. On the Tertiary sandstones and peats on the plateau around Lake Habbema (3240 m) in West Papua, *Sphagnum* seems to colonise wet areas caused by trampling, so is common along tracks through the blanket peats formed below cushion and grass bogs (Hope, 1980).

Subantarctic islands

On subantarctic Macquarie Island *Sphagnum* occurs in water-saturated conditions down to sea level, most commonly on old coastal terraces where drainage is impeded, or in old elephant seal (*Mirounga leonina*) wallows which have added nutrients and where the nutrient-favoured *Callitriche antarctica* occurs. On Macquarie Island plateau, *Sphagnum* often occurs in wet areas where skuas (*Catharacta lonnbergi*) add nutrients through washing themselves and their prey. However, *Sphagnum* does not form large peatlands on Macquarie Island, with a total area of less than 5 ha of *Sphagnum falcatulum*, although warmer temperatures over the past few years (Kininmonth, 1992), have coincided with an increase in *Sphagnum* moss (J. Whinam, unpublished data). *Sphagnum* is abundant on subantarctic Campbell Island on wet, deep, acid peats (Meurk et al., 1994), but mostly occurs either under or among other vegetation, or patchily along driplines, bases of erosional scars and footpaths or other disturbed areas.

The *Sphagnum* moss harvesting industry

The harvesting of *Sphagnum* moss is a major industry in both New Zealand and Australia. *Sphagnum* moss is harvested primarily for use in the horticultural industry, where species that have 'fat' moss strands able to hold a considerable amount of water are favoured (e.g. *S. cristatum* is favoured over *S. subnitens*). Harvesting is commonly done by hand, with the covering vegetation, usually rushes, cleared with a scrub cutter and rake. At some sites drains have been constructed around the edge of the peatland to allow easier extraction, but this practice appears to have long-term detrimental effects on recovery (Vasander, 1987). Harvested *Sphagnum* moss is put into nylon bales that weigh 100 to 120 kg when wet, therefore bale extraction has a high impact on the harvesting site. Extraction is carried out by various means – dragging bales by hand, using tramways, four-wheeled motorcycles, bulldozers, or, as has become more common in New Zealand, by helicopter.

Over the last three decades, the *Sphagnum* moss harvesting industry has expanded dramatically with exports leveling off in the early 1990s at about 1000 tonnes of dry moss in New Zealand and roughly 15 tonnes in Tasmania. A small amount of *Sphagnum* moss is harvested in Victoria. *Sphagnum* harvesting at Ginini Bog, in the Australian Capital Territory ceased in 1944, but has left damaged areas that are still apparent. In Australia, virtually all alpine and subalpine habitat is reserved in National Parks. Consequently there has been considerable pressure on unreserved peatlands. In New Zealand it is estimated that 20 to 30% of *Sphagnum* moss-producing land is in private ownership, the remainder being administered by two government agencies, Timberlands West Coast Ltd and the Department of Conservation, with a small portion reserved (c. 1800 ha in Westland National Park; Department of Lands and Survey, 1982; and 500 ha in formal Scenic Reserves; Wardle, 1980). Large parts of subalpine New Guinea are still remote and not accessible to harvesters, and a large subalpine reserve has been declared in West Papua. Traditional use is not affected by reserves but is not a threat in any area.

Sphagnum moss harvesting and management

Sphagnum regeneration on the bare peat surface left after complete moss harvesting in Australia and New Zealand is slow, or sometimes absent, leading to dominance by other species, notably Restionaceous and Cyperaceous graminoids.

Manipulation of the water table has been suggested, based on experimental trials in New Zealand, as a technique to promote moss, particularly *Sphagnum*, growth, and create conditions favouring the commercially more desirable *S. cristatum* (Stokes et al., 1999). Although one property owner exercises some control over water levels, no generally applicable protocols have been developed.

The rate of growth of *Sphagnum* will be an important determinant of ability to recover from disturbance. Several studies have been conducted on *Sphagnum* growth rates in Australasia. In general, growth rates decline with increasing altitude and latitude. Occasional moisture deficits limit growth. *Sphagnum* growth in montane situations in New Zealand and Australia is slow, ranging from 0.9 to 7.3 cm yr^{-1} (Whinam and Buxton, 1997).

Variation in height growth at lowland sites in New Zealand can be matched to temperature. Crank wires installed at permanent transects indicated that *S. cristatum* at Westport had a growth rate of 6.1 cm yr^{-1} (mean temperature 12.2 °C), Hokitika 5.4 cm yr^{-1}

(mean temperature 11.6 °C) and Kakapotahi 3.4 cm yr^{-1} (mean temperature 11.1 °C). These sites are all below 40 m above sea level with mean annual rainfall between 2200 and 3800 mm yr^{-1}.

Low winter temperatures limit *Sphagnum* growth in both lowland and montane situations, but in response to increased summer temperatures lowland sites appear capable of greater growth than montane sites (1.3 cm yr^{-1}). Buxton et al. (1995) found *Sphagnum* height growth is also enhanced by the presence of 20 to 60% rushes (*Juncus* and *Baumea*) and sedges (*Gahnia*).

The growth of *Sphagnum* was studied by Clark (1980) at Ginini Flats, a 75 ha subalpine bog at 1590 m in the Brindabella Mountains of the A.C.T. Up to 1.8 cm increase in height occurred in a growing season, but this was usually compressed by winter snow, so that the net annual growth varied from 9 to −2 mm, depending on the snow loading. Clark calculated the *Sphagnum* productivity at 1.7 tonne ha^{-1} dry weight, but thought that this might be an underestimate. By comparison, annual productivity in Westland, New Zealand, was estimated by Denne (1983) at 7.27 tonnes ha^{-1} dry weight.

The Delegate River floodplain at 900 m altitude near Bendoc, Victoria has an extensive epacridaceous *Sphagnum* bog overtopped by *Leptospermum* shrubland (Ladd, 1979). Gell et al. (1993) carried out high resolution analyses on short cores covering the historical period. They found that *Sphagnum* was suppressed and grass increased when the plain was burnt and used for cattle grazing. Reduction in fire frequency and clear felling of a high proportion of the eucalypt forest in the catchment has led to increased water supply and a recovery by *Sphagnum* and *Myriophyllum* over the last 50 years. *Sphagnum* may also be responding to increased nutrient provided by the inwash of sediment.

At sites in Tasmania and New Zealand, experimental harvesting has shown that reseeding (leaving 30% moss cover behind) resulted in faster recovery of the *Sphagnum* moss in terms of percentage cover than leaving a bare peat surface. In New Zealand, regrowth in reseeded 1 m^2 plots, either moderately or heavily harvested plots, resulted in approximately 90% cover of *Sphagnum* 36 months after harvesting compared with 50% in unseeded plots (R.P. Buxton unpublished data). Pressing of *Sphagnum* fragments into the water table to ensure good contact did not appear to substantially increase recovery rates (P.A. Alspach, unpublished data).

Reseeding and sensitive harvesting operations have enabled harvesting cycles as short as 2 to 3 years, with repeat harvesting of >15 cm *Sphagnum* fibers at some lowland sites in New Zealand, whereas in Tasmania, reseeding combined with hand-broadcasting of small amounts of slow release, recycled sewage pellets as fertiliser, has resulted in high-quality *Sphagnum* moss being harvested on a longer 10 year rotation (P. Binney, personal communication).

Like all plant growth, the rate of *Sphagnum* recovery after harvesting (when more or less 30% of the original acrotelm is not disturbed) is strongly influenced by climatic variables, with warmer, wetter sites recovering quicker than colder and drier sites.

On the basis of data collected to date (Whinam and Buxton 1997), *Sphagnum* moss harvesting is only likely to be sustainable in Australasia where the site

- is less than 600 m altitude;
- has 20% shade protection provided by other species;
- is large enough to allow harvesting rotation;
- is harvested while avoiding the use of heavy machinery;
- is left with an even surface with some meso-roughness to provide support for *Sphagnum* but keeping the moss close to the water table;
- an adequate period is provided between harvests, determined by growth rates and environmental conditions, to allow the moss to recover.
- has 30% moss *Sphagnum* cover left for reseeding.

Our observations in New Zealand and Tasmania suggest that the most damaging moss harvesting is done by poachers and harvesters operating on a once-off basis. Seeking short-term financial gain, they often over-pick a site leaving little for natural revegetation and take little care when extracting the moss. Poachers have become an increasing problem in both Tasmania and New Zealand (Yarwood, 1990). However, a system in New Zealand, which requires harvesters to be registered to avoid paying more tax at point of sale has deterred many poachers.

In places like Tasmania and Victoria, where observations suggest that *Sphagnum* moss can die due to desiccation in dry summers, *Sphagnum* peatlands may be near their climatic limits, in which case drier, warmer conditions associated with global warming are likely to be detrimental to their long-term survival. Moss harvesting activities add further pressures to this limited resource.

Conservation and management – peat mining

Most peat losses in Australia and New Zealand have been caused by agriculture, both through intentional drainage and through accidental fires and erosion. The valley mires (mostly *Carex* fen and grass bog) have gullied in many places with peat collapse, e.g. Jackson's Bog, New South Wales (Southern, 1982). Exposure of peat to drying (through peat mining, draining, etc.) has the potential to oxidise soils rich in iron (or other) sulphides, to produce sulphates which are hydrated to sulphuric acid, thereby posing a significant threat to the biota through reduced pH, with acidification an emerging issue in Western Australia (Sommer and Horwitz).

The scale of peat mining in Australasia is very small when compared to northern hemisphere operations. For example, a total of 5800 m^3 of peat is extracted from Tasmania annually. In South Australia, less than 6700 m^3 of peat yr^{-1} is mined from a deposit on the Woakwine Range near Lake Bonney. In Queensland, about 5–10,000 m^3 yr^{-1} is extracted from a 10 year old mining site on the Atherton Tableland. Currently, there is no mining in N.S.W., Victoria, or the A.C.T. Mining occurs in diatomous and restionaceous peats in W.A. (Meney and Pate, 1999; G. Hope, unpublished data). In New Zealand, a total of approximately 140,000 m^3 yr^{-1} of peat is extracted.

Sphagnum peat is preferred over restiad peat for horticultural purposes because it has better water holding ability, larger particles and is more freely draining. There is one small restiad mine in the Waikato region, harvesting about 3000 m^3 annually. However, the peat types can be mixed to conserve the resource. Australia is a net importer of peat, with supplies coming primarily from Canada, New Zealand, Germany and Ireland (in descending order of amount supplied). Approximately 67% of peat in Australia is used for mushroom cultivation, with a further 5% used for the production of grass turf (R. Wilkinson, personal communication).

The major impediments to expedite regeneration of peatland sites in Australasia are a lack of knowledge of restoration techniques appropriate to the environmental conditions and the absence of regeneration requirements in peat mining leases. However, data from *Sphagnum* moss harvesting regeneration combined with an understanding of bog succession can be used to provide some guidance for management and recolonisation of peat mining sites.

Before assessing the management and restoration options of peatlands subjected to mining, it is necessary to look at the context of the restoration goals. It is also necessary to evaluate the success of the restoration. One way to do this is to compare functional processes in the restored site with an adjacent unmodified peat bog ecosystem and to monitor whether peat accumulates. The re-establishment of *Sphagnum* communities is often the ultimate aim in restoration and is used as an indicator of peatland health. For example in the Snowy Mountain highlands of New South Wales, cattle grazing resulted in the destruction of *Sphagnum* peatlands in an important water catchment. Twenty years after the cessation of grazing, and many thousands of dollars later, the prevention of erosion and revegetation measures had led to the re-establishment of *Sphagnum* in these peatlands, which is interpreted as a sign of ecosystem recovery (Wimbush and Costin, 1979). Similarly, the combination of trampling by feral animals, and frequent fires has led to degradation of *Sphagnum* bogs and incision of water courses in the A.C.T. Removal of stock has allowed *Sphagnum* hummocks to regenerate and invade streamlines to re-establish wet conditions.

Of the six active *Sphagnum* peat mines in New Zealand (three in North Island, two in South Island) and Tasmania, only two – Gamman Mining and Yates-Watkins (New Zealand) are required to restore the peatland back to bog. This is because the other New Zealand mines were previously in pasture, not intact bogs, and there has not been a legislative requirement to restore the Tasmanian peatlands.

All three North Island mines work the Torehape peat bog in the Hauraki Plains. This 6000 year old bog originally covered more than 10,000 ha but now only about 700 ha of bog vegetation remains, mostly protected in reserve. Torehape has large deposits of *Sphagnum* peat, which is unusual because the main peat-forming species elsewhere in the Waikato/Hauraki Plains district are the restiads *Empodisma minus* and *Sporadanthus ferrugineus*. The current dominants in the nearby reserve, however, are *Empodisma* and *Sporadanthus* and there is also a surface layer 10 to 15 cm thick of restiad peat over the *Sphagnum* (Clarkson, 1994). It is thought that ring drainage in the early 1920s diverted water from surrounding hills out to sea, thus lowering water tables within the bog and causing a shift from *Sphagnum cristatum* to restiad species, which are better adapted to 'drier' conditions (Bates, 1973). The Torehape mining companies have a license to mine only the upper 1 m of peat (average thickness is 5 to 7 m) and then are required to restore the bared surface back to

a functioning bog. Initial results of restoration trials involving combinations of fertiliser, plants, and water table have resulted in 100% vegetative cover being achieved with some treatments after two years (Schipper, in press). This first stage is based on restoring a restiad cover but stage two will involve encouraging growth of *Sphagnum*.

The high conservation values on the Chatham Islands of New Zealand (Wardle et al., 1986) have so far prevented any peat mining proposals from being successful there. There is no peat mining on the subantarctic islands.

In the central highlands of Tasmania, a large (10 ha) montane *Sphagnum* peatland is currently being mined. When the peat supply is exhausted, this will be the first attempt in Tasmania to restore a *Sphagnum* peatland after mining. At a nearby site that had *Sphagnum* moss harvested and drains constructed in preparation for mining, the drier margins have now converted to a restionaceous/cyperaceous peatland, dominated by *Empodisma minus* and *Gymnoschoenus sphaerocephalus*.

Peat mining is not carried out in a systematic way in the tropics but the forested peatlands are widely utilised for logging. The losses of peat due to illegal tree felling and clearance for agriculture, particularly in Kalimantan and Sumatra over 35 years, probably exceeds 10 million hectares, although estimates vary. Fox (2000) assesses the 1997–1998 El Niño fires in Indonesia at 9.75 million hectares, much of this in peatlands (Reiley and Page, 1997). The 1997 fires caused major damage to subalpine peatlands in Irian Jaya, many former mires being burnt and invaded by grasses and introduced composites. Considerable volumes of peat have also been removed as a result of alluvial mining for tin in Malaya, and in developing swamps for oil palm and sugar plantations in Indonesia and the Pacific.

Case study of bad peat mining management: Wingecarribee

The gently sloping Wingecarribee Swamp, a montane peatland located in the Southern Highlands of New South Wales (670 m), originally covered more than 650 ha and was the largest upland (restionaceous) peat deposit in mainland Australia. In 1974 the western half of the swamp was submerged by the Wingecarribee Reservoir, with small scale peat mining occurring in the remaining eastern swamp (307 ha). Extraction subsequently changed to a wet mining process, in which a lake was excavated within the swamp. Extracted peat was converted into a slurry on a floating pontoon and then pumped via a pipeline to a processing plant on dry land. Production increased from 3000 m^3 yr^{-1} to about 30,000 m^3 yr^{-1} by the mid 1990s. In 1997 the mining pond was 20 ha in extent and several metres deep, with a pronounced steep face of peat exposed at the upslope end, due to the general gradient of the swamp.

On the night of 8–9 August 1998 the swamp upstream from the mine pond collapsed following heavy, but not exceptional, rain. An estimated 6000 megalitres of peat and sediment and 6500 megalitres of runoff water moved into Wingecarribee Reservoir (Arachchi and Lambkin, 1999). The dredge on its pontoon was also swept into the reservoir, gouging a major channel through the swamp which immediately enlarged under the peak flows. A Mining Warden's Inquiry into a proposed renewal of the mining leases was held in 1997 during which the potential instability of the swamp was pointed out. However objections from government agencies and peatland expert witnesses were not accepted by the Warden (Bailey, 1997) and mining continued until it was halted by imposition of a Heritage Order in 1998.

Post collapse, about 70% of the swamp has sunk by 3 to 4 m and is fragmented by a network of deep fissures reaching to basal clays (illustrated in White, 2000). The former filtering capacity of the swamp has been lost which has serious implications for water quality in the reservoir. The peat in the reservoir also lowered the storage capacity (by 18%) and increased turbidity (Arachchi and Lambkin, 1999).

Changes to the swamp environment

What was once a continuous extensive swamp system has become fragmented, with large areas of exposed peat (both as vertical faces and flat plains). The long-term impacts of the collapse on the hydrology and ecological stability of these swamp margin habitats are currently unknown. Restoration of the original swamp system is not possible. About 140 ha consist of stranded blocks of fibrous peat up to 3 m in height, which are extremely vulnerable to fire. The major management priorities are to reduce the likelihood of fire and institute weed control. In the longer term attempts to disperse water and encourage swamp regeneration may be made. The swamp still provides habitat for a rich flora and fauna, including several endangered species, and stands of a range of fen communities. Conservation of these features remains a high priority, but specific action has been delayed by the lack of expertise. These bogs differ greatly from the extensive peatlands of the northern hemisphere, and current restoration knowledge is merely superficial. Patterns of recovery at Wingecarribee may provide some insight for future restoration of these Australasian communities.

Conclusions

While *Sphagnum* peatlands form a relatively small part of the Australasian landscape, they are distinct communities and can form their own ecosystem (> 10 ha), be present in other peat forming ecosystems, or occur as small moss patches. There has been a significant loss of *Sphagnum* peatlands associated with draining, agriculture and fires. One of the major differences between resource use of *Sphagnum* peatlands in Australasia and the northern hemisphere is the importance of *Sphagnum* moss harvesting in Australia and New Zealand. Sustainable resource use and restoration techniques associated with *Sphagnum* moss harvesting are quite different to those associated with peat mining. With most of the subalpine and alpine *Sphagnum* peatlands in Australia and much of New Zealand's remaining peatlands in formal reserves, there are pressures from both moss harvesters and peat miners on remaining resources. Evidence to date suggests that it is easier to restore *Sphagnum* peatlands that have been subjected to drainage for moss harvesting and after peat mining to sedgeland peats dominated by Cyperaceae and Restionaceae than to *Sphagnum* moss. The limited knowledge about restoration after moss harvesting and even more limited understanding of ecosystem responses to mining indicate the need for further experimental trials. For peatlands near their climatic limits, global warming and an increased likelihood of fire pose significant threats.

Acknowledgements

Studies in New Zealand were funded by the Department of Conservation and the Public Good Science Fund, and those in Tasmania funded by Environment Australia and supported by the Department of Primary Industries, Water and Environment. Taxonomic assistance was provided by Dr Rod Seppelt, Australian Antarctic Division. Work on mainland Australian mires has been partly funded by grants from NSW National Parks and Wildlife Service and the ACT Government. We thank Dr Robin Clark for making available unpublished reports and Dr Andreas Touw, Leiden Herbarium, for information on tropical moss distributions. We are pleased to acknowledge Dr Pierre Horwitz, Dr Merna McKenzie, Prof Alan Mark, an anonymous referee and especially Dr Janet Wilmshurst, for useful comments on the paper.

References

Arachchi, B.K. and Lambkin, K.L. 1999. Wingecarribee Reservoir Swamp Failure. ANCOLD Bulletin 113: 37–45.

Ashton, D.H. and Hargreaves, G.R. 1983. Dynamics of subalpine vegetation at Echo Flat, Lake Mountain, Victoria. *In:* Purdie, R. and Noble, I. (eds.), Mountain Ecology in the Australian Region. Proceedings of the Ecological Society of Australia, vol. 12. pp. 35–60. Ecological Society of Australia, Canberra, Australia.

Australian Nature Conservation Agency. 1996. A Directory of Important Wetlands in Australia. Second Edition. Australian Nature Conservation Agency, Canberra, Australia.

Bailey, J.A. 1997. Report to the Minister for Mineral Resources under Section 334 of the Mining Act 1992. Inquiry into renewal of Special Leases 567 and 568 (Mining Act 1906) for peat extraction at the Wingecarribee Swamp. Unpublished Report. New South Wales Department of Mineral Resources. Sydney, Australia.

Bartram, E.B. 1942. Third Archbold Expedition mosses from the Snow Mountains, Netherlands New Guinea. Lloydia 5: 245–292.

Bartram, E.B. 1957. Mosses of eastern Papua, New Guinea. Brittonia 9: 32–56.

Bates, P.M. 1973. Peat bogs in the South Auckland area, New Zealand. NZ Soil News 21: 177–179.

Bowman, D.M.J.S., Maclean, A.R. and Crowden, R.K. 1986. Vegetation-soil relations in the lowlands of south-west Tasmania. Aust. J. Ecol. 11: 141–153.

Bridgman, H.A., Warner, R.F. and Dodson, J.R. 1995. Urban Biophysical Environments. Oxford University Press, Melbourne, Australia.

Buxton, R.P., P.N. Johnson and Espie, P.R. 1995. *Sphagnum* Research Programme: The Ecological Effects of Commercial *Sphagnum* Harvesting. Unpublished report to Department of Conservation, Wellington, New Zealand.

Burrows, C.J. and Dobson, A.T. 1972. Lakes Manapouri and Te Anau: Mires of the Manapouri – Te Anau lowlands. Proc. NZ Ecol. Soc. 19: 75–99.

Campbell, E.O. 1983. Mires of Australasia in Mires: Swamp, bog, fen and moor. *In:* Gore, A.J.P. (ed.), Ecosystems of the World 4B. pp 153–180. Elsevier, Oxford, UK.

Clark, R.L. 1980. *Sphagnum* growth on Ginini Flats, A.C.T. Unpublished Report to New South Wales National Parks and Wildlife Service, Australia.

Clarke, P.J. and Martin, A.R.H. 1999. *Sphagnum* peatlands of Kosciuszko National Park in relation to altitude, time and disturbance. Aust. J. Botany 47: 519–536.

Clarkson, B.R. 1994. Part Torehape Government Purpose Reserve (Wetland Management): Botanical Survey. Landcare Research Contract Report, LC 9495/46. New Zealand.

Clarkson, B.R. 1997. Vegetation recovery following fire in two Waikato peatlands at Whangamarino and Moanatuatua. NZ J. Botany 35: 167–179.

Clymo, R.S. and Hayward, P.M. 1982. The ecology of *Sphagnum*. *In:* Smith, A.J.E. (ed.), Bryophyte Ecology. pp. 229–289. Chapman and Hall, London, UK.

Costin, A.B. 1954. A Study of the Ecosystems of the Monaro Region of New South Wales with Special Reference to Soil Erosion. Government Printer, Sydney, Australia.

Crocker, R.L. and Eardly, C.M. 1939. A South Australian *Sphagnum* bog. Transcr. Royal Soc. South Aust. 63: 210–214.

Crum, H. and Seppelt, R.D. 1999. *Sphagnum leucobryoides* reconsidered. Contrib. Univ. Michigan Herb. 22: 29–31.

Dalton, P.J., Seppelt, R.D. and Buchanan, A.M. 1991. An annotated checklist of Tasmanian mosses. *In:* Banks, M.R., Smith, S.J., Orchard, A.E. and Kantvilas, G. (eds.), Aspects of Tasmanian Botany, A Tribute to Winifred Curtis. pp. 15–32. Royal Society of Tasmania, Hobart, Australia.

Davoren, A. 1978. A survey of New Zealand Peat Resources. Water & Soil Technical Publication No 14. University of Waikato, Hamilton, New Zealand.

Denne, T. 1983. *Sphagnum* on the West Coast, South Island, New Zealand: Resource Characteristics, the Industry and Land Use Potential. M.Sc. thesis. University of Canterbury, Canterbury, Australia.

Department of Lands and Survey. 1982. New Zealand Land inventory, Franz Josef – Mount Cook Vegetation (map) NZMS 290 H34/35/36. Wellington, New Zealand.

Dickinson, K.J.M. and Mark, A.F. 1994. Forest-wetland vegetation patterns associated with a Holocene dune-slack sequence, Haast Ecological District, south western New Zealand. J. Biogeography 21: 259–281.

Dodson, J.R., Greenwood, P.W. and Jones, R.L. 1986. Holocene forest and wetland vegetation dynamics at Barrington Tops, New South Wales. J. Biogeography 13: 561–585.

Eddy, A. 1977. Sphagnales of tropical Asia. Bull. Brit. Museum (Natural History) Botany 5: 359–445.

Eddy, A. 1988. A Handbook of Malesian Mosses, Vol I Sphagnales to Dicranales. British Museum (Natural History), London, UK.

Fife, A.J. 1996. A synopsis of New Zealand Sphagna, with a description of *S. simplex*, sp. nov. NZ J. Botany 34: 309–328.

Fox, J.J. 2000. The impact of the 1997–98 El Nino on Indonesia. *In:* Grove, R.H. and Chappell, J. (ed.), El Nino history and Crisis. pp. 171–190. White Horse Press, Cambridge, UK.

Gell, P.A., Stuart, I.M. and Smith, J.D. 1993. The response of vegetation to changing fire regimes and human activity in East Gippsland, Victoria, Australia. The Holocene 3: 150–160.

Gibson, N. and Hope, G.S. 1986. On the origin and evolution of Australasian alpine cushion plants. *In:* Barlow, B. (ed.), Flora and Fauna of Alpine Australasia. pp. 62–81. CSIRO, Melbourne, Australia.

Hancock, S. 1998. Problems and challenges of peat in Australia. *In:* Sepo, R. (ed.), The Spirit of Peatlands 30 years of the International Peat Society. pp. 36–38. International Peat Society, Helsinki, Finland.

Hope, G.S. 1980. New Guinea mountain vegetation communities. *In:* van Royen, P. (ed.), Alpine Flora of New Guinea. pp. 111–222. Cramer Verlag, Vaduz, Liechtenstein.

Hope, G.S. 1996. Quaternary change and historical biogeography of Pacific Islands. *In:* Keast, A. and Miller, S.E. (eds.), The Origin and Evolution of Pacific Island Biotas, New Guinea to Eastern Polynesia: Patterns and Process. pp. 165–190. SPB Publishing, Amsterdam, The Netherlands.

Hope, G.S. and Southern, W. 1983. Peatlands of the Southern Tablelands of New South Wales. Unpublished report to NSW National Parks and Wildlife Service, Australia.

Horwitz, P., Pemberton, M. and Ryder, D. 1998. Catastrophic loss of organic carbon from a management fire in a peatland in southwestern Australia. *In:* McComb, A.J. and Davis, J.A. (eds.), Wetlands for the Future. pp. 487–501. Gleneagles Publishing, Adelaide, Australia.

Hunter, G.G. and Blaschke, P.M. 1986. The New Zealand land resource inventory vegetation cover classification. Water & soil miscellaneous publication No 101. New Zealand.

Jarman, S.J., Kantvilas, G. and Brown, M.J. 1988. Buttongrass Moorland in Tasmania. Research Report No. 2, Tasmanian, Forest Research Council Inc., Hobart, Australia.

Kershaw, A.P. and Bohte, A. 1997. The impact of prehistoric fires on tropical peatland forests. *In:* Rieley, J.O. and Page, S.E. (eds.), Biodiversity and Sustainability of Tropical Peatlands. pp. 73–80. Samara Press, Tresaith, Cardigan, UK.

Kershaw, A.P., Reid, M. and Bulman, D. 1997. The nature and development of peatlands in Victoria, Australia. *In:* Rieley, J.O. and Page, S.E. (eds.), Biodiversity and Sustainability of Tropical Peatlands. pp. 81–92. Samara Press, Tresaith, Cardigan, UK.

Kininmonth, W. 1992. Role of Antarctica's energy processes in global climate. ANARE News 70: 5–7.

Kirkpatrick, J.B. and Gibson, N. 1984. Dynamics of a Tasmanian bolster heath string fen. Vegetatio 58: 71–78.

Kodela, P.G. and Dodson, J.R. 1989. Late Holocene vegetational change from Ku-ring-gai chase National Park, New South Wales. Proc. Linnean Soc. New South Wales 110: 317–326.

Ladd, P.G. 1979. Past and present vegetation on the Delegate River in the highlands of eastern Victoria. I. Present vegetation. Aust. J. Botany 27: 167–184.

Lappalainen, E. 1996. Global Peat Resources. International Peat Society, Jyvaskyla, Finland.

Mark, A.F., Johnson, P.N., Dickinson, K.J.M. and McGlone, M.S. 1995. Southern hemisphere patterned mires, with emphasis on southern New Zealand. J. Royal Soc. NZ 25: 23–54.

Mark, A.F., Rawson, G. and Wilson, J.B. 1979. Vegetation pattern of a lowland raised mire in eastern Fiordland, New Zealand. NZ J. Ecology 2: 1–10.

McKenzie, G.M. 1997. The late Quaternary vegetation history of the south-central highlands of Victoria, australia. I. Sites above 900 m. Aust. J. Ecology 22: 19–26.

Meney, K.A. and Pate, J.S. 1999. Australian Rushes. Biology, Identification and Conservation of Restionaceae and Allied Families. UWA Press, Perth, Australia.

Meurk, C.D., Foggo, M.N. and Wilson, J.B. 1994. The vegetation of subantarctic Campbell Island. NZ J. Ecology 18: 123–168.

Mew, G. 1983. Application of the term 'pakihi' in New Zealand – a review. J. Royal Soc. NZ 13: 175–198.

Millington, R.J. 1954. *Sphagnum* bogs of the New England Plateau. New South Wales J. Ecol. 42: 328–344.

Mueller-Dombois, D. and Fosberg, F.R. 1998. Vegetation of the Tropical Pacific Islands. Springer Verlag, Berlin, Germany.

Newsome, P.G.F. 1987. The Vegetative Cover of New Zealand. Water and Soil Misc. Publ. No 112. New Zealand.

Newsome, P.F. 1991. New Zealand Land Resource Inventory ARC/INFO data manual. DSIR Land Resources technical record 81. DSIR Land Resources, Lower Hutt, New Zealand.

Rieley, J.O. and Page, S.E. (eds.). 1997. Biodiversity and Sustainability of Tropical Peatlands. Samara Press,Tresaith, Cardigan, UK.

Rochefort, L. 2001. Restauration écologique. *In:* Payette, S. and Rochefort, L. (eds.), Écologie des tourbières du Québec-

Labrador. pp. 449–504. Les Presses de l'Université Laval, Sainte-Foy, Québec, Canada.
Schipper, L.A., Clarkson, B.R., Vojvodic-Vukovic, M. and Webster, R. (in press). Restoring cut-over peat bogs: a factorial experiment of nutrients, seeds and cultivation. Ecol. Enging.
Seppelt, R.D. 2000. The Sphagnopsida (Sphagnaceae; Ambuchananiaceae) in Australia. Hikobia 13: 163–183.
Seppelt, R.D. and Crum, H. 1999. *Sphagnum fuscovinosum*, a new species from Australia. Contrib. Univ. Michigan Herb. 22: 131–134
Smale, P.E., Nelson, M.A., Alspach, P.A. and Halligan, E.A. 1995. *Sphagnum* moss production: Experience from environmental room trials to compare growth of two species of *Sphagnum* moss. Int. Plant Propag. Soc. Comb. Proc. 45: 389–392.
Smith, G.G. 1969. *Sphagnum subsecundum* in Western Australia. W Aust. Nat. 11: 56–59.
Sommer, B. & Horwitz, P. 2001. Water quality and macroinvertebrate response to acidification following intensified summer droughts in a Western Australian wetland. Marine & Freshw. Res. 52: 1015–1021.
Southern, W. 1982. Late Quaternary vegetation and environments of Jackson's Bog and the Monaro Tablelands, New South Wales. M.Sc. Thesis, Monash University, Melbourne, Australia.
Stokes, J.R., Alspach, P.A. and Stanley, C.J. 1999. Effect of water table on growth of three New Zealand *Sphagnum* species: implications for *S. cristatum* management. J. Bryology 21: 25–29.
Streimann, H. and Curnow, J. 1989. Catalogue of mosses of Australia and its external territories. Australian. Flora & Fauna Ser. 10(i-vii): 1–479.
Vasander, H. 1987. Diversity of understorey biomass in virgin and in drained and fertilised southern boreal mires in eastern Fennoskandia. Annales Botanici Fennici 24: 137–153.
Vitt, D.H. 1979. The moss flora of the Auckland Islands, New Zealand, with a consideration of habitats, origins, and adaptations. Can. J. Botany 57: 2226–2263.
Wardle, P. 1980. Scenic Reserves of South Westland. Biological Survey of Reserves Series no. 5. Department of Lands and Survey, Wellington, New Zealand.
Wardle, P. 1991. Vegetation of New Zealand. University Press, Cambridge, UK.
Wardle, P., Atkinson, I.A.E., Given, D.R., Molloy, B.J.P., Brown, C.M. and Manning, D. 1986. Botany Division visit to the Chatham Islands, February–March 1985. Unpublished report to the Liquid Fuels Trust Board. DSIR, Botany Division, Christchurch, New Zealand.
Whinam, J. 1990. A Study of the Ecology of Tasmanian *Sphagnum* peatlands. Ph.D. thesis, University of Tasmania, Australia.
Whinam, J. and Buxton, R. 1997. *Sphagnum* peatlands of Australasia: an assessment of harvesting sustainability. Biol. Conserv. 82: 21–29.
Whinam, J., Eberhard, S., Kirkpatrick, J. and Moscal, A. 1989. Ecology and Conservation of Tasmanian *Sphagnum* Peatlands. Tasmanian Conservation Trust Inc., Hobart, Australia.
Whinam, J., Barmuta, L.A. and Chilcott, N. 2001. Floristic description and environmental relationships of Tasmanian *Sphagnum* communities and their conservation management. Aust. J. Botany 49: 673–685.
Whinam, J. and Kirkpatrick, J.B. 1994. The Mount Wellington string bog. Tasmania Pap. & Proc. Royal Soc. Tasmania 128: 63–68.
Wimbush, D.J. and Costin, A.B. 1979. Trends in vegetation at Kosciusko. Aust. J. Botany 27: 741–871.
White, M.E. 2000. Running Down: Water in a Changing Land. Kangaroo Press, Sydney, Australia.
Yarwood, V. 1990. Green gold. NZ Geographer 7: 55–69.

Plant species recorded from Wingecarribee Swamp, Central Tablelands, N.S.W.

Revised Edition January 1994

P.G. Kodela[1,2], T.A. James[1], R.G. Coveny[1] and P.D. Hind[1]

MOSSES

BRACHYTHECIACEAE

Eurhynchium praelongum

SPHAGNACEAE

Sphagnum sp.

FERNS

BLECHNACEAE

Blechnum minus	Soft Water Fern
B. nudum	Fishbone Water Fern

GLEICHENIACEAE

Gleichenia microphylla	Scrambling Coral Fern

OSMUNDACEAE

Todea barbara	King Fern

SCHIZAEACEAE

Schizaea fistulosa[A]	Narrow Comb Fern

MONOCOTS

ATHERICACEAE

?*Caesia alpina*	
Sowerbaea juncea	Rush Lily, Vanilla Plant

CYPERACEAE

Baumea rubiginosa	Soft Twigrush
Carex appressa	Tall Sedge, Tussock Sedge
C. fascicularis	Tassel Sedge
C. gaudichaudiana	Tufted Sedge
C. polyantha	
Chorizandra cymbaria	Bristlerush
Cyperus lucidus	
C. sanguinolentus	
C. sphaeroideus	
Eleocharis acuta	Common Spikerush
E. gracilis	Spikerush
E. sphacelata	Tall Spikerush
Gahnia sieberiana	Red-fruited Sawsedge, Swordgrass
Isolepis crassiuscula	
I. habra	
I. inundata	
I. sp. aff. *inundata*	
I. producta	
**I. prolifera*	
Schoenus apogon	Common Bogrush, Fluke Bogrush

ERIOCAULACEAE

Eriocaulon scariosum	Common Pipewort

HYDROCHARITACEAE

Ottelia ovalifolia	Swamp Lily

IRIDACEAE	
**Sisyrinchium iridifolium*	
JUNCACEAE	
Juncus alexandri subsp. *melanobasis*	
**J. articulatus*	Jointed Rush
**J. bulbosus*	
J. continuus	
J. laeviusculus subsp. *illawarrensis*	
J. planifolius	Broad Rush
J. prismatocarpus	Branching Rush
Luzula modesta	
JUNCAGINACEAE	
Triglochin procera	Water Ribbons
LEMNACEAE	
Lemna sp.[A]	Duckweed
LILIACEAE	
Bulbine bulbosa	Native Leek, Bulbine Lily, Golden Lily
ORCHIDACEAE	
Cryptostylis sp.	
Microtis parviflora	Slender Onion-orchid
M. unifolia	
Prasophyllum uroglossum	Leek-orchid
Spiranthes sinensis subsp. *australis*	Austral Ladies' Tresses
Thelymitra pauciflora	Slender Sun-orchid
POACEAE	
**Anthoxanthum odoratum*	Sweet Vernal Grass
Agrostis avenacea var. *avenacea*	Blown Grass
Deyeuxia quadriseta	Reed Bent Grass
Dichelachne inequiglumis	
**Festuca elatior*	Meadow Fescue
**Glyceria declinata*	Glaucous Sweetgrass
**G. maxima*	Reed Sweetgrass, Water Meadow Grass
Hemarthria uncinata	Matgrass
**Holcus lanatus*	Yorkshire Fog
Isachne globosa	Swamp Millet
Phragmites australis	Common Reed
**Poa annua*	Winter Grass, Annual Poa
P. labillardieri var. *labillardieri*	Poa Tussock, Tussock Grass
POTAMOGETONACEAE	
Potamogeton tricarinatus	Floating Pondweed
RESTIONACEAE	
Empodisma minus	Spreading Rope-rush
Lepyrodia anarthria	
Restio australis	Cordrush
SPARGANIACEAE	
Sparganium subglobosum (*S. antipodum*)	Floating Bur-reed
TYPHACEAE	
Typha orientalis	Broadleaf Cumbungi, Bulrush

XYRIDACEAE	
Xyris operculata	Tall Yellow-eye
DICOTS	
APIACEAE	
Centella cordifolia	Swamp Pennywort
Hydrocotyle peduncularis	Pennywort
Lilaeopsis polyantha	Lilaeopsis
ASTERACEAE	
Bracteantha bracteata (*Helichrysum bracteatum*)	Yellow Paper Daisy, Golden Everlasting
**Cirsium vulgare*	Spear Thistle, Black Thistle
Craspedia canens	
Gnaphalium involucratum	
Helichrysum sp. aff. *scorpioides*	(undescribed species)
**Hypochaeris radicata*	Catsear, Flatweed
**Lactuca serriola*	Prickly Lettuce
**Leontodon taraxacoides*	
Olearia glandulosa	Daisy-bush
**Picris hieracioides*	
Pseudognaphalium luteoalbum	Jersey Cudweed
Senecio minimus	
**Sonchus oleraceus*	Common Sowthistle
**Taraxacum officinale*	Dandelion
BRASSICACEAE	
**Rorippa nasturtium-aquaticum*	Watercress
CALLITRICHACEAE	
Callitriche stagnalis	Common Starwort
CAMPANULACEAE	
Wahlenbergia ceracea	Bluebell
CARYOPHYLLACEAE	
**Cerastium glomeratum*	Mouse-ear Chickweed
Stellaria angustifolia	Swamp Starwort
CLUSIACEAE	
Hypericum japonicum	Matted St John's Wort
CONVOLVULACEAE	
Dichondra repens	Kidney Weed
DROSERACEAE	
Drosera binata	Forked Sundew
D. peltata	Pale Sundew
D. spatulata	Common Sundew
EPACRIDACEAE	
Epacris paludosa	Swamp Heath
FABACEAE - Faboideae	
**Lotus uliginosus* (*L. pedunculatus*)	
Pultenaea divaricata	Bush-pea
**Trifolium pratense*	Red Clover
**T. repens*	White Clover

FABACEAE - Mimosoideae	
Acacia melanoxylon	Blackwood
GENTIANACEAE	
Gentiana wingecarribiensis	Gentian
GERANIACEAE	
Geranium neglectum	
HALORAGACEAE	
Gonocarpus humilis	Raspwort
G. micranthus subsp. *micranthus*	Creeping Raspwort
Myriophyllum pedunculatum	Mat Water Milfoil
M. simulans	
LAMIACEAE	
Lycopus australis	
Prunella vulgaris	Self-heal
LENTIBULARIACEAE	
Utricularia australis	Yellow Bladderwort
U. dichotoma	Fairies' Aprons
LOBELIACEAE	
Pratia surrepens	
LOGANIACEAE	
Mitrasacme serpyllifolia	
LYTHRACEAE	
Lythrum salicaria	Purple Loosestrife
MENYANTHACEAE	
Nymphoides geminata	Entire Marshwort
Villarsia exaltata	Yellow Marsh Flower
MYRTACEAE	
Baeckea utilis	Mountain Baeckea
Eucalyptus ovata	Swamp Gum
Leptospermum grandifolium	Woolly Tea-tree
L. juniperinum	Prickly Tea-tree
L. obovatum	Tea-tree
ONAGRACEAE	
Epilobium gunnianum	Mountain Willow-herb
E. pallidiflorum	Willow-herb
POLYGALACEAE	
Comesperma retusum	Milkwort
POLYGONACEAE	
Persicaria decipiens	Slender Knotweed
P. hydropiper	Water Pepper
P. praetermissa	
* *Rumex* sp.	Dock
PORTULACEAE	
Neopaxia australasica	White Purslane

PRIMULACEAE	
**Anagallis arvensis*	Scarlet Pimpernel
**Lysimachia vulgaris* var. *davurica*	
RANUNCULACEAE	
**Ranunculus flammula*	Buttercup
R. inundatus	River Buttercup
**R. repens*	Creeping Buttercup
ROSACEAE	
**Rubus discolor*	Blackberries, Brambles
RUBIACEAE	
Asperula cf. *gunnii*	Woodruff
Galium sp.	
SALICACEAE	
**Salix alba*	White Willow
**S. cinerea*	Grey Sallow
**S. fragilis*	Crack Willow
SCROPHULARIACEAE	
Gratiola peruviana	Brookline
Veronica gracilis	
Veronica sp. A	
VIOLACEAE	
Viola caleyana	Violet

Key
* introduced taxon (naturalised on swamp)
[A] R. Bates (pers. comm.)

Acknowledgement
Identifications were assisted by staff at the National Herbarium of New South Wales, Royal Botanic Gardens Sydney.

[1] Royal Botanic Gardens, Mrs Macquarie's Rd, Sydney NSW, 2000.
[2] School of Geography, University of New South Wales, Kensington NSW, 2033.

2001, Regards Phillip

Coast and Wetlands Society Inc. Newsletter No. 40 (1992), pp. 3-6.

Peat extraction threatens environmentally important swamps on the Southern Highlands

Phillip G. Kodela
School of Geography, University of New South Wales, Kensington, NSW, 2033

Recently there has been much debate over the continued extraction of peaty sediments and peat from Long Swamp near Penrose and from Wingecarribee Swamp between Moss Vale and Robertson. Long Swamp lies in a headwater of Paddys River and Wingecarribee Swamp is in the upper catchment of Wingecarribee River. Both rivers flow into the Wollondilly River which contributes to the Warragamba catchment area and they are part of the Hawkesbury-Nepean system. Wingecarribee Reservoir is also connected to the Shoalhaven system as it receives water pumped from the Shoalhaven River via the Fitzroy Falls Reservoir. Water from Wingecarribee Reservoir is released into Wingecarribee River or from the Glenquarry cut and Glenquarry Creek into the Nepean River.

Objections to peat mining based on the important ecological, hydrological and scientific values of Long Swamp, and peatlands or mires in general, were submitted to Wingecarribee Shire Council (the consent authority) by the Royal Botanic Gardens, National Trust, NSW National Parks & Wildlife Service, National Parks Association of NSW, The Hawkesbury River Environment Protection Society, Coast & Wetlands Society, Nature Conservation Council of NSW and various professional biologists and hydrologists.

Freshwater peatland ecosystems are not common in Australia and are important for the following reasons:

* Flora and fauna habitat. Swamps contain many specialised plant species, some being rare and only occurring in wetland habitats. Examples of rare species in the Moss Vale region include *Eucalyptus macarthurii* (Paddy's River Box or Camden Woollybutt), a rare species often occurring near streams and swamps and is at its southern limit of distribution at Paddys River; *Eucalyptus aquatica*, a vulnerable species "known only from a single stand on a broad swampy river flat near Penrose" (Johnson & Hill, 1990, page 56); and the endangered herb *Gentiana wingecarribiensis* which is only known to grow in restricted habitats on Wingecarribee Swamp (see Kodela, 1992b). If not directly affected by swamp sediment extraction or associated disturbances on the adjacent land, riverine and swamp species may be indirectly affected by altered water tables resulting from extraction processes elsewhere in the catchment.

* Biogeochemical and nutrient cycling.

* Protection of downstream water quality. Swamp sediments and their vegetation cover, together act as a natural filter that traps sediments, nutrients and heavy metals (including nutrients and chemicals from fertilizers and pesticides used in agriculture that can contribute to stream eutrophication [which stimulates algal blooms] and water pollution). Williams (1990, page 21) states "toxic residues from waste products, such as heavy metals, pesticides and herbicides, can be removed from water by ion exchange and absorption in the organic and clay sediments (in effect they become buried in the sediment) and by uptake by plants". The remaining Wingecarribee Swamp is a major filter for water draining from the surrounding slopes and upper catchment (containing improved pastures, cultivated fields, etc.) into Wingecarribee Reservior (a water supply for communities in the region). Waterplants such as *Phragmites australis* (Common Reed) and *Typha* (Cumbungi or Bulrush) are often very efficient in absorbing and accumulating nitrogen, phosphorus and other nutrients, and would play an important role in the ecosystem's capacity to remove excess nutrient inputs from the catchment (e.g. nutrients from nitrogenous and superphosphate fertilizers) (Roberts & Ganf, 1986; Hocking, 1989; Williams, 1990).

* Regulating streamflow. Peat and peaty sediments in upper catchment swamps act as natural sponges, absorbing water from rainfall, surface runoff and important groundwater sources. The swamps capture excessive water during heavy rainfall which helps to mitigate potential downstream erosion and the impacts of flooding by reducing peak flow discharge and velocity. Water is more slowly released from the sediments which helps maintain flows during dry periods (this can be an important supply of water during droughts).

* Carbon sinks. The burning or drying of peat releases carbon dioxide which contributes to the Greenhouse Effect (Adam, 1992).

* Potential sites for palaeoecological, archaeological and other scientific research. Swamp sediments have great potential for the study of long-term vegetation dynamics and past environmental changes. This is because sediments record their own development and a history of the environment in which they developed. We can elucidate environmental changes and processes by studying the fossil pollen and charcoal records, the stratigraphy, mineralogy, mineral magnetics, chemical composition and plant macrofossils etc. of the sediments (see Kodela, 1992a). Hope & Southern (1983, page 89) state "The peatlands of the Southern Tablelands provide opportunities for ecological and palaeoenvironmental research which cannot be matched elsewhere in New South Wales". "Past environmental analogues are useful in showing rates of change, differential rates of response, and magnitudes of change" (De Deckker *et al.*, 1988, page 473). Scientists are now looking at environmental changes during the last period of climatic warming which began some 15,000 years ago (at the end of the last glacial) to provide insights into the possible future impacts of the global Greenhouse Effect. Suitable sites for this type of study are few in Australia.

* Socio-economic benefits gained from erosion control, flood mitigation, water quality protection and other natural functions of peatlands.

The Environmental Impact Study (EIS) for the proposed (continued) extraction of peat "compost" at Long Swamp does not fully consider the implications of degrading the swamp ecosystem. The technical argument that the sediments extracted from Long Swamp are not true peat does not reduce the Swamp's habitat values or hydrological functions as a type of peatland. Regardless of the definition of peat (which varies widely) the swamp sediments are still part of a mire ecosystem that plays an important role in the regional hydrology.

A lowered water table caused by sediment extraction often has adverse impacts in the catchment upstream of the development. Lowering the base level can initiate streambank erosion and gullying upstream by creating a "headcut" or lowered "nickpoint" (i.e. progressive stream degradation and instability in the catchment as the stream adjusts to a new base level).

The botanist who investigated the Long Swamp site described organic-rich sediments and natural plant communities that would have taken a very long period of time to develop and are comparable to other upland swamps in the tableland region that are thousands of years old. The peaty sediments and the cover of dense sedgeland and Tea Tree scrub contribute to an important ecosystem that functions to regulate water quality and flows for the catchment. It is unlikely that this system is around 80 years old (as claimed by the landowner) when similar swamps in the region, some of the most important to science and wildlife conservation in NSW, have basal sediments radiocarbon dated to 3000 years old, and often much older. The depth, extent and high organic (peaty silt) nature of the Long Swamp sediments, as well as the established swamp plant communities suggest that deposition occurred over a very long period of time (probably thousands of years) in a low energy environment.

The Long Swamp EIS mainly assesses the flora and fauna in the area on the grounds of whether there are rare or endangered species, overstressing that no rare species were recorded in the surveys. This approach is highly undesirable as plants and animals interact with their environment and thus an ecosystem or community approach to impact assessment is much more acceptable. For example, other factors to be considered include community structure and uniqueness, species diversity and specialisation, as well as the interdependent roles plants and animals play in ecosystem and environmental processes. The natural swamp vegetation is not composed of "choking weeds" (as described in Volume 2 of the EIS), but plays an important role in the ecosystem's hydrological functions as discussed above. The wetland vegetation is also part of a wildlife corridor, and this moist environment may be an important refuge for fauna in times of drought. Flora and fauna surveys need to be carried out over longer periods of time and in all seasons. Small plant species can also be easily missed in the dense swamp vegetation cover, and many monocots are difficult to identify when not flowering or fruiting. Rare and uncommon plant species are known from similar swamps in the region, and could yet be found at Long Swamp after more intensive surveys.

The EIS suggests that removing sediments from part of the swamp (about 80,000 cubic metres over 8 years) and creating an open waterway will "enhance" the environment. The EIS also claims "no significant environmental impact of the proposed development has been assessed". These views ignore the habitat values and hydrological functions of the natural (pre-excavated) swamp ecosystem. Fragmenting an upper catchment "peat" swamp like Long Swamp will reduce its effectiveness and efficiency to function as a natural system interacting with the hydrological cycle to filter and regulate water supply in the larger catchment. It is important to view these systems with the total catchment approach. Long Swamp helps maintain ecosystems and agricultural systems downstream.

At Wingecarribee Swamp the effluent water discharged from the peat extraction and processing operation is high in suspended organic particulate matter and is more acidic. Acidification of streams can threaten native and recreational fish and crustaceans by causing pH shock, increasing the potential for Aluminium toxicity, etc. (Cox, undated; Woodward *et al.*, 1991; Carline *et al.*, 1992). Peat mining on Wingecarribee Swamp also threatens the water quality of Wingecarribee Reservoir as a major water supply for the region by reducing the capacity and efficiency of the peatland to act as a natural filter for the catchment water supply, and by direct pollution from the operation's effluent water, as well as from potential fuel leaks, etc.

Peat extraction is not a sustainable industry when considering the length of time it has taken for these deposits to accumulate. Alternatives to peat for horticultural purposes include compost blends using coconut fibre (coir), composted bark, woodfibre, sawdust, timber residue mixes, recycled mushroom compost, rice hulls, straw, pumice, perlite, vermiculite, sand, farm waste mix, sewage sludge etc.. Trials using many of these materials (including propagation and potting compost mixes) have been positive, with results often comparable with, and sometimes better than, using peat. For example, "trials showed that good quality commercial crops of forced [bulbs of] narcissus 'Carlton' and tulip 'Golden Apeldoorn' could be grown in bark/wood fibre, with cropping dates, stem length and quality similar to standard peat substrates. Most interestingly, less *Penicillium* infection was recorded on the tulips" (Ellis, 1992, page 28). Rooting of cuttings and root vigour have also shown good results. Handreck (1991, page 17) claims Australia's best pine bark-based mixes are superior in many aspects to European peat mixes and "the disease-suppressive properties of media based on composts are in contrast to the often disease-conducive nature of peats - particularly the black, more highly decomposed ones". Recycling waste- and by-products (e.g. organic materials from local timber and farm industries) will help reduce problems with waste disposal (e.g. land-fill), will create jobs and set us on track towards a more sustainable future. We need to weigh the short-term economic gains against the long-term (and possibly more costly) adverse environmental impacts of peat mining. Environmentally conscious people are all to often labelled as "greenies" in an attempt to dismiss their efforts towards more sensible management of the environment and its limited resources. Society must consider viable options for sustainable development, rather than degrading natural ecosystems, for our very survival.

With the increased awareness of the values of wetlands it is unfortunate that they are still threatened from mining, dam flooding, excessive burning by humans and drainage for agriculture and development. There is an international movement towards the use of peat substitutes and the conservation of remaining peatlands. In Australia the extraction of peat and peat-like sediments should ideally be phased out, with peat being replaced by more environmentally sound and sustainable materials.

Acknowledgements

This article is largely based on my paper that was recently published in *Eucryphia* No. 7 (Newsletter of the Robertson Environment Protection Society). I am very grateful to many people for discussions and advice on wetlands. These authorities included members of the University of NSW Schools of Geography & Biological Sciences, Royal Botanic Gardens (botanical, ecological & horticultural experts), NSW National Parks & Wildlife Service, Department of Water Resources, Water Board, Environment Protection Authority and the National Trust. I also thank my friends and various professional and environmental conservation societies for their support.

Bibliography and Further Reading

Adam, P. (1992). The problems with peat. *Native Plants for New South Wales* 27(1): 28-29. [reprinted from the June 1991 issue of *Nature Conservation News*, published by the Nature Conservation Council].

Adams, L.G. & Williams, J.B. (1988). *Gentiana* sect. *Chondrophyllae* (Gentianaceae) in Australia. *Telopea* 3: 167-176.

Atkins, P. (1991). Peat and the gardener. Part I [why large-scale use of peat threatens UK's lowland bogs]. *The Garden* 116(1): 10-13.

Beers, A.R. & Getz, T.J. (1992). Composting biosolids saves $3.3 million in landfill costs. *BioCycle** 33(5): 42, 76-77.

Briggs, J.D. & Leigh, J.H. (1988). Rare or Threatened Australian Plants. *Special Publication* No. 14, Australian National Parks & Wildlife Service, Canberra.

Briggs, S.V. (1981). Freshwater wetlands. In: R.H. Groves (editor), *Australian Vegetation*. Cambridge University Press, Cambridge.

Butler, G. (1992). Cocopeat - A viable alternative to peat moss?. *Society for Growing Australian Plants (Canberra Region Inc.) Journal* 9(5): 19.

Carline, R.F., Sharpe, W.E. & Gagen, C.J. (1992). Changes in fish communities and trout management in response to acidification of streams in Pennsylvania. *Fisheries* 17(1): 33-38.

Coghlan, A. (1992). Britain backs coconut composts. *New Scientist* 133(1814): 18.

Cox, G.F. (undated). The toxicity of Aluminium to fishes. *Aquarium Life, Australia* 2(3): 35-36.

Creagh, C. (1992). What can be done about toxic algal blooms?. *Ecos* 72 (winter): 14-19.

De Deckker, P., Kershaw, A.P. & Williams, M.A.J. (1988). Past environmental analogues. In: G.I. Pearman (editor), *Greenhouse - Planning for Climatic Change*. CSIRO, Melbourne. pp. 473-488.

Ellis, G. (1992). There can be life after peat. *Horticulture Week* 211(20): 28-29.

Goldstein, N. (1992): Building the infrastructure for sludge reuse. *BioCycle* 33(3): 58-62.

Goldstein, N. (1992). Composting the commercial organic stream. *BioCycle* 33(5): 46-52.

Good, R.E., Whigham, D.F. & Simpson, R.L. (editors) (1978). *Freshwater Wetlands: Ecological Processes and Management Potential.* Academic Press, New York.

Gore, A.J.P. (editor) (1983). *Ecosystems of the World. Volumes 4A & 4B, Mires: Swamp, Bog, Fen and Moor.* Elsevier Scientific, Amsterdam.

Greeson, P.E., Clark, J.R. & Clark, J.B. (editors) (1979). *Wetland Functions and Value: The State of Our Understanding.* Minneapolis, MN: Water Resources Association Technical Publication.

Haigh, C. (editor) (undated). Wetlands in New South Wales. *Parks and Wildlife*, a series published by NSW National Parks & Wildlife Service, Sydney.

Handreck, K. (1991). What will happen to European peat? *Australian Horticulture* 89(2): 16-17.

Handreck, K.A. & Black, N.D. (1984). *Growing Media for Ornamental Plants and Turf.* New South Wales University Press, Kensington.

Hocking, P.J. (1989). Seasonal dynamics of production, and nutrient accumulation and cycling by *Phragmites australis* (Cav.) Trin. ex Struedel in a nutrient-enriched swamp in inland Australia. I. Whole Plants. *Australian Journal of Marine and Freshwater Research* 40: 421-444. (Part II. Individual shoots, pp. 445-464).

Hope, G.S. & Southern, W. (1983). *Organic Deposits of the Southern Tablelands Region, New South Wales.* National Parks & Wildlife Service of NSW, Sydney.

Jones, B.J. (1992). Composting food and vegetative waste. *BioCycle* 33(3): 69-71.

Kodela, P.G. (1992a). Rainforest, pollen and palaeoecological studies in the Robertson area. *Eucryphia* No.5: 5-8.

Kodela, P.G. (1992b). Native vegetation remnants and notes on some rare and locally significant plant species in the Robertson area, New South Wales. *Eucryphia* No. 6: 6-9.

Johnson, L.A.S. & Hill, K.D. (1990). New taxa and combinations in *Eucalyptus* and *Angophora* (Myrtaceae). *Telopea* 4: 37-108.

LaGasse, R.C. (1992). Marketing organic soil products. *BioCycle* 33(3): 30-33.

Legoe, G.M. (1981). Peat and Peatlands: A Summary of Research and Literature. *National Parks and Wildlife Service of NSW Occasional Paper* No. 3.

Macphail, M.K. & Hope, G.S. (1984/1985). Late Holocene mire development in montane southeastern Australia: a sensitive climatic indicator. *Search* 15: 344-348.

McComb, A.J. & Lake, P.S. (editors) (1988). *The Conservation of Australian Wetlands.* Surrey Beatty & Sons, Chipping North.

Melville, M.D. & Fitzpatrick, E.A. (1983). Some hydrological characteristics of the sandstone plateau near Barren Grounds, N.S.W. In: R.W. Young & G.C. Nanson (editors), *Aspects of Australian Sandstone Landscapes.* Australian and New Zealand Geomorphology Group, Wollongong. pp. 39-47.

Moore, P.D. (1986). Hydrological changes in mires. In: B.E. Berglund (editor), *Handbook of Holocene Palaeoecology and Palaeohydrology.* John Wiley & Sons, Chichester. pp. 91-107.

Moore, P.D. & Bellamy, D.J. (1973). *Peatlands.* Elek Science, London.

Morris, J.T. (1991). Effects of nitrogen loading on wetland ecosystems with particular reference to atmospheric deposition. *Annual Review of Ecology and Systematics* 22: 257-279.

Nolan & Associates (1992). Environment Impact Statement. Peat Compost Extraction and Processing, Paddy's River, New South Wales. Nolan & Associates, Bowral. [3 volumes].

Pollock, M. (1991). Peat and the gardener. Part II [report on the alternatives on trial at Wisley]. *The Gardener* 116(1): 13-15.

Roberts, J. & Ganf, G.G. (1986). Annual production of *Typha orientalis* Presl. in inland Australia. *Australian Journal of Marine and Freshwater Research* 37: 659-668.

Soil Conservation Service of N.S.W. (1976). *Land Capability Study: Wingecarribee Dam and Fitzroy Falls Dam Catchment Areas.* Soil Conservation Service of N.S.W., Sydney.

Spencer, R. (1992). Sludge composting takes town out of the landfill. *BioCycle* 33(1): 52-54.

Williams, M. (editor) (1990). *Wetlands: A Threatened Landscape.* Basil Blackwell, Oxford.

Williams, M. (1990). Understanding wetlands. In: M. Williams (editor), *op. cit.*, pp. 1-41.

Woodward, D.F., Farag, A.M., Little, E.E., Steadman, B. & Yancik, R. (1991). Sensitivity of Greenback Cutthroat Trout to acidic pH and elevated Aluminium. *Transactions of the American Fisheries Society* 120: 34-42.

Young, A.R.M. (1986). Quaternary sedimentation on the Woronora Plateau and its implications for climatic change. *Australian Geographer* 17: 1-15.

**BioCycle* is an American journal on waste recycling with many articles on the practicle and economic side of composting and recycling residential (e.g. household organics), commercial, farm and industrial waste, as well as sewage sludge.

Sydney
WATER

Wingecarribee Swamp

Plan of Management

November 1995

Community Input

Sydney Water, in conjunction with the National Parks and Wildlife Service, has developed a Draft Plan of Management for Wingecarribee Swamp and the 15 metre wide Special Area surrounding Wingecarribee Reservoir. The Plan is designed to protect the water quality in the reservoir, while ensuring that the significant wetland ecosystem within the swamp is adequately managed and safeguarded.

This brochure has been prepared to provide you with more information on the role and environmental significance of Wingecarribee Swamp and the Special Area.

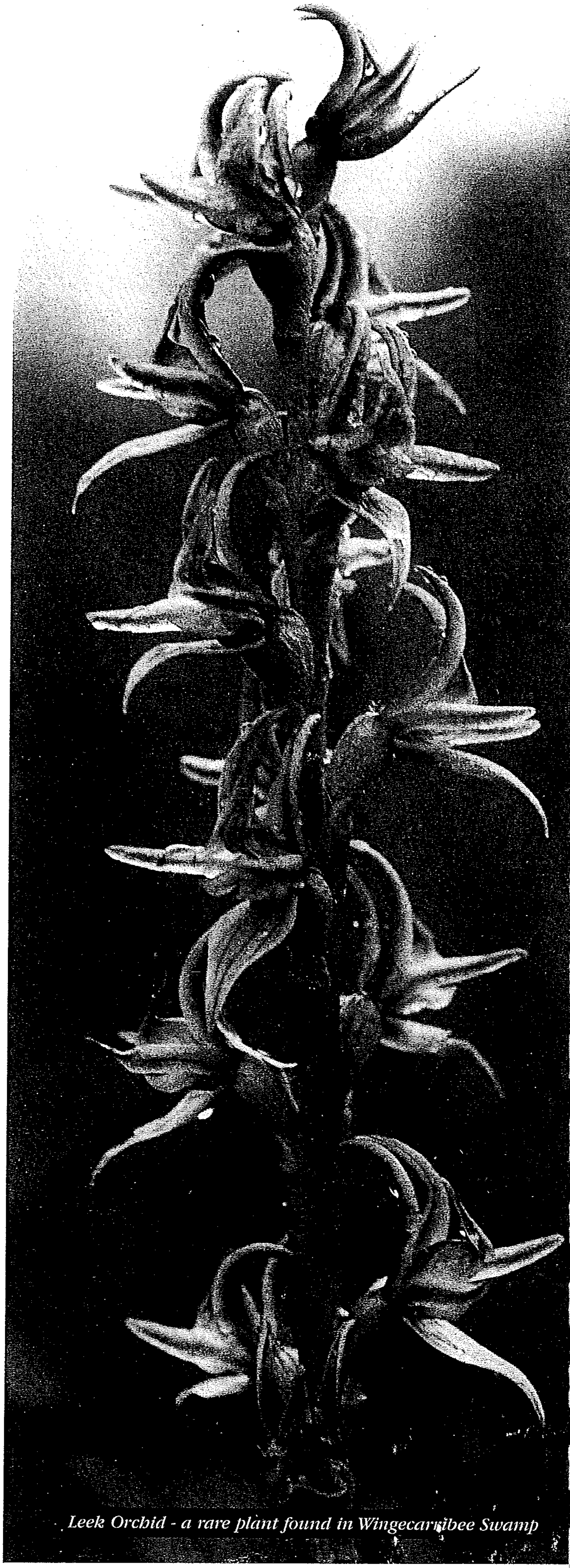
Sydney Water is actively seeking community input to the development of the Plan of Management.

We want to hear your views.

Location

Wingecarribee Swamp is owned by Sydney Water Corporation and is located about 100 kilometres south west of Sydney in the Southern Highlands of New South Wales. About 680 metres above sea level, the swamp extends over an area of 690 hectares, half of which is covered by Wingecarribee Reservoir.

The swamp lies in the gently sloping upper catchment valley of the Wingecarribee River and forms a large part of the immediate catchment of Wingecarribee Reservoir. The reservoir is used to supply water to Wingecarribee Shire and for bulk water transfers to Sydney and Wollongong during drought, via Warragamba and Nepean Dams.

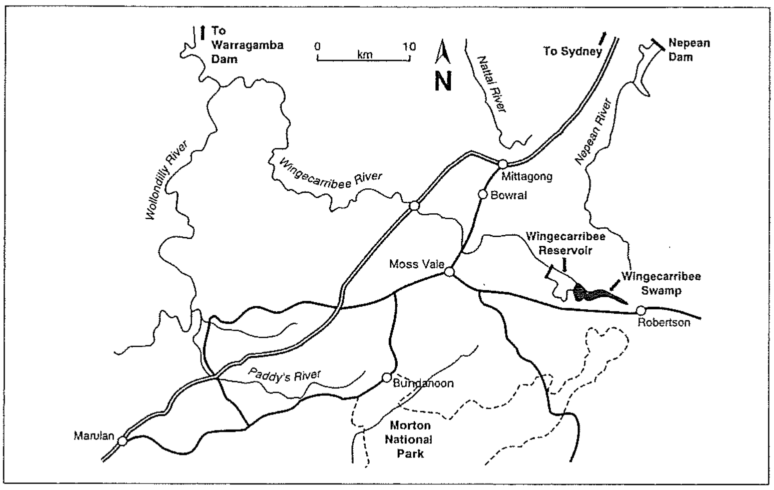


Leek Orchid - a rare plant found in Wingecarribee Swamp

A fen or a bog - or both?

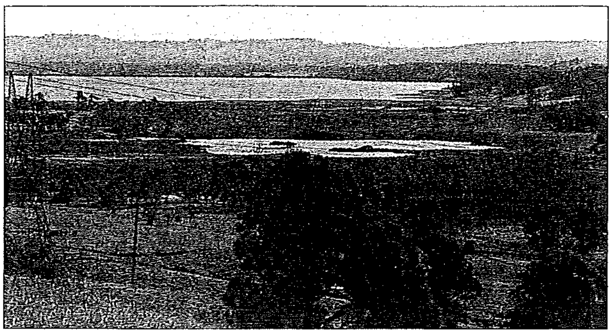
A fen is a wetland that develops on mineral-rich waterlogged soils and is maintained by groundwater and surface runoff but has little or no surface water. Wingecarribee Swamp is one of only a few upland fens found in mainland Australia. Typical fen vegetation, which is dominated by sedges and rushes, is found at Wingecarribee.

In some parts of the swamp, bog conditions have developed. A bog is a wetland type that develops under more acidic and mineral poor conditions than a fen and surface water is usually present.



The conditions which led to the development of fen and bog conditions have also resulted in the formation of peat. Wingecarribee Swamp contains the largest peat deposit in Australia. The average depth of peat is three metres and up to ten metres of peat occurs in some areas. Peat has been extracted from Wingecarribee Swamp for about 20 years.

Management issues for the swamp and its environment include draining, fire, grazing, weed invasion and feral animals.



Wingecarribee Reservoir with Wingecarribee Swamp in foreground

Water quality and quantity

Upland swamps of this type have significant beneficial effects on downstream water quality and flow characteristics. The catchment of the swamp is mostly agricultural land used for dairy farming and grazing. Part of the urban area of Robertson also drains to the swamp.

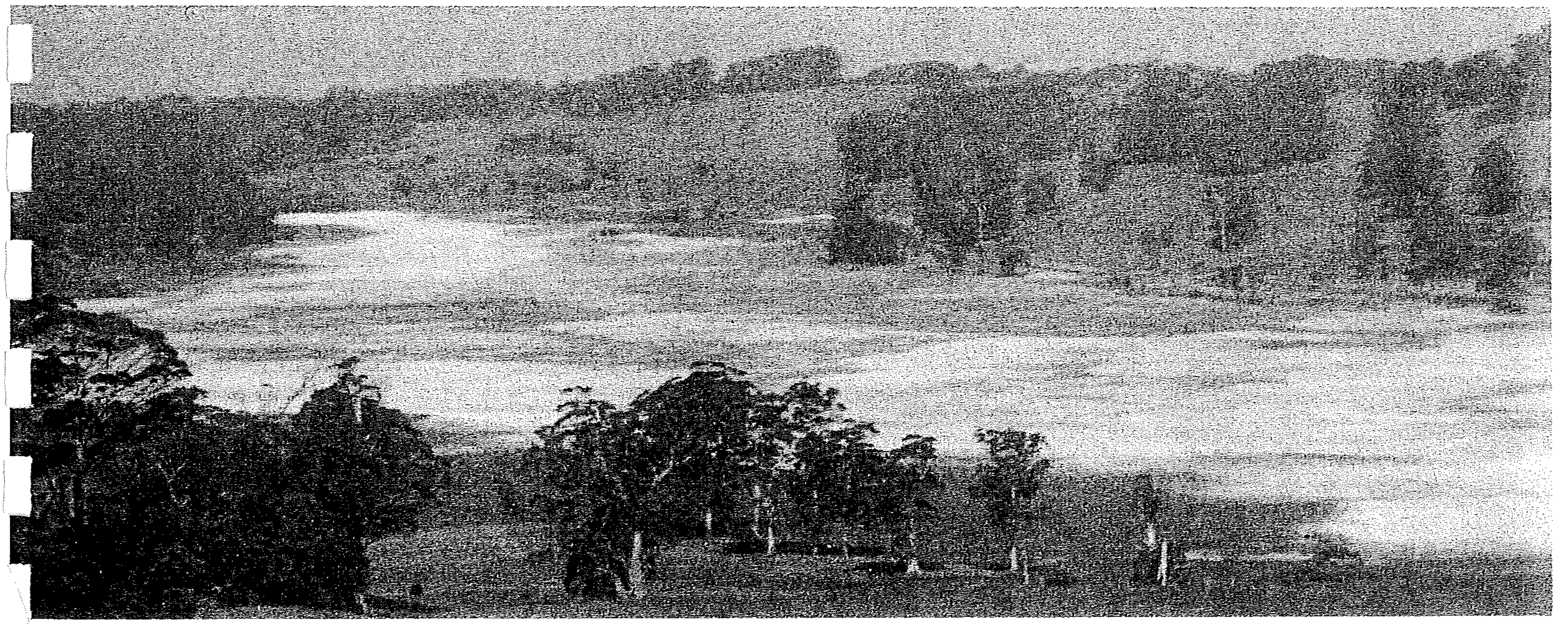
Both areas produce nutrient and bacterial contamination of the rain-water run-off. Sediment, pollutants and nutrients are filtered from water flowing through the organic matter and its mantle of plants. Consequently, water flowing out of the swamp is of better quality than that which went into it, making the swamp an important part of the supply of quality drinking water to Wingecarribee Shire.

The peaty material also buffers water flows by acting as a sponge, reducing flood peaks and releasing water during dry periods to maintain flows downstream.

Scientific research

The moist, anaerobic conditions in which the peatland formed, produced an excellent preservation medium for organic material.

Evidence preserved within the peat deposit, such as plant macrofossils and pollen, provide information on past climate, fire regimes and



vegetation and allows scientists to understand how the environment responds to changes in climatic conditions. Carbon dates, from 10 metres depth, indicate that the deposit is at least 15,000 years old, however, wood found in the area indicates that the river valley is between 35,000 to 40,000 years old.

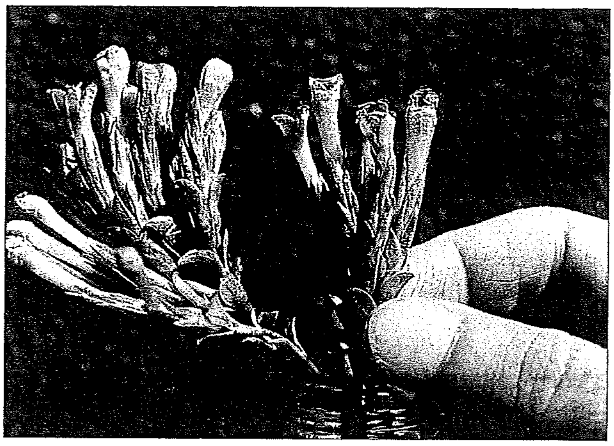
Wingecarribee Swamp is a habitat and refuge for swamp dependent communities and endangered species

Animals

A variety of bird, mammal, reptile, amphibian and invertebrate species can be found within the swamp. It is likely that many habitats offered by the swamp provide an unknown number of species with their last refuge within the catchment, particularly as the swamp is now isolated from the forests that once bordered it.

Wildlife in Wingecarribee Swamp

Petalura gigantea, one of the rarest dragonflies in NSW, was last sighted at Wingecarribee Swamp in 1974. The adults are rarely seen but are amongst the world's largest dragonflies. Although not recorded since 1941, it is also possible that the rare *Litoria aurea* (Green and Golden Bell Frog) still lives in the area.



Gentian (Gentiana Wingecarribiensis)

Plants

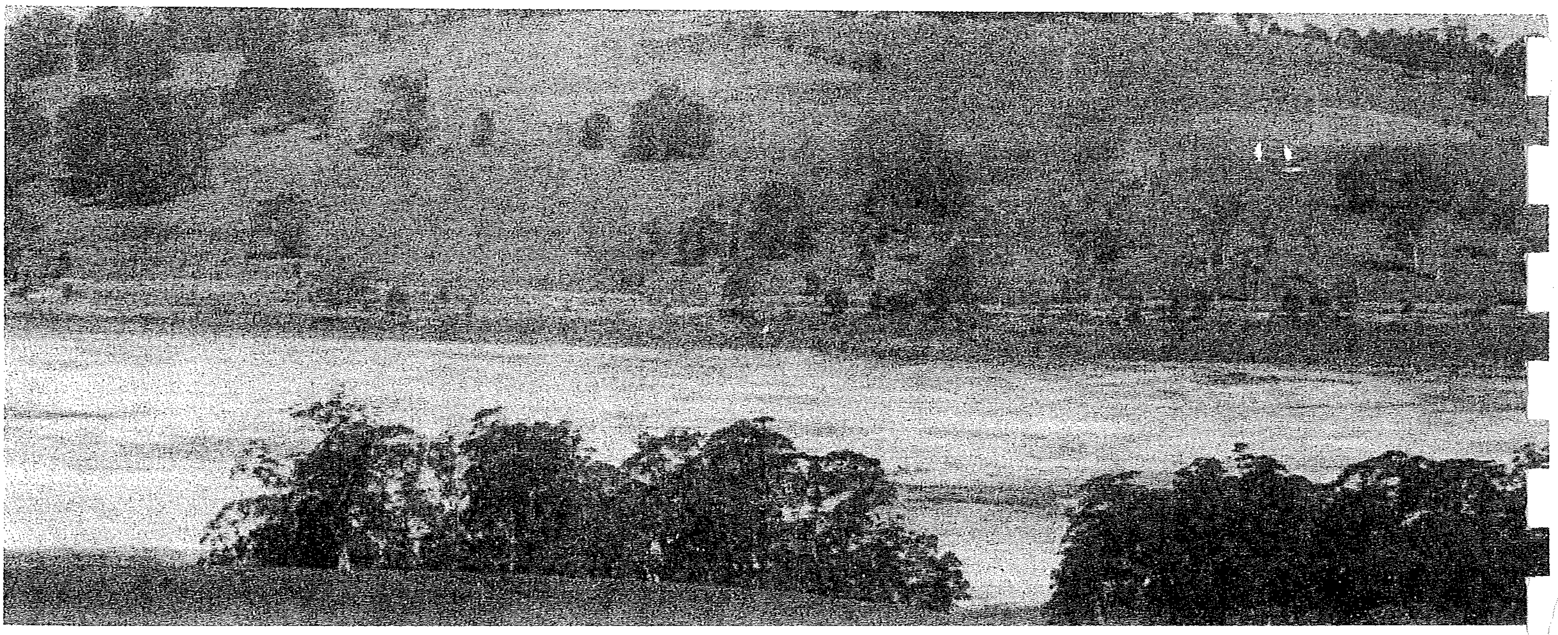
The vegetation is diverse and ranges from mosses, ferns, aquatic plants and rushes, to tea-trees and two species of *Eucalyptus*. The plant associations of the Swamp and its catchment are limited in distribution and are of high conservation value. Three rare plants which occur in Wingecarribee Swamp include *Prasophyllum uroglossum* (Leek Orchid), *Gentiana wingecarribiensis* (Gentian) and *Eucalyptus macarthurii* (Camden Woollybutt or Paddy's River Box).

Gentiana wingecarribiensis is a short-lived (annual) plant between 4 cm and 9 cm tall, with blue flowers. The species has only been found in Wingecarribee Swamp and Hanging Rock Swamp in the Southern Highlands.

The rare orchid *Prasophyllum uroglossum* is also only known to occur at Wingecarribee Swamp. Like the Gentian, *Prasophyllum uroglossum* survives most of the year in a dormant state underground, appearing above the ground in spring to reproduce.

Eucalyptus macarthurii (Camden Woollybutt or Paddy's River Box) grows on agricultural land around the swamp and reservoir. This species

View of Wingecarribee Swamp



Dairy cattle near Wingecarribee Swamp

has been classified as rare and inadequately reserved.

Unfortunately, alien grasses and other herbs have become naturalised in the swamp as a result of past and current land use practices.

Aboriginal Heritage

Wingecarribee Swamp is in the area traditionally occupied by the Wodi Wodi Aborigines. Based on the coast, their land included the present day Wollongong, Lake Illawarra and the north bank of the Shoalhaven River. Seven occupation sites have been located along 5.5 kilometres of undisturbed shoreline, excluding the area affected by peat mining. A further seven areas of potential archaeological deposit have also been identified. Evidence suggests that the swamp was an important focus of Aboriginal occupation and it is likely that cultural material is present below the surface in all relatively level locations around the swamp.

The Aboriginal words "Winge Karrabee" appear in early literature as "Wingie Wingie Charabie" meaning "flight of the birds" and "waters to rest beside".

European Heritage

The Southern Highlands were first occupied by John Oxley in 1816. Land grants around Wingecarribee Swamp began in the late 1830's. Most of the terrain was heavily forested and neither land values nor husbandry practices warranted the expense of clearance until the 1850's or 1860's. Up to this time, expansive pastoralism or large landholdings were common.

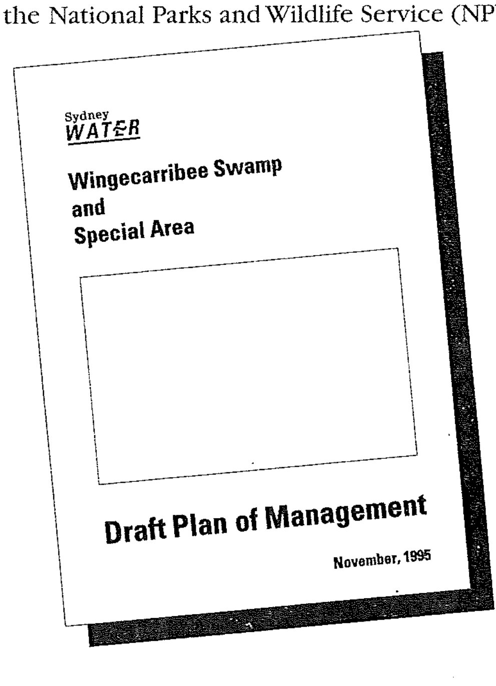
With the population increase partly stimulated by the gold rush in the 1850's, small farms and their intensive husbandry practices became economically viable. Most of the small dairy farms in existence today near Wingecarribee Swamp, began in this period.

Natural and Cultural Significance

The National Trust of Australia (NSW) has listed the Wingecarribee Swamp as a Landscape Conservation Area and the Australian Heritage Commission listed the swamp on the register of the National Estate on 15/5/95. The Wingecarribee Swamp is therefore recognised as an ecosystem and environment resource of local, state and national significance.

Plan of Management

To ensure that this significant wetland is adequately managed and protected and in compliance with the requirements of clause 5.23 of its Operating Licence, Sydney Water Corporation (Sydney Water), in conjunction with the National Parks and Wildlife Service (NPWS), has prepared the Wingecarribee Swamp and Special Area Plan of Management.



Key elements of the plan include:

- protecting and improving water quality and the area's ecological integrity through controls over cattle access, mining, weed and fire control, and
- allowing for further scientific research into the peat deposit and rare plants.

If you would like to obtain a copy of the Plan of Management, please write to:

Plan of Management
Wingecarribee Swamp
Sydney Water Corporation
PO Box 365
GUILDFORD NSW 2161
Fax: (02) 795 4363

Sydney Water Corporation Limited ACN 063 279 649

Kodela (1996) PhD UNSW

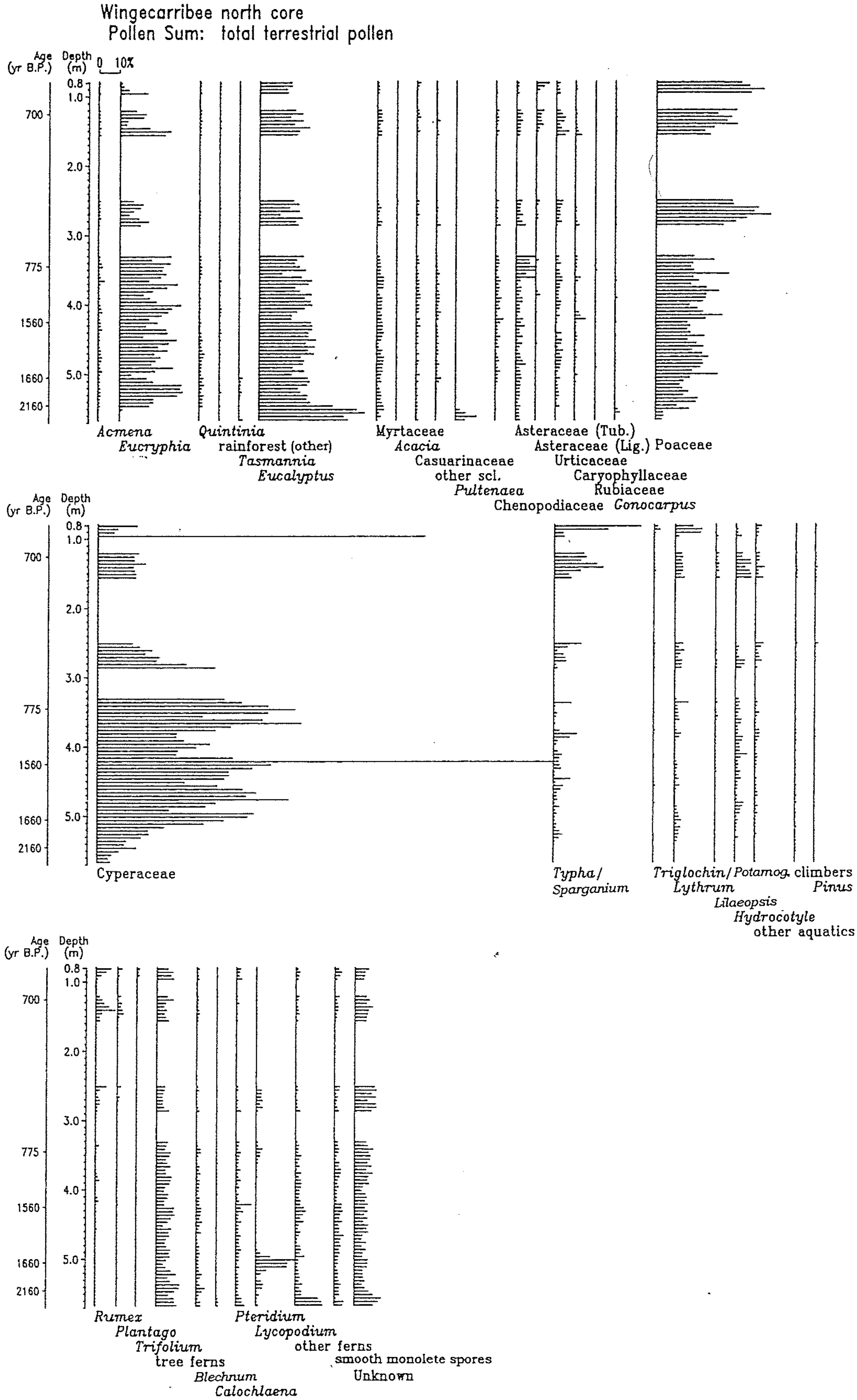


Figure 5.8 Pollen diagram for Wingecarribee Swamp core W_1.

The loss of Wingecarribee Swamp will go down in history as a classic example of our collective stupidity and inability to read the signs and take action.

WINGECARRIBEE SWAMP—GONE!

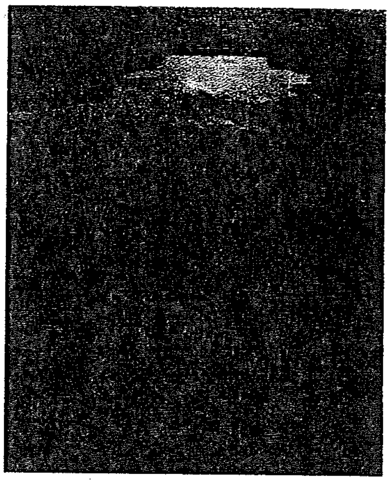
BY GEOFF SAINTY

WINGECARRIBEE Swamp—the largest montane peat swamp on the Australian mainland—is gone. Originally more than 500 hectares, she lay between Robertson and Moss Vale in the New South Wales Southern Highlands. For those who were privileged to see her and walk across her broad expanse, she was something special—even though signs of her demise were already obvious. She was loaded with history going back more than 20,000 years. She was a living entity. If you go there now, you will not believe your eyes.

When Europeans arrived in Botany Bay in 1788, the area surrounding this magnificent peatland was covered in rainforest. The fertile land was quickly cleared and subsequently used to grow potatoes and dairy cattle. From then on everyone took from her. Slices were cut through her surface to deflect water away from the fledgling peat-mining industry, to improve grazing and to supply water. In 1997 close inspection of her surface showed signs of drying, with blackberries and other dry-loving plants becoming common. The signs were there but no-one was watching. Then on 8 August 1998 a massive deluge took advantage of her weakened state.

The 20-hectare, four-metre-deep pool—created by mining peat from the swamp—had recently been enlarged following approval to harvest a further seven hectares of peat. This extension accelerated drying of the peat on the upstream edge of the pool and so, when the heavy rains came, huge chunks of peat broke away and floated to the downstream edge, forming a temporary dam. Eventually the force of the rising water became so great that it ripped through the barrier, taking with it a dredging machine and cutting a five-metre-deep channel through the peat. Thereafter large areas of peat became undermined

PHOTOS: SKYCAM, COURTESY GEOFF SAINTY



Top: Wingecarribee Swamp as it used to be when viewed from the south, showing the extent of the peat area. Wingecarribee Dam, part of Sydney's water supply, can be seen at the bottom left edge of the photo and the peat-mining area is visible as the waterhole in the top right. Bottom: Taken above the peat-mining area and looking west towards the dam, this picture shows the area that was once Wingecarribee Swamp. The peat-mining waterhole is now filled in and the dam is filled with the mud, soil and dead organisms that once made up the swamp. A creek now cuts through the centre and the lines on either side are crevasses about two to three metres deep.

and floated downstream into Wingecarribee Dam. The before and after photographs show it all.

So who is to blame? All of us really, but particularly the mining process for digging that gaping hole in her guts and destabilising her. Others, too, for cutting drains through her and setting the drying process in motion. Farmers for planting pasture species in the peat, further hastening the drying process. Residents and land holders for enriching her when she did not want the nutrients. All of us for knowingly and unknowingly introducing exotic weeds to the area. Sydney Water (the builders of Wingecarribee Dam) for drowning more than 100 hectares of peat on her western flank and, as landlords, for failing to spend any money on her welfare—even though she provided a priceless water-cleaning facility. The Environment Protection Authority and Department of Land and Water Conservation for not comprehending the critical state she was in—they now have to deal with the coffee-coloured water flowing down the Wingecarribee River into Sydney's water supply. And National Parks, which, rather than focussing on the big picture, dillydallied on single rare-species issues, including one plant (Yellow Loosestrife, *Lysimachia vulgaris*) that is far from endangered and possibly an introduced weed!

Then there are those who approved the seven-hectare extension to the peat-mining pool, accelerating her destruction; the State mining authority for believing you could continue to mine her and get away with it; and those consultants and scientists who, by being paid to concentrate on isolated issues, failed to report the obvious desperate state she was in. They all to varying degrees helped in her death.

The loss of Wingecarribee Swamp is a disaster of monumental proportions. It will go down in history as a classic example of our collective stupidity and inability to read the signs and take action. There must be a full inquiry into who said what about her welfare—who flannelled the truth—so that the uninvolved public can see how environmental care and science is lost in the quest for dollars.

Wingecarribee Swamp cannot be restored; small bits may survive, but most of it is now subject to desiccation and death.

The maelstrom as she broke up (and the more than two million cubic metres of her body as it was washed into Wingecarribee Dam) must have been a sight to see. Although she went out with a bang, she did it in style, under the cover of rain and mist, with no-one there to witness her last stand. ■

Geoff Sainty is a wetlands consultant working in Sydney. He has worked on wetlands since 1961, and is co-author of Waterplants of NSW *(1981) and* Waterplants in Australia *(1994).*

The Last Word is an opinion piece and does not necessarily reflect the views of the Australian Museum.

Late Holocene Fire History:
Human impacts and climate variability at Wingecarribee Swamp

Mistral de Montfort

Supervisor: Dr Scott Mooney

Honours thesis submitted in partial fulfilment of the requirements for the degree of

Bachelor of Environmental Science

School of Biological, Earth and Environmental Sciences,

Faculty of Science,

The University of New South Wales

November 2008

that has since been submerged by the filling of Wingecarribee Reservoir in the 1970s (*pers. comm.* Kelvin Lambkin, SCA). Significant fire seasons occurred in the region in the 1940s and 1960s (*pers. comm.* Ford Kristo, NPWS). The last fire occurred in August 1997 and burned only the surface vegetation of the swamp as the water table at this time was at the surface (*pers. comm.* Kelvin Lambkin, SCA). This fire took only 2 hours to burn across the swamp from west to east (*pers. comm.* Kelvin Lambkin, SCA).

History and land use

Wingecarribee Swamp lies within the tribal boundaries of the Wodi Wodi (Illawarra) language group, with Tharawal (or Dharawal) tribal boundaries to the north, and Gandangara (or Gundungarra) boundaries to the west (SCA 2007; Tindale 1974). Early observations in the late 1790s-1850s suggest that the region was permanently occupied by mobile family groups of the Gandangara and Wodi Wodi language groups (McDonald 2003). Archaeological evidence of occupation dates back to as early as around 5000 BP (Jaunzemis 1983). Evidence of occupation of the swamp dates to as late as 100 years after first European contact and suggests the main occupation phase began during the 'Middle Bondaian' era and has continued into the 'Late Bondaian', dating from about 1600 to 400 BP (McDonald 2003).

Settlement began in the Wingecarribee district around 1817-1818 (Cambage 1921). Grazing lands within the Eucalypt woodland and grassland areas around Mittagong, Bowral and Moss Vale were first occupied as these areas were easier to clear than the dense Yarrawa Brush surrounding Wingecarribee Swamp (Jaunzemis 1983). The swamp itself was first surveyed in 1830 when a bridle track was cut through the Yarrawa Brush from Bong Bong to the coast (Latham 1999). The *Crown Lands Act* 1861 allowed for the intensification of European settlement in the area, breaking trends of occupation by squatter-pastoralists and further displacing indigenous groups.

Prior to the 1970s the swamp covered an area of approximately 650 ha before the western half was submerged by the filling of Wingecarribee Reservoir in 1974 (Whinam *et al.* 2003). Small-scale peat mining began in the remaining 370 ha eastern part of the swamp, but production increased ten-fold by the mid 1990s (Whinam *et al.* 2003). Sydney Water (now SCA) acquired about 307 ha of the swampland in 1993 for water supply catchment protection and a joint Plan of Management for Wingecarribee Swamp and Special Area was prepared by SCA and the NPWS (National Parks and Wildlife Service) in December 1996 (Arachchi and Lambkin 1999). Peat mining continued and a dredge pool of approximately 20 ha had been excavated by the late 1990s (Arachchi and Lambkin 1999). A mining dredge came loose after heavy rainfall on the night of 8th August 1998 and was swept into Wingecarribee Reservoir, gouging a large channel through the swamp and resulting in a catastrophic collapse of the swamp surface (Arachchi and Lambkin 1999; Whinam *et al.* 2003). This resulted in an estimated 6000 megalitres of peat and sediment and 6500 megalitres of runoff water to flow into Wingecarribee Reservoir (Arachchi and Lambkin 1999; Whinam *et al.* 2003). Around 20% of the swamp lost its peat cover and eroded and another 60% has sunk approximately 3-4 m causing massive fissures and drying areas (Arachchi and Lambkin 1999). Since this collapse the swamp has been permanently altered and there are only two relatively intact areas covering approximately 62 ha (only 20% of the post-collapse swamp area) (SCA 2007). The collapse has increased the possibility of peat fires due to drying and has significantly reduced the swamp's filtering capacity (Arachchi and Lambkin 1999).

3. Methods

Five sediment cores were extracted from two different locations within Wingecarribee Swamp (Fig. 2) using a Russian D-Section corer (Jowsey 1966). Locations were selected to compare spatial differences in the fire record, but were limited to two sites by accessibility and the level of disturbance of the peat deposits (Fig. 2, SCA 2007). The impacts of mining activities and the collapse of Wingecarribee Swamp have left only two areas that remain relatively intact (SCA 2007). The W1 and W2 cores were extracted in 2005 and subsamples from W2 were submitted for Accelerator Mass Spectrometry radio carbon (AMS ^{14}C) dating. Dating analysis determined the age and rates of sediment deposition for W2 and dates have been described as calibrated radiocarbon years BP before AD 1950 (cal. yr BP). One of the aims of this study was to analyses the spatial variation between sites over the last 1000 years. It was estimated that cores of at least 125 cm depth would span approximately 1000 years and the W3, W4 and W5 cores were subsequently taken from the swamp in July 2008. The W3, W4 and W5 cores were described using a modification of the Troels-Smith method (Kershaw 1997).

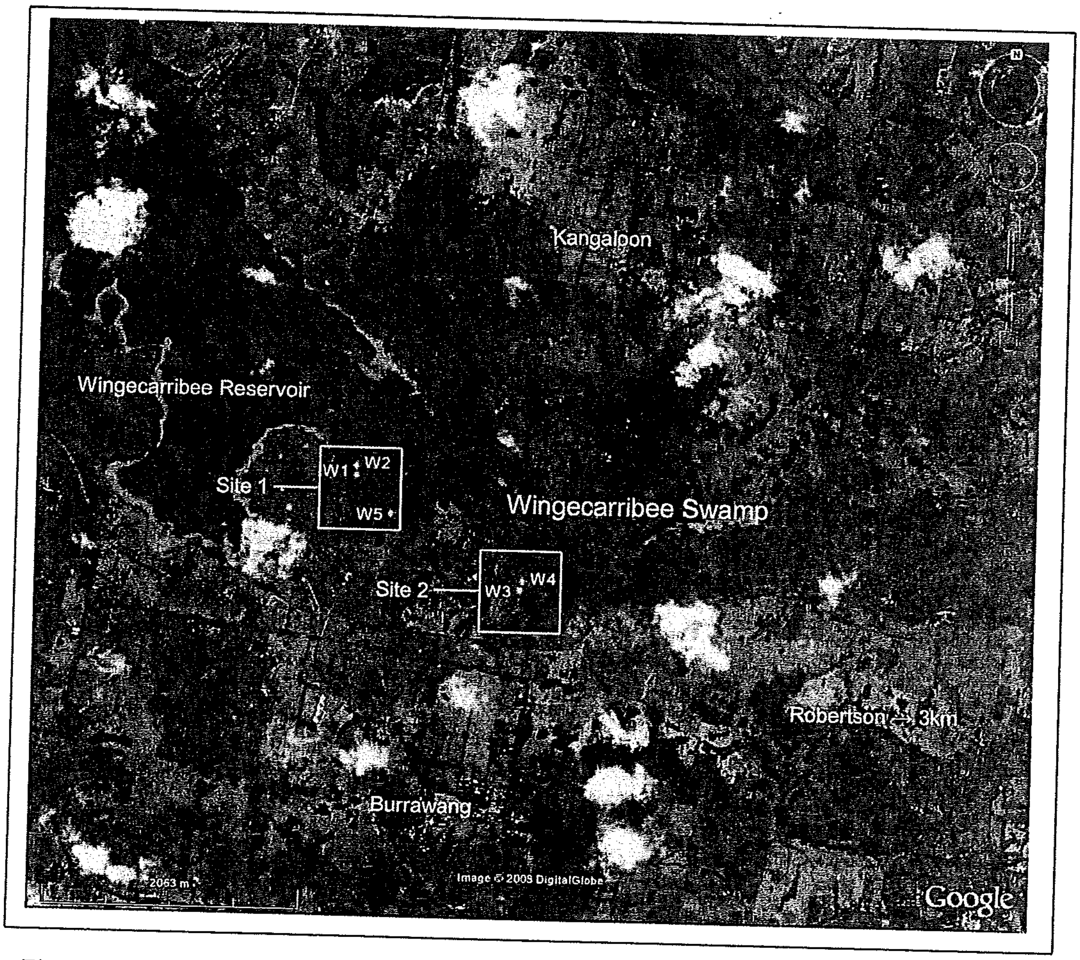


Figure 2: Core location map showing Sites 1 and 2 of Wingecarribee Swamp and cores W1, W2, W3, W4 and W5. Map created using Google Earth (2005).

Charcoal Analysis

Each core was subsampled at 1cm contiguous intervals and known volumes of sediment (1.5-2cm^3) were treated with dilute (4.2 %) sodium hypochlorite (bleach) for 24 hours to remove pigment from organic matter. The treated subsamples were washed through sieves of two different mesh diameters (125 μm and 250 μm) using a modification of the 'Oregon sieving method' (Long *et al.* 1998; Mooney and Radford 2001). This separated macroscopic charcoal particles of two different size classes, 125-250 μm and >250 μm.

Core Chronology

Results from Radiocarbon AMS ^{14}C dating are given in Table 1 and provide the basis for the age-depth model shown in Figure 5. Radiocarbon ages were calibrated to calendar years BP (cal. yr BP) using the computer program OxCal v3.10 and to calendar years (AD/BC) using Calib 5.0.2. Dates are standardised for comparisons with other palaeoecological and archaeological records as radiocarbon years begin at AD 1950. Dates obtained from the presence of *Pinus sp.* pollen in cores W3 and W4 fit in well with the age-depth model and are graphed with the AMS ^{14}C dates in Figure 5.

Table 1. AMS ^{14}C dating results for core W2 and *Pinus sp.* pollen age-depth relationships for cores W3 and W4.

Core (dating method)	Laboratory Number	Depth *range* (cm)	Depth *mid-point* (cm)	Radio-carbon Years BP (± error)	Calibrated ^{14}C Calendar Years BP *range*	Calibrated ^{14}C Calendar Years *midpoint*	Calibrated Calendar Years *range* (AD/BC)	Calibrated Calendar Years *midpoint* (AD/BC)
			0			-55	2005	2005
W2 (AMS ^{14}C)	Wk 23316	70-80	75	617 ± 36	520 to 650	585	1305 to 1362 and 1377 to 1428	1334
W2 (AMS ^{14}C)	Wk 23316	70-80	75	617 ± 36	520 to 650	585	1305 to 1362 and 1377 to 1428	1403
W2 (AMS ^{14}C)	Wk 23317	215-225	220	1721 ± 31	1510 to 1700	1605	315 to 438	377
W2 (AMS ^{14}C)	Wk 23318	350-360	355	2869 ± 31	2790 to 3040	2915	1056 to 890 BC	973 BC
W3 (*Pinus sp.* pollen)		24-25	25			80	1820 to 1920	1870
W4 (*Pinus sp.* pollen)		26-27	27			80	1820 to 1920	1870

Figure 8. Core comparison using standardised charcoal influx data (excludes the last 205 years). Solid vertical lines indicate charcoal influx phases.
* indicates new ages determined by the dated core W2.

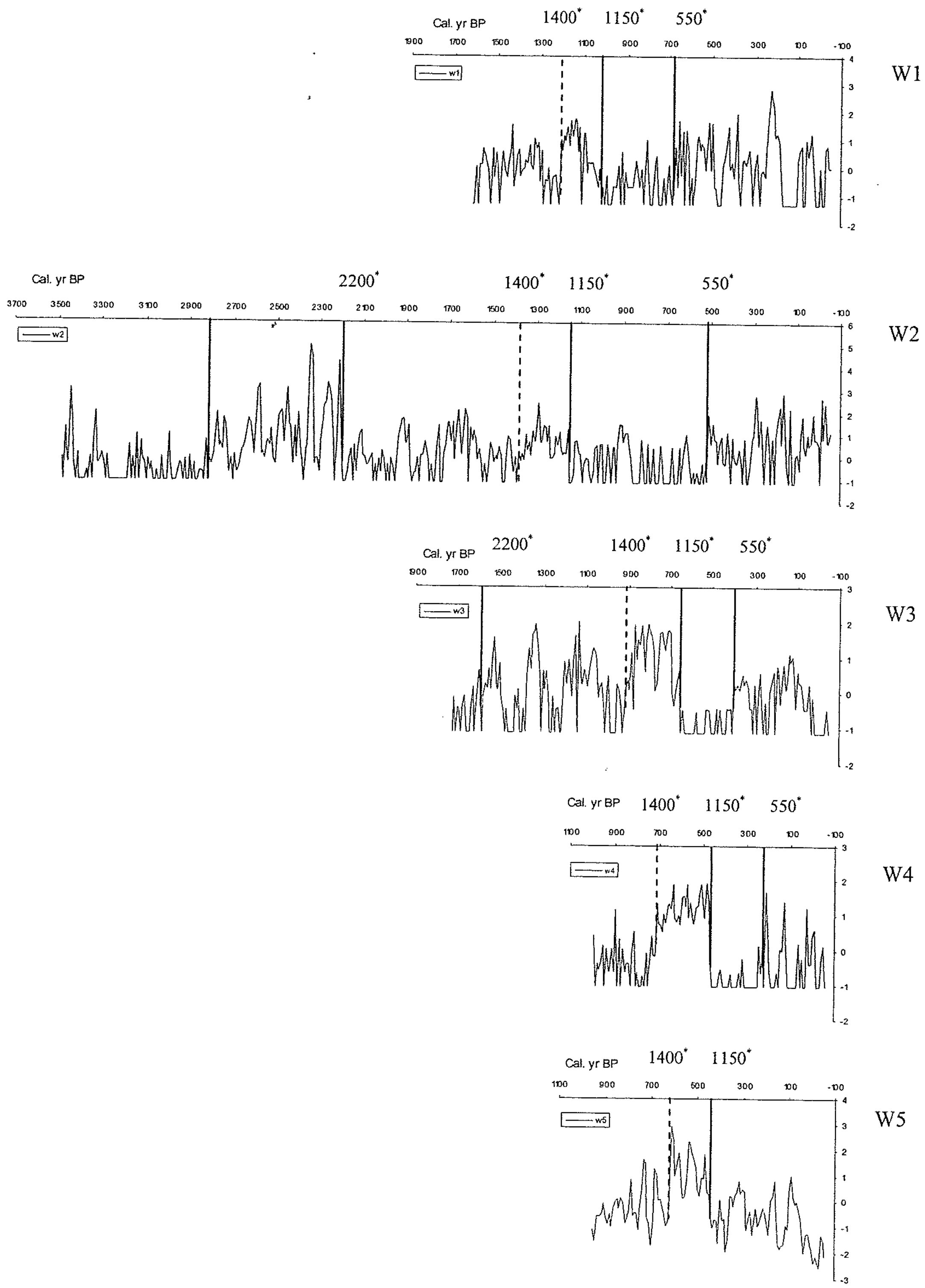


Figure 11. Fire frequency at W2 (where calib. Y BP is from AD 2005) v warm ENSO events (according to Moy *et al.* 2002)

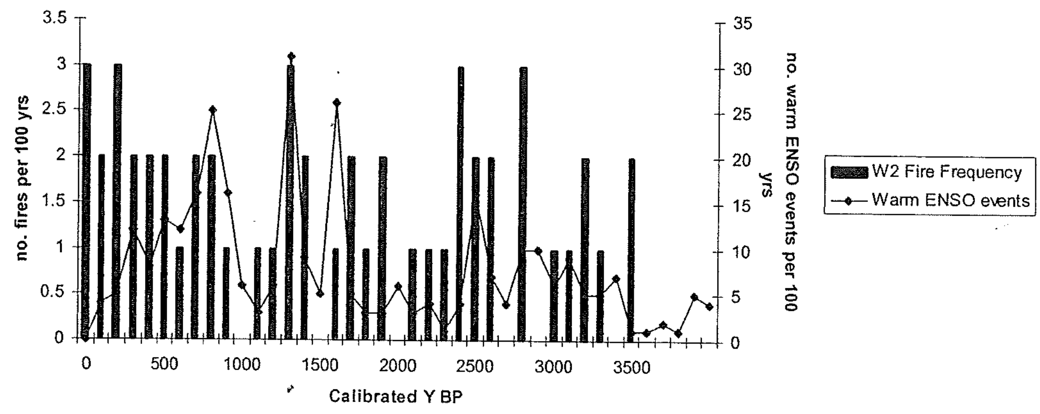


Table 2. El Niño activity according to Riedinger *et al.* (2002) from Bainbridge Crater Lake, Galápagos Islands.

	Strong/ Very Strong Events	Moderate Events
1000 BP-Present	36	5
2000-1000 BP	14	152
3000-2000 BP	30	29
4000-3000 BP	7	83
5000-4000 BP	9	4
6100-5000 BP	14	52