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

D.H. Benson

Abstract

Benson, D.H. (National Herbarium of New South Wales, Royal Botanic Gardens, Sydney, New South Wales, Australia 2000) 1992. The natural vegetation of the Penrith 1:100 000 map sheet. Cunninghamia *2(4) 541–596.* The composition and extent of the present natural vegetation on the Penrith 1:100 000 map sheet 9030 (lat. 33° 30' – 34° 00' S, long. 150° 30' – 151° 00' E) is mapped and described in terms of structure and characteristic species. Eighteen plant communities are recognised including tall open-forests, open-forests, woodlands and sedgelands. Vegetation patterns relate strongly to underlying geology with major groups of communities being restricted to either Wianamatta Shale, Tertiary alluvium, Holocene (Recent) alluvium or Hawkesbury Sandstone. Within these groups, patterns relate to rainfall gradients and soil drainage conditions. Comments are made on the adequacy of the major conservation reserves and botanically significant species are indicated. Conservation issues relate to different land uses on major geological types. Western Sydney's Cumberland Plain makes up the major part of the Penrith sheet; because of the suitability of its soils and terrain for agriculture and suburban development, very little of its vegetation remains and very little of this is conserved. Of 84 species regarded as having particular conservation significance in western Sydney, 44% were recorded in Cumberland Plain Woodlands and 36% in River-flat Forests (including freshwater wetlands), highlighting the need for better conservation of remnants of these vegetation types.

Introduction

'One immense tract of forest land extends, with little interruption, from below Windsor, on the Hawkesbury, to Appin a distance of 50 miles', wrote James Atkinson in 1826. Since then, this forest land has virtually disappeared, replaced by farms, factories and suburban estates. One hundred and sixty years later the few remnants of forest remaining still lack adequate long-term protection.

As part of the Sydney Region Vegetation Map Series, this paper describes the vegetation of the Penrith 1:100 000 map sheet area and, in particular, draws attention to how little remains of the vegetation of western Sydney.

Location, physiography and climate

The Penrith 1:100 000 Vegetation Sheet (based on the Penrith 1:100 000 Topographic Sheet 9030, AUSLIG, Canberra) is bounded by latitudes 33°30' and 34°00' S, and by longitudes 150°30' and 152°00' E. It covers the western region of Sydney extending from Parramatta westward to Springwood on the lower Blue Mountains, and from Kurrajong in the north to Bringelly in the south. This includes the central basin of the Cumberland Plain, which lies between Parramatta and the Blue Mountains, and extends from Richmond in the north to Picton in the south (Figure 1). This is gently

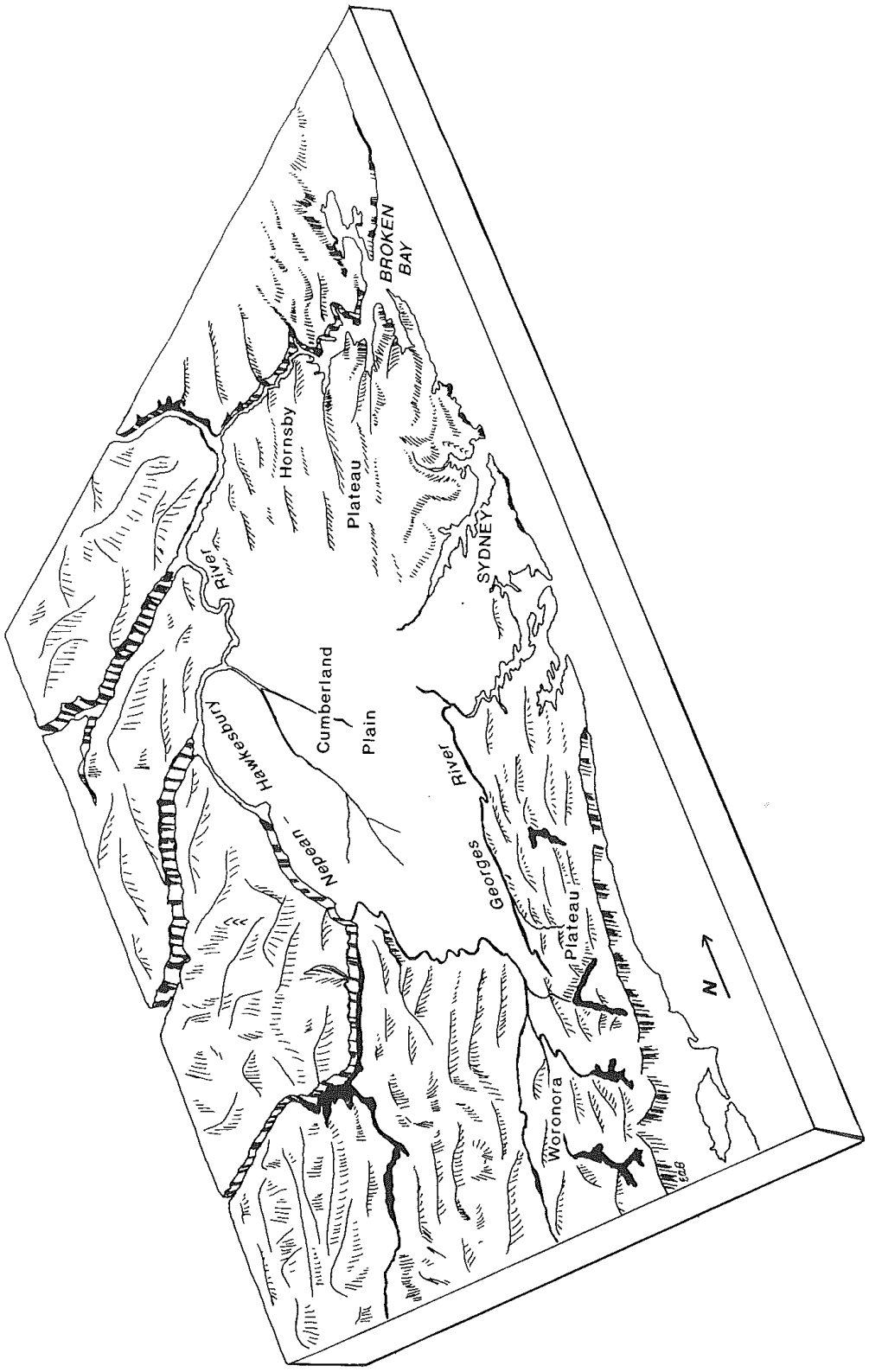


Figure 1. Block diagram of Sydney showing topography of the Penrith sheet area centred on the Cumberland Plain.

undulating to hilly country (altitude generally ranging from 20-100 m a.s.l.), on Triassic Wianamatta Group shale (New South Wales Department of Mines, 1966) and contrasts with the rugged Hawkesbury Sandstone of the lower Blue Mountains and coastal Sydney area.

The Cumberland Plain is bounded on the north and west by the Hawkesbury–Nepean River. Along this river and associated creeks (South Creek, Rickabys Creek, Eastern Creek), and the Georges River, are extensive alluvial deposits of Holocene (Recent) geological age. The largest deposits are on the floodplain of the Hawkesbury River, between Penrith and Windsor, and along the Nepean River near Camden. The fertile agricultural soils formed from these deposits were eagerly sought by the early European settlers who established farms near Windsor in the 1790s. As a result most of these areas are now completely cleared of native vegetation and indeed had probably been cleared by the 1830s.

Between Penrith and Windsor are older alluvial deposits of gravel, sand, silt and clay of mainly Tertiary age, deposited by an ancestral Hawkesbury–Nepean river system (Gobert 1978). Many of these deposits still retain their original natural vegetation though this is being destroyed by extensive sand, gravel and clay extraction and piecemeal suburban expansion.

Along the western edge of the Cumberland Plain, the lower Blue Mountains rise from about 200 m a.s.l. along the Lapstone Monocline at Glenbrook to 500 m at the western margin of the map sheet. They form a dissected plateau of Hawkesbury Sandstone of Triassic age but stratigraphically lower than the Wianamatta Shale which covers the downwarped Cumberland Plain. Remnant Wianamatta Shale cappings persist along the sandstone ridges followed by the Great Western Highway as far west as Faulconbridge and as far as Mt Tomah on the ridge followed by Bells Line of Road. Hawkesbury Sandstone borders the northern edge of the Cumberland Plain and occurs extensively between Annangrove and Cattai in the north-eastern corner of the Penrith Sheet and near the Georges River in the south-east corner. Many areas of Hawkesbury Sandstone still carry relatively undisturbed natural vegetation.

A number of volcanic outcrops (mostly diatremes) occur on the sheet area, though most have been cleared of native vegetation including the largest, at Prospect. Smaller uncleared outcrops are found in the Blue Mountains.

Soil landscapes of the Penrith sheet (Bannerman & Hazelton 1990) relate strongly to geology and can generally be associated with characteristic natural vegetation. Soils derived from Hawkesbury Sandstone are strongly acid. They are characteristically deficient in phosphate and are often locally deficient in nitrogen. Soils from the Wianamatta Group are strongly acid and intrinsically deficient in phosphorus, nitrogen and calcium.

Average annual rainfall on the Cumberland Plain is low. It is highest on the eastern edge (Parramatta 911 mm p.a.) and decreases westward (St Marys 759 mm, Windsor 757 mm, Bringelly 760 mm p.a.), increasing again with the rising elevation of the Blue Mountains (Faulconbridge 1 150 mm, Bilpin 1 300 mm p.a.). Mean maximum temperatures for January are 28–29°C for most of the sheet (e.g. Parramatta 28.1°C). The highest maximum temperature recorded for Parramatta is 46.3°C. Mean temperatures for July are highest on the eastern side (Parramatta 4.5°C) and decrease westward (Richmond 3.6°C). Frosts are common on the Cumberland Plain and the lowest minimum temperature for Richmond is -8.3°C. (Figures from Bureau of Meteorology, 1979).

In terms of regional rainfall the Penrith map sheet area is almost wholly within Zone 3 of Edwards' (1979) rainfall zones which extends to the northwest of New South

Wales. Stations within this zone have median annual rainfall of 440–810 mm and a tendency for a higher proportion of that annual total to occur in the warmer months of the year. In the Penrith area, as well as being greater, the summer rainfall is less variable than the winter rainfall (Figure 2).

Soil moisture availability in this zone is relatively high throughout the year reaching a peak in winter when the lower rainfall is more than compensated for by the low evaporation. Plant growth is limited by low temperatures during winter and by low soil moisture at other times.

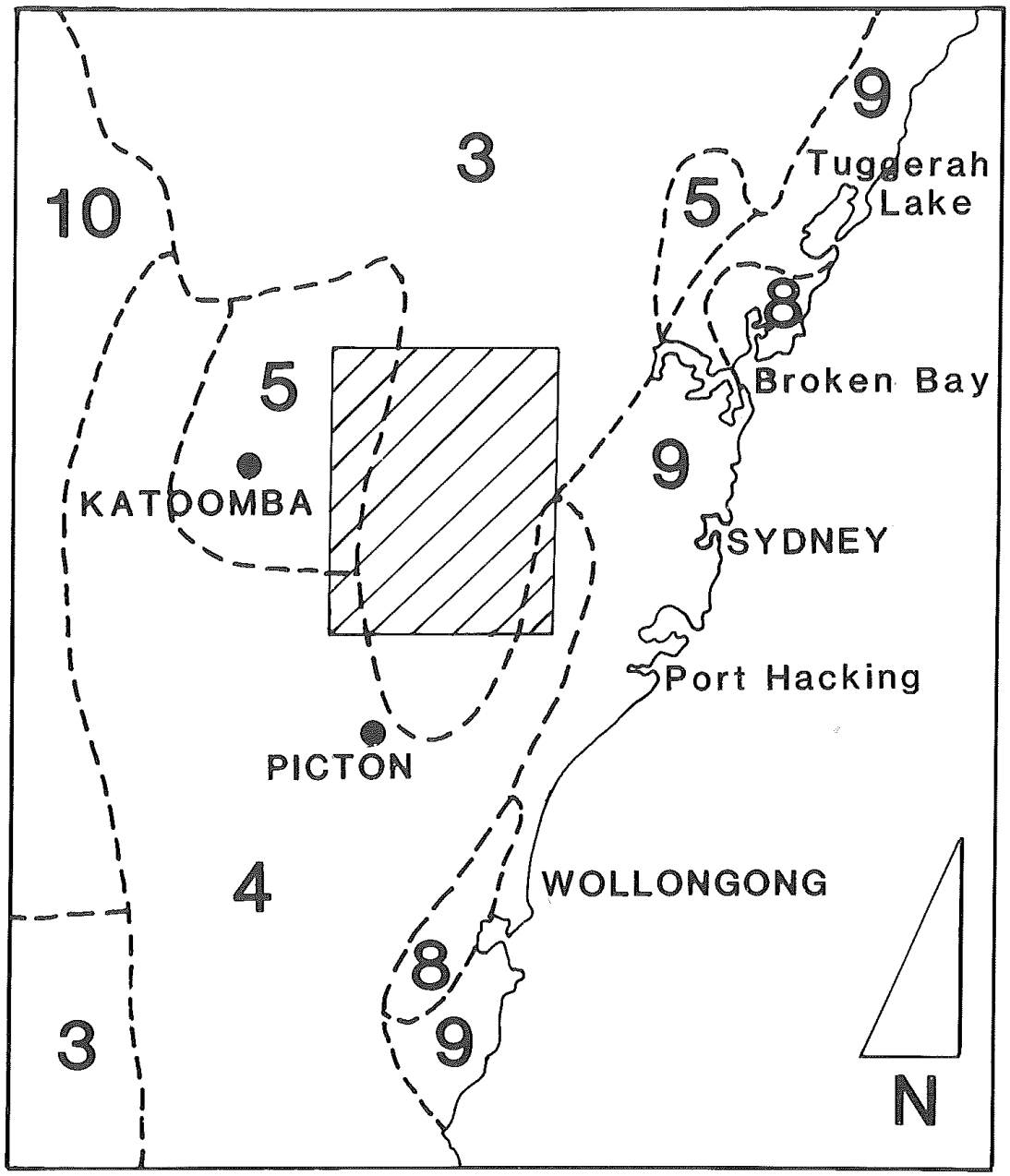


Figure 2. Location of Penrith map sheet area showing rainfall zones of Edwards (1979). Stations within zone 3 have median annual rainfalls of 440-810 mm with a higher proportion occurring in the warmer months. Adjoining zones 4, 5 and 9 receive higher rainfall.

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. Black-and-white aerial photography from the New South Wales Department of Lands (Penrith 1:40 000 scale taken in September 1979) was used initially and updated with late–1988 and early–1989 photography. Compilation maps were prepared at 1:25 000 scale and subsequently reduced to 1:100 000 scale.

Present-day (i.e. 1989) vegetation is mapped, but comments on the original natural vegetation of some agricultural and urban areas are also provided. 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 1986, Keith & Benson 1988, Benson & Keith 1990).

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 plant communities associated with a particular geological or physiographic type (e.g. map units 28a) whereas others are more clearly plant associations (*sensu* Beadle & Costin, 1952) (eg. map units 10c, 14a). Generally the term 'plant community' is used for the basic vegetation unit. Map units have also been provided with common names based loosely on habitat and composition, for ease of reference.

The vegetation map is a diagrammatic attempt to simplify the distribution patterns of an often rich and varied flora, over an extensive region. 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 represented by a line.

Field checking has been carried out intermittently between 1975 and 1990, and included notes on structure, characteristic species of major strata and associated environmental factors. Extensive species lists were compiled for particular areas. Available species lists are listed in bibliographies such as those of Pickard (1972), Bryant & Benson (1981) and Keith (1988); copies of some of these are available from the Royal Botanic Gardens Library.

Specific sets of data were collected for the Wianamatta Shale and Tertiary alluvium. The Wianamatta Shale data consisted of 100 sites, each 400 m^2 in area, randomly located in Western Sydney, for which species presence had been recorded. Data collection was carried out between 1973–1978. The Tertiary alluvium data was of 30 similarly recorded sites, collected between 1978–1980 on a grid basis. Basal area and plant density data from these sites has been presented for some plant communities. A high frequency of small size classes, for example, probably indicates a period of regeneration following clearing or logging. Such data give an indication of community dynamics as well as providing guidelines for regeneration and planting programs.

Botanical names used are those currently recognised at the National Herbarium of New South Wales. For authorities see Jacobs & Pickard (1981), with alterations in Jacobs & Lapinpuro (1986), or Harden (1990–1991).

Vegetation

The Penrith area was explored within months of the settlement at Port Jackson in 1788 and accounts of the expeditions of Governor Arthur Phillip, John Hunter and Watkin Tench exploring the Nepean–Hawkesbury River include descriptions of the landscape and its general vegetation (see Benson & Howell 1990*a*). References to the occurrences of particular species occur in the writings of George Caley (Currey 1966) and Allan Cunningham (Lee 1925). The strong correlations between the type of vegetation and the potential agricultural value of the land was frequently commented upon. In particular the marked differences between the Hawkesbury Sandstone landscapes and those of the heavier-textured and agriculturally superior soils developed from Wianamatta Shale and alluvium of the floodplains were frequently observed. For example, Allan Cunningham reports in his journal on 23 December 1816, after travelling from Parramatta to Sydney: 'As I advanced on the Road, I observed that the Botany fell off, on some rich pasture lands that I pass'd, and [on] those spots where the Vegetable Kingdom appear'd in greater Luxuriance their exuberance was a certain indication of the Sterility of the Soil.'

Scientific study of the plant communities began with Pidgeon (1937, 1941) who described general differences in vegetation on Wianamatta Shale and Hawkesbury Sandstone in the Sydney Region. Phillips (1947) described the main plant communities of western Sydney and Forster *et al.* (1977) included descriptions based on early work by the present author though neither work included detailed mapping. The distribution of the original vegetation of the floodplain of the Nepean-Hawkesbury River has been mapped (Benson 1974). A recent account of the vegetation of the Sydney area, defined by the County of Cumberland, describes and maps eight major vegetation types (Benson & Howell 1990*a*). A modified section of that map showing the extent of natural vegetation in 1788 for the Penrith map area is given in Figure 3. As this map sheet deals with about half of the area covered by Benson & Howell, the relationship between those vegetation types and the map units described here is given in Table 1.

Table 1. Vegetation types of Benson & Howell (1990*a*) (in bold) with corresponding map units and codes.

Turpentine - Ironbark Forest	Turpentine - Ironbark Forest	9o
Cumberland Plain Woodlands	Spotted Gum Forest	9b
	Shale/gravel Transition Forest	9d
	Grey Box Woodland	10c
	Grey Box - Ironbark Woodland	10d
Castlereagh Woodlands	Shale/gravel Transition Forest	9d
	Castlereagh Ironbark Forest	9e
	Castlereagh Scribbly Gum Woodland	14a
	Agnes Banks Woodland	14b
	Swamp Woodland	14c
River-flat Forests	Camden White Gum Forest	6d
	River-flat Forest	9f
Sandstone heaths, woodlands & forests	Sydney Sandstone Gully Forest	10ag
	Sydney Sandstone Ridgetop Woodland	10ar
	Lower Blue Mountains Heath (part)	21f
Freshwater and Estuarine wetlands	Estuarine Complex	4a
	Freshwater Reed Swamps (floodplain wetlands only)	28a

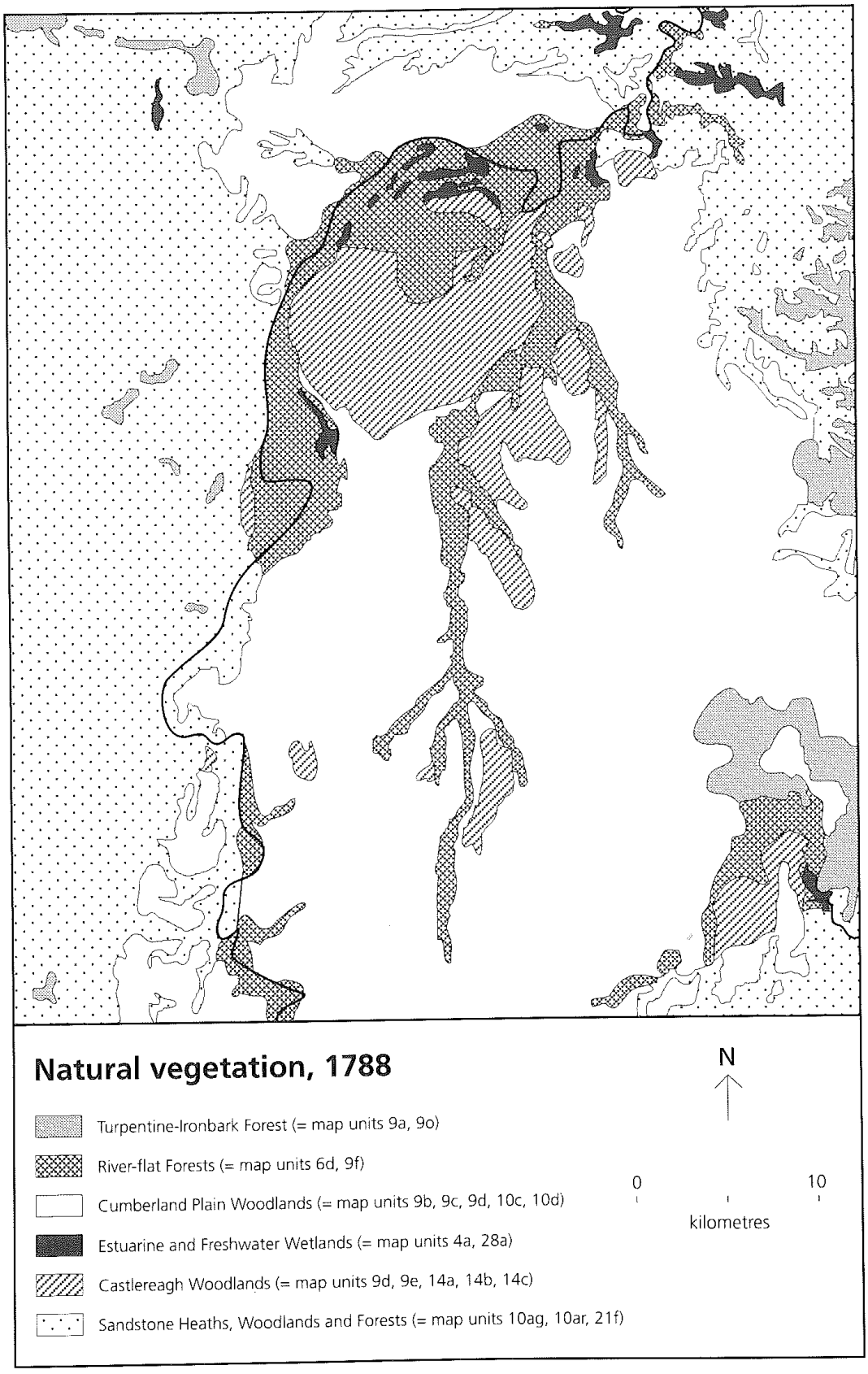


Figure 3. Presumed 1788 or pre-European pattern of natural vegetation of the Penrith map sheet area.

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

Map Unit	Structure	Main canopy species	Geology	Occurrence
4a	**Estuarine Complex**			
	Open-scrub	*Avicennia marina* *Aegiceras corniculatum*	Holocene alluvium	Estuarine mudflats regular tidal inundation
	Rushland / Reedland	*Juncus kraussii* *Phragmites australis*		Infrequent inundation. Brackish water
	Low open-forest	*Casuarina glauca*		
	Open-scrub	*Melaleuca ericifolia*		
6c	**Glen Forest**			
	Tall open-forest	*Eucalyptus deanei*	Diatremes	Isolated outcrops in Blue Mountains
6d	**Camden White Gum Forest**			
	Tall open-forest	*Eucalyptus benthamii*	Holocene alluvium	Confined to Nepean River at Bents Basin, Wallacia
9a	**Shale Cap Forest**			
	Open-forest	*Eucalyptus paniculata* *Eucalyptus notabilis*	Wianamatta Shale	Ridges along Bells road
9b	**Spotted Gum Forest**			
	Open-forest	*Eucalyptus maculata* *Eucalyptus moluccana*	Wianamatta Shale	On hills around Hoxton Park. Also around Werombi
9c	**Ironbark Forest**			
	Open-forest	*Eucalyptus crebra* *Eucalyptus fibrosa*	Wianamatta Shale	On shale remnants at Glenbrook
9d	**Shale/Gravel Transition Forest**			
	Open-forest	*Eucalyptus fibrosa* *Eucalyptus moluccana*	Wianamatta Shale/ Tertiary alluvium	On transition zone between these geological units

Map Unit	Structure	Main canopy species	Geology	Occurrence
9e	**Castlereagh Ironbark Forest**			
	Open-forest	*Eucalyptus fibrosa*	Tertiary alluvium	Castlereagh area on clay soils
9f	**River-flat Forest**			
	Open-forest	*Angophora subvelutina* *Eucalyptus amplifolia* *Eucalyptus tereticornis*	Holocene alluvium	Alluvial flood plains along Nepean-Hawkesbury River and major tributary creeks
9o	**Turpentine-Ironbark Forest**			
	Open-forest	*Syncarpia glomulifera* *Eucalyptus paniculata*	Wianamatta Shale	Bankstown area
Sydney Sandstone Complex				
10ag	**Sydney Sandstone Gully Forest**			
	i) Tall open-forest	*Eucalyptus deanei* or *Eucalyptus saligna* *Angophora floribunda* *Syncarpia glomulifera*	Hawkesbury Sandstone/ Narrabeen Group	Sheltered gullies Hillsides Sheltered gorges
	ii) Closed-forest	*Ceratopetalum apetalum* *Doryphora sassafras*		
	iii) Open-forest	*Eucalyptus piperita* *Angophora costata* *+/- Eucalyptus pilularis*	Hawkesbury Sandstone	Gullies, sheltered hillsides
10ar	**Sydney Sandstone Ridgetop Woodland**			
	i) Low open-forest	*Eucalyptus sieberi* *Eucalyptus piperita*	Hawkesbury Sandstone	Ridgetops and plateaus >1200 mm pa

Map Unit	Structure	Main canopy species	Geology	Occurrence
10ar	**Sydney Sandstone Ridgetop Woodland (continued)**			
	ii) Woodland / Open woodland	*Eucalyptus gummifera* *Eucalyptus eximia* *Eucalyptus sparsifolia* *Angophora costata* *Angophora bakeri*	Hawkesbury Sandstone	Ridges and dry exposed hillsides
	iii) Open-forest / woodland	*Eucalyptus gummifera* *Angophora costata* *Eucalyptus notabilis* *Eucalyptus sparsifolia* *Eucalyptus punctata* *Syncarpia glomulifera*	Hawkesbury Sandstone with clay influence	Ridges
	iv) Open-scrub	*Angophora hispida*		Broad plateau surfaces
10c	**Grey Box Woodland**			
	Woodland	*Eucalyptus moluccana* *Eucalyptus tereticornis*	Wianamatta Shale	Flat to gently undulating basin of of Cumberland Plain. Clay soils
10d	**Grey Box-Ironbark Woodland**			
	Woodland	*Eucalyptus moluccana* *Eucalyptus tereticornis* *Eucalyptus crebra*	Wianamatta Shale	Undulating to hilly country on margins of Cumberland Plain. Clay soils
14a	**Castlereagh Scribbly Gum Woodland**			
	Low Woodland	*Eucalyptus sclerophylla* *Angophora bakeri*	Tertiary alluvium	Castlereagh-Londonderry and Holsworthy on sandy soils

Map Unit	Structure	Main canopy species	Geology	Occurrence
14b	**Agnes Banks Woodland** Low woodland / open scrub	*Eucalyptus sclerophylla* *Angophora bakeri* *Banksia serrata*	Tertiary alluvium	Confined to sand deposit at Agnes Banks
14c	**Swamp Woodland** Low woodland	*Eucalyptus parramattensis*	Tertiary alluvium	Poorly drained depressions and creek lines
21f	**Lower Blue Mountains Heath** Open-heath	*Eucalyptus stricta* *Allocasuarina nana*	Hawkesbury Sandstone	Dry, rocky ridge tops
26a	**Blue Mountains Sedge Swamps** Closed-sedgeland	*Gymnoschoenus sphaero-cephalus* *Lepidosperma limicola* *Xyris ustulata* *Baeckea linifolia*	Hawkesbury Sandstone	Poorly-drained sites on plateaus
28a	**Freshwater Reed Swamps** Open-sedgeland	*Eleocharis sphacelata* *Juncus usitatus* *Persicaria* spp.	Holocene alluvium	Freshwater swamps
C	**Cleared**	These areas are generally the better agricultural soils along the river alluvial flats or on the Wianamatta Shale country. Small remnants of native vegetation too small to show on the map may occur here.		

Description of map units

A summary of the map units recognised on the Penrith sheet, their structural formations, main canopy species, geology and occurrence are given in Table 2. The map unit numbering system applies to the complete Sydney Region Vegetation Map Series. Missing numbers are those used for plant communities that are not found on the Penrith sheet. The vegetation map is located inside the back cover. The current work enlarges upon and updates a previous draft report (Benson 1981) and provisional maps (1981, 1985).

Map unit 4a - Estuarine Complex

Open-scrub: *Avicennia marina*

Rushland/reedland: *Juncus kraussii - Phragmites australis*

Low open-forest: *Casuarina glauca*

Open-scrub: *Melaleuca ericifolia*

Estuarine vegetation is confined mainly to the saline and brackish estuary of the Georges River downstream from Milperra Bridge. There is a variety of vegetation relating to the degree of flooding and the levels of salinity involved. The margin of the Georges River is fringed with mangroves, with both species that occur near Sydney, *Avicennia marina* and *Aegiceras corniculatum*, represented. They also extend into tributary creeks, in particular Deadmans Creek at Sandy Point and Williams Creek at Voyager Point. These mangroves are restricted to the intertidal zone. *Avicennia* is a ready coloniser of silt deposits, growing rapidly once established from water-dispersed seedlings. Studies in the Lane Cove River (McLoughlin 1985) indicate that *Avicennia* has responded to changes in sedimentation patterns in the river resulting from European settlement. This has generally caused increased silt deposits and in some places mangroves have increased their extent considerably, spreading further into the river. For the Georges River, Mitchell (1988) reports that over the last 50 years there has been a decrease in the area of saltmarsh communities and that generally mangroves have spread inland into saltmarsh areas. Local bank erosion and the loss of mangroves is occurring in some places possibly as a result of power boat wave damage (Ted Trainer pers. comm.).

Extensive saltmarsh with *Sarcocornia quinqueflora*, characteristic of saltmarsh further down the estuary and in particular at Towra Point, does not occur upstream of Mill Creek, probably because of different salinity or flooding frequencies. However, near the mouth of Williams Creek, behind the mangrove margin, is an estuarine sedgeland of *Juncus kraussii*, *Baumea juncea* and *Phragmites australis* and a number of saltmarsh species such as *Samolus repens*. An interesting record here is of *Wilsonia backhousei*, a rare saltmarsh plant previously known in the Sydney area only from Homebush Bay on the Parramatta River. This area would receive periodic brackish flooding.

Boundary relationships between mangroves and saltmarsh in the Georges River have been studied by Mitchell (1988). Boundary elevations of mangrove and saltmarsh decrease with distance from Botany Bay. These decreases appear to be more strongly related to river salinities than to tidal influences. Because of their decreased elevation and the increased tidal range further upstream, saltmarsh communities are tidally inundated more frequently up-river than in Botany Bay. Mitchell (1988) estimates that mangroves along the Georges River are tidally flooded between 17 and 60 times per month and saltmarsh 0 to 26 times.

Thickets or dense scrub of *Melaleuca ericifolia* 2–3 m high with some *Melaleuca linariifolia* and *Kunzea ambigua* (these last two species are normally asociated with non-brackish sites) occurs on sites with perhaps less saline influence but low lying and subject to occasional flooding. There is an extensive area of this scrub at Hammondville and it appears to have been common on the Milperra side of the Georges River in Kelso Park, though these areas have now been destroyed. Scrub in Deepwater Park is related but has less saline influence.

Zones of *Casuarina glauca* forest occur behind the mangroves along the Georges River and along Williams Creek. Low open-forest of *Casuarina glauca* is characteristic of estuaries but also occurs away from the coast in non-estuarine sites where there is some saline influence (for example in the Hunter Valley and on the Cumberland Plain). *Casuarina glauca* occurs between Liverpool and Camden, and south of Penrith where it is probably influenced by the salinity of the Wianamatta Shale groundwater (Figure 4). It occurs, for example, along creeks draining from shale areas such as Lansdowne Creek and Cabramatta Creek.

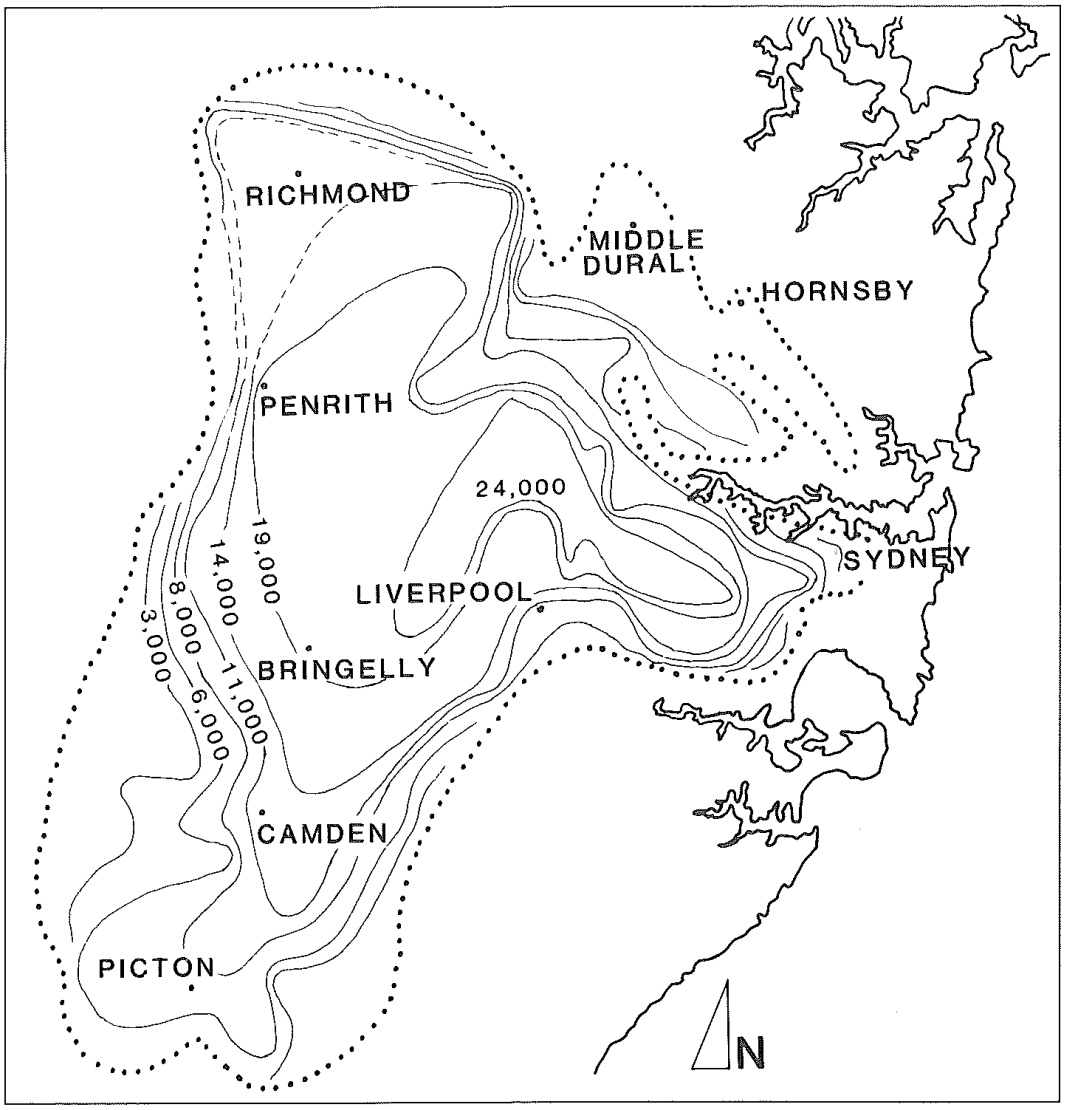


Figure 4. Soil salinity contours (ppm) for Wianamatta Shale groundwater (from Old 1942).

Swamp Oak Forest would have graded into the 'River Flat Forests' on the better drained alluvial flats and the 'Grey Box Woodlands' on nearby Wianamatta Shale hills. A stand of *Casuarina glauca* representing the intergrading form of the community is included within a proposed Nature Reserve at Kemps Creek.

Adam & Stricker (1989) report about 65 ha of estuarine wetland occurs along the Georges River in the Liverpool 1:25 000 map sheet area, with high naturalness ratings for Deadmans Creek, Williams Creek and Lieutenant Cantello Reserve.

Map unit 6c - Glen Forest

Tall open-forest: *Eucalyptus deanei*

In the lower Blue Mountains there are a number of small amphitheatre-shaped valleys formed from eroded volcanic intrusions or diatremes. Diatreme soils are variable, derived from the mixing of sandstone and basalt or breccia substrate as a result of the collapse of the sandstone wall-rocks into the volcanic intrusion and the subsequent deposition of sand eroded from the surrounding sandstone ridges (Crawford *et al.* 1980). They may have a sandy loam overlying a hardsetting clay loam forming red or yellow podzolic soils of the Volcanic Soil Landscape (Bannerman & Hazelton 1990). Such sites are more fertile than the surrounding Hawkesbury Sandstone countryside and have distinctive vegetation. This may be tall open-forest with trees of *Eucalyptus deanei* and *Syncarpia glomulifera*, an understorey with tall shrubs of *Notelaea longifolia, Acacia obtusifolia, Pultenaea flexilis, Hakea dactyloides* and *Polyscias sambucifolia*, climbers including *Smilax australis, Tylophora barbata, Eustrephus latifolius, Cissus hypoglauca, Hibbertia dentata, Clematis aristata* and *Comesperma volubile*, and ground cover dominated by *Calochlaena dubia, Dianella caerulea, Lomandra longifolia* and *Pteridium esculentum*, as at Murphys Glen on the adjacent Katoomba Sheet (Keith & Benson, 1988). On drier aspects there may be ironbarks, *Eucalyptus beyeriana* with a predominantly grassy understorey as at Machins Crater or on the Jack Evans Track near Erskine Creek. However, these diatremes often provided the best, though very localised, agricultural sites and were sought out and cleared or grazed by the early settlers. Tobys Glen and St Helena were grazed before becoming National Park. The ground cover is now dominated by ferns, particularly *Calochlaena dubia* and *Pteridium esculentum* and scramblers such as *Smilax* and *Cissus*, indicating a similar floristic composition to Murphys Glen, before stock grazing. St. Helena had 'well grassed forest land' at the turn of the century (Carne 1908). Where the soil fertility is lower, perhaps derived more from the surrounding rock than from volcanic breccia basalt, other species may occur. The Valley at Valley Heights, now mainly cleared, has remnant trees of *Eucalyptus amplifolia* and appears to have had a more grassy understorey. In William Cox's Journal of Road Construction over the Blue Mountains in 1814, mention is made of feeding and watering stock in the Valley, 'Nine and a half miles [from Emu Plains] grass and water in valley to right of road about a quarter of a mile' (quoted in Carne 1908). This indicates the importance of these grassy *oases* to the early settlers struggling through the poor sandstone country.

Small diatremes are also scattered across the Wianamatta Shale of the Cumberland Plain to the east (Crawford *et al.* 1980). These have all been cleared, and many quarried for crushed aggregate and there is very little evidence of their original flora, which would have been more like Valley Heights than Murphy Glen because of the lower rainfall and the clay influences from the surrounding Wianamatta Shale.

The large volcanic intrusion at Prospect forms a hill rather than an amphitheatre, but the vegetation here was cleared long before its flora had been recorded. It appears to have had *Eucalyptus moluccana* woodland similar to that of the surrounding Wianamatta Shale country (Phillips 1947). A number of uncommon ground species includ-

ing *Ranunculus sessiliflorus, Scutellaria humilis* and possibly *Pultenaea microphylla* may be indicative of volcanic influence (Benson 1989). *Eucalyptus moluccana* is a common species on diatremes in the Putty area north of Windsor (Barwick 1903).

Map unit 6d - Camden White Gum Forest

Tall open-forest: *Eucalyptus benthamii*

A localised patch of tall open-forest restricted to a sand-bank and adjacent river bank of the Nepean River at Bents Basin, south of Wallacia, is dominated by large trees of *Eucalyptus benthamii*, Camden White Gum, originally up to 40 m in height, but altered by recent fire occurrences. Smaller trees include *Eucalyptus baueriana, E. elata* and *Angophora subvelutina*. The understorey has tall shrubs of *Acacia binervia* and *A. floribunda* with smaller native shrubs such as *Breynia oblongifolia* and *Hymenanthera dentata*. Ground cover is variable with patches of *Lomandra longifolia, Pteridium esculentum*. Introduced weed species, including *Cynodon dactylon, Olea africana, Tradescantia albiflora, Araujia hortorum* and *Ligustrum sinense* are common (Benson, Thomas & Burkitt 1990).

Eucalyptus benthamii is now a rare tree species but formerly occurred along the Nepean River flood-plain as far downstream as the Grose junction and along parts of the Coxs River and Kedumba Creek (Keith & Benson, 1988). Clearing has reduced its occurrence along the Nepean River to scattered trees, and Warragamba Dam has flooded much of its former occurrence in the Coxs valley. It is a long-lived tree (possibly up to 250 years) with periods of recruitment related to flooding and silt deposits, and death related to periods of frequent, or perhaps extreme fire events (Benson 1985). Whilst mature trees are able to recover from fire by suckering, small trees and newly growing suckers are vulnerable.

The occurrence of this relatively fire-sensitive species and the closely-related *E. viminalis* on alluvium along the floodplain of the Nepean may be attributable to particular soil and moisture requirements, but is also consistent with a fire regime, in the nearby Cumberland Plain woodland, of frequent low intensity burns confined to the grassy understorey, that failed to burn the more mesic vine and shrubby understoreys associated with the riverbanks, (such understorey can be inferred from early writers such as John Hunter; (see Benson & Howell 1990*a*), together with an occasional infrequent intense fire event under exceptional fire conditions.

Map unit 9a - Shale Cap Forest

Open-forest: *Eucalyptus notabilis - E. globoidea - Syncarpia glomulifera*

The most western remnants of Wianamatta Shale, reduced to cappings along the sandstone ridges are found along the Bells Line of Road from Kurrajong Heights to beyond Bilpin and near Springwood. Soils here are deep, relatively well drained clays, and originally carried tall open-forest on the wetter sites and open-forest on the drier sites and shallower margins of the shale. The tall open-forest was characterised by *Eucalyptus deanei* and *Syncarpia glomulifera* but has almost all been cleared for orchards and housing. Patches of the open-forest remain. This has tree species such as *Eucalyptus notabilis, E. globoidea, E. paniculata, E. cypellocarpa* and *Syncarpia glomulifera*. Common on the ecotone with the adjoining Hawkesbury Sandstone are *E. punctata* and *E. piperita*. The understorey has shrubs of *Acacia parramattensis* up to 4 m high and lower shrubs, commonly *Indigofera australis, Helichrysum elatum* and *H. diosmifolium*. A conspicuous component of the understorey are vines, *Smilax australis, Tylophora barbata, Kennedia rubicunda, Eustrephus latifolius* and *Glycine* spp. Grasses include *Entolasia marginata, Dichelachne rara, Microlaena stipoides* and *Echinopogon ovatus*, herbs include *Dichondra repens* and *Poranthera microphylla* and ferns, *Pteridium*

esculentum and *Culcita dubia*. South of Springwood rainfall is lower and isolated shale residuals have the closely related Ironbark Forest, map unit 9c. Map units 9a and 9c are all part of the broadly defined Turpentine-Ironbark Forest of Benson & Howell (1990*a* & *b*).

Map unit 9b - Spotted Gum Forest

Open-forest: *Eucalyptus maculata - E. moluccana*

Open-forest of *Eucalyptus maculata*, the easily recognisable Spotted Gum, and *E. moluccana* is found on Wianamatta Shale on hilly country at Hoxton Park and Cecil Park west of Liverpool, and from Werombi southward to The Oaks. There is also an outlier at Appin. Rainfall ranges from 750 to 875 mm p.a. The hilly topography at Hoxton Park and the topographic position of the shale which overlies Hawkesbury Sandstone near Werombi, appears to improve the drainage of the normally damp Wianamatta Shale soils and may explain the occurrence of *Eucalyptus maculata*. A slightly higher rainfall at Werombi (1 000 mm p.a.) may also explain its distribution there.

Eucalyptus maculata made up nearly 60% of the total basal area and over 40% of the total density (Table 3). Usage for timber evidently began very early. A sale notice in the Sydney (Morning) Herald in November 1831 for a farm watered by Orphan School Creek, probably near Edensor Park or Cecil Park advertised 'Timber growing of valuable qualities, one of which (Spotted Gum) is now daily rising in repute for Staves of Casks ...'.

Other tree species are *E. fibrosa*, which occurs sporadically, *E. crebra*, which is particularly important around Werombi, *E. tereticornis* which is frequently important in depressions and *E. quadrangulata* which is found in a few moist, sheltered sites in the Werombi area. Occasional small tree species include *Allocasuarina torulosa*, *A. littoralis*, *Melaleuca decora* and *Acacia implexa*.

At Hoxton Park the understorey is mainly grasses with dense patches of shrubs 2 m high. These patches of shrubs are composed almost entirely of *Bursaria spinosa* (frequency 88% i.e. recorded at 88% of sites) accompanied occasionally by scattered

Table 3. Basal area and density of major tree species from 9 sites in *Eucalyptus maculata - E. moluccana* open-forest.

	Basal area (m^2/ha)			Density (plants/ha)		
	mean	(± s.e.m.)	% of total area	mean	(± s.e.m.)	% of total density
Eucalyptus maculata	14.2	4.1	59	225	97	43
E. moluccana	2.4	1.0	10	67	42	13
E. fibrosa	2.2	1.2	9	42	27	8
Total	24.0	3.1		516	135	

Other species contributing to total basal area - trees *Eucalyptus crebra*, *E. tereticornis*, *E. longifolia*, *E. punctata*, *E. quadrangulata*; small trees *Allocasuarina torulosa*, *A. littoralis*, *Melaleuca styphelioides*, *M. decora*, *Acacia implexa*, *A. parramattensis*, *Exocarpos cupressiformis*.

shrubs of *Dillwynia juniperina* and *Indigofera australis*. The normally prostrate twiner *Hardenbergia violacea* occurs as a 'shrub form' commonly up to 0.5 m high. Grass species are *Aristida vagans* (frequency 44%), *Entolasia marginata* (55%), *Eragrostis leptostachya* (44%), *Themeda australis* (66%) and *Echinopogon caespitosis* (55%). Common native herb species are *Brunoniella australis* (66%), *Dichondra repens* (77%), *Oxalis corniculata group* (44%), and *Pratia purpurascens* (55%).

At Werombi the understorey is much richer in shrub species, with *Breynia oblongifolia, Persoonia linearis, Allocasuarina torulosa, Acacia implexa* and *Clerodendrum tomentosum*. Twiners, *Geitonoplesium cymosum, Eustrephus latifolius, Stephania japonica* and *Clematis* species also occur here. Most of these species do not occur at Hoxton Park. At Appin, along the Appin-Campbelltown Road where there is a conspicuous outlier of Spotted Gum Forest, the understorey is much denser than at Hoxton Park and includes tall shrubs of *Acacia decurrens* and *A. implexa* and low shrubs of *Olearia viscidula* and *Lissanthe strigosa*.

Spotted Gum Forest is floristically similar to both the *E. moluccana - E. tereticornis* woodland and the *E. moluccana - E. crebra* woodland. It grades into the former on the lower slopes of hills around Hoxton Park and the latter on the lower slopes of the uplifted plateau west of Camden. The gradation is indistinct as many species are common to these communities. At some sites at Werombi it also grades into the Turpentine Forest. Again the transition is indistinct as many species overlap. *Eucalyptus maculata* also occurs along the Warringah Peninsula. However the Warringah Spotted Gum Forest is found in much wetter sites and has a much more mesic group of understorey species.

Most of the Cumberland Plain Spotted Gum Forest has been cleared, but in the past where small patches remained, the understorey usually remained as native pasture. Increasingly now, pasture improvement with exotic species is eliminating native species, which previously survived despite grazing. Much of the area has been subdivided for 'hobby farms', increasing the impact on natural remnants, but there are relatively undisturbed stands on some of the steeper slopes around Hoxton Park and smaller patches around Werombi, again on the steeper slopes. There is also a small stand on Water Board land on the southern side of Prospect Reservoir. Appin is also an important site for conservation as it provides a wildlife corridor between the Nepean and Georges River systems. No areas have been preserved in any Nature Reserve or National Parks and the small areas that exist in council reserves have generally been cleared of their native understorey and replaced with mown grass.

Map unit 9c - Ironbark Forest

Open-forest: *Eucalyptus crebra - Eucalyptus fibrosa*

This community is found on remnants of Wianamatta Shale along the Lapstone Monocline near Euroka, south of Glenbrook at Little Mountain, south of Bents Basin (Benson *et al.* 1990) and at Silverdale. The dominant trees are ironbarks, *Eucalyptus crebra, E. beyeriana* and *E. fibrosa*. At Little Mountain *E. punctata, E. eugenioides* and *Allocasuarina torulosa* also occur. There is an understorey of grasses and scattered shrubs of *Daviesia ulicifolia*. The vegetation contrasts with the surrounding Hawkesbury Sandstone vegetation but appears to differ somewhat from the vegetation on nearby Wianamatta Shale, along the Great Western Highway between Glenbrook and Springwood. Though much of the vegetation has been cleared for urban development, *Syncarpia glomulifera* appears to have been a major constituent of the vegetation near Springwood.

Map unit 9d - Shale/gravel Transition Forest

Open-forest: *Eucalyptus fibrosa - Eucalyptus moluccana*

This community occurs on the transitional zone between Wianamatta Shale and Tertiary alluvium (including gravel sediments), mainly between Penrith and Windsor. It contains a mixture of species found on these two areas. *Eucalyptus fibrosa*, one of the most common species on Tertiary alluvium, and *E. moluccana*, a common species on Wianamatta Shale, are the main dominants. Other tree species are *E. eugenioides* and *E. sclerophylla*. The understorey is dominated by low shrubs with a mixture of the hardier species from the Wianamatta Shale and Tertiary alluvium. *Bursaria spinosa, Daviesia ulicifolia, Dillwynia juniperina, Hardenbergia violacea, Exocarpos cupressiformis, Melaleuca nodosa* and *Acacia parramattensis* are the most common species. Small trees of *Melaleuca decora* are often conspicuous. A small patch of the community is protected in Longneck Lagoon Field Studies Centre at Pitt Town, and includes a small population of the rare shrub *Acacia pubescens*.

Map unit 9e - Castlereagh Ironbark Forest

Open-forest: *Eucalyptus fibrosa*

This unit, together with map units 14a, 14b, 14c, and the transitional 9d make up the Castlereagh Woodlands of Benson & Howell (1990*a* & *b*). Their conservation is one of the most critical issues for long-term planning for western Sydney.

On deep, well-drained reddish clay soils of the Tertiary alluvium around Castlereagh Ironbark open-forest is prominent. The best remaining stands are in Castlereagh State Forest where trees are up to 25 m high. *E. fibrosa* is the dominant tree species, generally forming pure stands, but may also be associated with *E. sideroxylon* and *E. crebra*, though these may be overlooked, since they are ironbarks with similar appearance to *E. fibrosa* and certainly much less common. In measured stands *E. fibrosa* made up about 43% of total basal area but only 21% of total plant density (Table 4). The bulk of density (69%) and 44% of total basal area is made up by *Melaleuca decora* which generally forms a small tree layer, (60–80% of the stems are less than 10 cm d.b.h.). Stems of *E. fibrosa* are now mostly 11–20 cm d.b.h. but much larger stems would once have been common.

An understorey of sclerophyllous shrubs up to 2 m high is generally associated with the pure stands of *E. fibrosa*. No particular species predominates, though the pea family Fabaceae is well represented. Shrub species which may be locally abundant

Table 4. Basal area and density of major tree species from 6 sites in *Eucalyptus fibrosa* open-forest.

	Basal area (m^2/ha)			Density (plants/ha)		
	mean	(± s.e.m.)	% of total area	mean	(± s.e.m.)	% of total density
Melaleuca decora	5.1	1.7	44	470	183	69
Eualyptus fibrosa	4.9	1.3	43	145	31	21
Total	11.5	2.5		679	184	

Other species contributing to total basal area are the trees *Eucalyptus crebra, E. eugenioides, E. moluccana, E. sclerophylla, E. tereticornis* and the small trees *Angophora bakeri* and *Hakea sericea*.

are *Dillwynia tenuifolia, Dodonaea filifolia, Hakea sericea, Melaleuca nodosa, Mirbelia rubiifolia* and *Pultenaea villosa*. Less conspicuous, but frequent ground layer plants, are *Lissanthe strigosa, Cheilanthes sieberi, Brunoniella australis, Pratia purpurascens, Lepidosperma laterale* and *Dianella revoluta*. A number of species are of particular interest: *Micromyrtus minutiflora* (Myrtaceae); *Dillwynia tenuifolia; Pultenaea parviflora* (Fabaceae); *Grevillea juniperina* (Proteaceae); and *Dodonaea falcata* (Sapindaceae), including a number of local endemic species and forms (see Benson & McDougall 1991). For a species list for Castlereagh State Forest see Forestry Commission of NSW (1984).

This community usually grades into *E. sclerophylla - Angophora bakeri* woodland (map unit 14a) where the soil becomes more sandy, or into the *E. fibrosa - E. moluccana* open-forest (map unit 9d) on adjacent Wianamatta Shale.

The Tertiary alluvium provides very poor agricultural soils and there has been little serious agricultural usage. Recent increases in hobby farm and suburban development, and extensive gravel and clay extraction, are now leading to the clearing of much of the original vegetation. Good stands of *E. fibrosa* remain in Castlereagh State Forest, and although selective logging has altered the former open-forest structure, the floristic composition of the community is essentially undisturbed. It is highly desirable that the Forestry Commission manage this area as a conservation reserve. There is also an area of this community in Windsor Downs Nature Reserve though it is less diverse here than at Castlereagh. The *E. fibrosa* open-forest is a robust community, tolerant of most likely above-ground adjacent disturbances. Although rubbish dumping has been prolific in many areas, there is little sign of any major weed invasion problems. The shrub understorey may be reduced to a grassy understorey if an over-frequent fire regime is imposed.

Map unit 9f - River-flat Forest

Open-forest: *Angophora subvelutina - Eucalyptus amplifolia*

The floodplain of the Nepean–Hawkesbury River was the site of the first major intensive agriculture by the early european settlers. The River acquired two names as a result of being 'discovered' from two different directions; it is the Nepean above the Grose junction near Yarramundi, and the Hawkesbury below. The original distribution of vegetation related to floodplain topography. The levee banks along the river, and the back swamps beyond, produced a floodplain with tall open-forest on the well-drained crest and upper slopes of the levee bank adjacent to the river, and various sedge, rush and reed swamps in the depressions between the levee bank and sandstone cliffs (Benson 1974; Benson & Howell 1990*a* & *b*).

Between Richmond and Windsor, and on the levee banks along the Hawkesbury River downstream from Windsor, where the floodplain narrows, the levee bank forest was composed of trees over 30 m high. In 1791 John Hunter, standing on the banks of the Hawkesbury River near Richmond wrote, 'the banks are high, and the soil a light sand, but producing fine straight timber' (Hunter 1793). The largest trees were on the levee banks along the main channels of the river; smaller trees were associated with the poorly drained back-swamps. Referring to the lands of the Hawkesbury, Hunter and Shoalhaven Rivers, James Atkinson (1826) wrote 'Most of the alluvial lands were originally forest; the timber was large, principally blue and flood gum, [he could be referring to *Eucalyptus tereticornis, E. saligna* or *E. deanei*] with an abundance of the tree known in the Colony by the appellation of the apple tree, [either *Angophora subvelutina* or *A. floribunda*] which is of little value'. Today, remnant trees along the floodplain indicate that *Eucalyptus tereticornis, E. deanei* and *Angophora floribunda* were originally the main forest tree species along the Hawkesbury.

The forest understorey appears to have been shrubby, and particularly dense. Evidently it made travelling difficult, as Hunter describes. 'The person who was charged with counting his paces, and setting objects to which they directed their march, had hitherto gone first; but the long sedge [*Gahnia, Lomandra longifolia*], the dead branches which had fallen from the trees, the nettles [*Urtica incisa*], and a weed resembling ivy which entangled the feet [*Smilax australis*?], made walking on, or near the banks of the river very fatiguing' (Hunter 1793).

There would have been a fringe of *Casuarina cunninghamiana* subsp. *cunninghamiana* along the water's edge and *Casuarina cunninghamiana* forest with occasional individuals of *Angophora subvelutina* was also found on islands of sand and gravel in the Nepean River between Penrith and Richmond. This has now been virtually destroyed by sand and gravel extraction, but remnant trees, up to 18 m high, indicate the original open-forest structure. Because of the scouring effects of floods, there would have been multistemmed shrubs of *Leptospermum polygalifolium* and *Tristaniopsis laurina*, which would have survived best on outcrops of boulders and gravel, now largely removed, that would have provided secure rooting. These species are still found in the Nepean Gorge upstream from Bents Basin. Other species would probably have been *Acacia binervia, Acacia floribunda, Goodenia ovata* and *Persicaria* species. A number of *Acacia* species, *A. floribunda, A. elata, A. binervia, A. ulicifolia, A. obtusifolia* and *A. parvipinnula* together with *Bossiaea rhombifolia, Pultenaea flexilis* and *Kennedia rubicunda* have been recorded colonising disturbed sand deposits at Penrith. With the exception of *Acacia binervia* and *A. floribunda*, mature plants of these species are rarely found in *Casuarina cunninghamiana* open-forest as young plants may be washed away by floodwaters before they can be properly established.

On sites sheltered by the steep-sided sandstone cliffs, particularly downstream from Sackville, there were pockets of low dense-forest with small trees and shrubs, many of 'rainforest type' species. They included small trees of *Acmena smithii, Trema aspera, Ficus coronata, Duboisia myoporoides, Backhousia myrtifolia* and *Tristaniopsis laurina*. Vines *Eustrephus latifolius, Geitonoplesium cymosum* and *Pandorea pandorana* twisted among the shrubs, while on the ground, clumps of ferns, commonly *Doodia aspera* and *Adiantum aethiopicum*, grew in the restricted light in the moist litter layer. Where moisture and shelter were less favourable, a more open shrub layer of *Leptospermum polygalifolium* and bipinnate wattles such as *Acacia parramattensis, A. decurrens* and *A. filicifolia* was present. Ground cover was *Pteridium esculentum* and native grasses. *Lomandra longifolia* was frequent, particularly on the river banks.

On the alluvial flats of the river upstream of Richmond, where the river becomes the Nepean, and tributary creeks, the predominance by *Eucalyptus tereticornis* gradually changed to predominance of *Eucalyptus amplifolia* subsp. *amplifolia* and *Angophora subvelutina*. Phillips (1947) described these species as occurring as far down the Hawkesbury River as Sackville, but Benson (1974) regarded the vegetation on the alluvial flats between Richmond and Sackville as *Eucalyptus tereticornis* tall open-forest. Because the original vegetation in this area has been almost completely destroyed, and the two communities were very similar, it is now impossible to give exact boundaries, though it is likely the two communities intergraded between Agnes Banks and Windsor.

The fringing forest along the Nepean River had some characteristic species. Peter Cunningham (1827) wrote 'The banks of the Cow-pasture river near Narellan are high, sandy, and clothed with goodly gum-trees, swamp oaks and scrubby brushwood'. The water's edge was probably lined with *Casuarina cunninghamiana* and occasional *Tristaniopsis laurina*. More localised tree species included *Eucalyptus viminalis, E. botryoides-saligna* intergrades, *E. elata, E. benthamii, E. baueriana* and *E. bosistoana*.

Eucalyptus viminalis and *E. botryoides-saligna* were found along the Nepean between Menangle and Camden, with *E. elata* common as far downstream as Wallacia. *Eucalyptus benthamii* occurred occasionally as far down as the junction with the Grose River although it is now restricted to the Cobbitty-Wallacia section. Of *Eucalyptus baueriana* Woolls (1880) wrote 'in the County of Cumberland on the banks of the Georges River, the Nepean, and the Hawkesbury, it is a tree of very moderate size ... I have found a tree of this species occasionally amongst forest-trees in the neighbourhood of Liverpool and Richmond but its proper habitat is near the banks of rivers and creeks. It does not occur as far as I have been able to ascertain, near Sydney or Parramatta'. It is a tree of slow growth and there are some large old specimens along the Nepean River at Camden Park. *Eucalyptus bosistoana* was probably always rare along the Nepean. A localised occurrence was also found at Milperra on the Georges River.

Though most of the forest on the Nepean River floodplain would have been of *Eucalyptus amplifolia* subsp. *amplifolia* and *Angophora subvelutina*, the closely related *Angophora floribunda*, appears to have replaced *Angophora subvelutina* along the smaller, slower-flowing Cumberland Plain creeks such as South, Kemps and Badgerys Creeks. There is also some intergradation between these two species.

The understorey of the floodplain forests would probably have had a discontinuous shrub layer of *Bursaria spinosa*. Paperbarks, *Melaleuca linariifolia, M. decora* and *M. styphelioides*, with a ground cover of *Juncus* species, chiefly *J. usitatus*, or sedges, were found in periodically waterlogged depressions. Along the river banks were denser shrubs; Peter Cunningham's 'scrubby brushwood' on the banks of the Nepean would have included *Acacia binervia, Tristaniopsis laurina, Backhousia myrtifolia, Acmena smithii, Acacia floribunda, Melia azedarach* and *Trema aspera*. Smaller shrubs would have included *Hymenanthera dentata, Phyllanthus gunnii, P. gasstroemii, P. similis, Goodenia ovata, Duboisia myoporoides, Calomeria amaranthoides*, and ground-cover plants, *Microlaena stipoides, Stipa verticillata, Geranium homeanum, Pratia purpurascens, Adiantum aethiopicum* and *Pellaea falcata*. *Phragmites australis* was common along the Nepean River near Penrith in 1860, and is still common there.

Where the river passes through sandstone gorges south of Penrith the alluvium vegetation is very restricted. A fringe of *Casuarina cunninghamiana* and *Angophora subvelutina* with *Eucalyptus deanei* on the lower slopes is common. The gorge above Bents Basin has woodland of *Tristaniopsis laurina* and *Casuarina cunninghamiana* (Benson *et al* 1990). On a boat trip from Penrith upstream to the Nepean Gorge, George Bennett (1860) observed amongst other things on the banks 'some Red Cedar-trees (*Cedrela Australis*) [now *Toona ciliata*], now becoming very rare to the colony; the largest was about 16 feet in height'. How widespread Red Cedar was originally on the floodplain is unknown though it was probably restricted to the banks of the Nepean and Hawkesbury. Bennett's trees were obviously young saplings and indeed there are still a couple of trees near the junction with Euroka Creek. No other Red Cedar trees appear to remain on the floodplain now, though *Melia azedarach*, White Cedar, a related native species, is still common along the Nepean and Hawkesbury river banks, and has been planted widely in the district.

On the smaller floodplains of the creeks, *Casuarina glauca* frequently formed dense stands, particularly where the watercourse was sluggish or intermittent. Clumps of small trees are often the result of its root-suckering nature. This species is characteristic of saline estuarine situations, often associated with mangrove and saltmarsh and its distribution may be related to the presence of the saline ground water found below much of the Wianamatta Shale country, particularly in the low lying central basin of the Cumberland Plain (Old 1942). Subsurface salt concentrations here are

considered to be much higher than that suitable for crops and gardens and could be expected to affect native vegetation in low-lying sites. High salinities were noted in the early nineteenth century and are not necessarily a result of poor land use (Old 1942).

The River-flat Forests occupied some of the most fertile agricultural land in the Sydney area, land that has been farmed since the 1790s and most of the original vegetation has now been cleared. In most situations all that remains now are a few scattered old trees surrounded by improved pasture. As early as 1826, James Atkinson was writing, 'The greater part of the alluvial lands upon the Hawkesbury and Nepean have been cleared, and are under cultivation'. Old photos and paintings of the Hawkesbury in the late nineteenth century show an agricultural landscape similar to that of today.

Scattered remnants survive along the lower Hawkesbury below Windsor and tributary creeks such as Wheeny Creek. The main area mapped is at Agnes Banks on the Hawkesbury Campus of the University of Western Sydney, where a remnant of open-forest of *Angophora subvelutina - E. amplifolia* subsp. *amplifolia* associated with important wetland species survives. This area was recommended for preservation by Forster *et al.* (1977) and may become part of a joint conservation agreement between the National Parks & Wildlife Service and the University. No other examples of this type of forest in the area have been reserved. Small patches of open-forest with *E. tereticornis*, often surviving as quite large trees may be found in narrow valleys near Ebenezer and Cattai. At Kemps Creek, where *E. amplifolia* and *Casuarina glauca* forest are found along the creek, the latter appears to indicate salinity in the ground water. In other places *Casuarina glauca* forms pure stands, often as a result of its ability to root-sucker.

Along the Georges River was similar floodplain forest. Along Williams Creek near where it joins the Georges River are alluvial soils with floodplain forest with trees of *Angophora floribunda, Eucalyptus tereticornis, E. moluccana* and some less common *Eucalyptus baueriana*. This species was once common on the alluvium of the Georges River between Liverpool and Milperra, but has mostly been cleared. Where it remains, as at Deepwater Park, Milperra, it is now mown parkland where there are no chances of natural populations of seedlings establishing to replace it. Park management systems need to be appropriately changed to ensure its conservation.

Similarly small, often weed-infested, remnants occur sporadically along the Nepean–Hawkesbury River. Though often degraded these areas may contain local populations of the native species. The flora of these river-flats and floodplains disappeared very quickly after colonisation. As a result we have little idea of the interactions between native species, flood dispersal and the particular ecological adaptions that may have been involved. Rivers and creek systems are often recommended for protection as corridors for wildlife to allow propagule and genetic interchange, in otherwise developed environments. Such areas will need rehabilitation and the re-establishment of appropriate native vegetation if they are to be successful wildlife corridors. The protection of remaining native populations along creeks and rivers, particularly the Nepean-Hawkesbury will be essential if sources of appropriate material are to be available. The ephemeral nature of many native floodplain species means that their transitory habitats must be protected even when species are apparently absent.

Map unit 9o - Turpentine-Ironbark Forest

Open-forest: *Syncarpia glomulifera - Eucalyptus paniculata* subsp. *paniculata*

On the eastern edge of the map area near Bankstown are remnants of the Turpentine-Ironbark Forest originally found on moderate rainfall Wianamatta Shale soils further east. Tree species in Bankstown remnants include *Syncarpia glomulifera, Eucalyptus fibrosa* and *E. globoidea.* There is a mixing of species from the Cumberland Plain Woodlands - *Eucalyptus moluccana-E. tereticornis* dominated - of the drier shale areas the understorey contains species from both areas. There are also some interesting sites (for example, The Crest of Bankstown) with rainforest species such as *Euodia micrococca, Achronychia oblongifolia* and *Rhodamnia rubescens.*

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

This is the widespread vegetation complex found on the Hawkesbury Sandstone areas of the sheet. It occurs widely on the coastal plateaus up to 800 m elevation. It contains considerable local structural and floristic variation depending particularly on topographic position, local soil texture, drainage and aspect. Two broad subunits, have been recognised from aerial photos. 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). The units have been used on the Katoomba and Wallerawang map sheets. On the lower Blue Mountains however this pattern is complicated by the presence of extensive areas of ridgetop with soils influenced by the Wianamatta Group and the Mittagong Formation, located stratigraphically between the lowest unit of the Wianamatta Group shale and the Hawkesbury Sandstone. Such areas occur for example on the Oakdale Tablelands, south of Glenbrook, Winmalee and near Bowen Mountain (Bannerman & Hazelton 1990). Soils here are yellow podzolics belonging to the Lucas Heights soil landscape, are deeper and more clayey than found on the Hawkesbury Sandstone elsewhere and support open forest vegetation. Because much of this area is within national parks and, because of its rugged terrain, difficult of access, much less field checking has been carried out in comparison with Cumberland Plain region.

Descriptions of most of the common Blue Mountains species are given in Baker *et al.* (1984, 1985) and a list of species occurring in sandstone areas on the margins of western Sydney is included in Benson & McDougall (1991).

Map unit 10ag - Sydney Sandstone Gully Forest

i) Tall open-forest: *Eucalyptus deanei* or *E. saligna - Angophora floribunda - Syncarpia glomulifera*

ii) Closed-forest: *Ceratopetalum apetalum - Doryphora sassafras*

iii) Open-forest: *Eucalyptus piperita - Angophora costata*

Sandstone Gully Forest is generally confined to gullies and sheltered hillsides, particularly on southern to eastern aspects. There are extensive areas around Kurrajong Heights and along creeks flowing southward to the Grose, apparently due to the high rainfall in the area (over 1 200 mm p.a.), the steep sheltered gorges along the tributaries of the Grose and enrichment from the shale soils on the ridges. It is less extensive south of the Grose River where annual rainfall is less than 1 000 mm.

Vegetation structure ranges from open-forest to tall open-forest and closed-forest. Floristic variation is considerable. Floristic groups may be recognised but there is considerable intergrading between these. Major gradients relate to increasing moisture, shelter and soil fertility. Closed-forest occurs where these three factors are

combined to form favourable conditions. Major vegetation groupings are:

i) Tall open-forest: *Eucalyptus deanei* or *E. saligna* - *Angophora floribunda* - *Syncarpia glomulifera*

This vegetation is confined to valley floors or lower sheltered slopes where moisture, shelter and soil fertility are high. It occurs along major watercourses such as the Grose River, and creeks of the lower Blue Mountains as well as along Cattai and Little Cattai creeks near Maroota. *Eucalyptus deanei* and the closely related *E. saligna* rarely occur together. *Eucalyptus deanei* is more common in the lower Blue Mountains, *E. saligna* in the Cattai-Maroota area. Other tree species are *Angophora floribunda* and *Syncarpia glomulifera*. Associated species include shrubs, *Backhousia myrtifolia, Acacia elata* and *Allocasuarina torulosa*, scramblers, *Cissus hypoglauca, Cissus antarctica, Morinda jasminoides* and *Smilax australis* and ferns, *Calochlaena (Culcita) dubia, Doodia aspera* and *Pellaea falcata*.

ii) Closed-forest: *Ceratopetalum apetalum* - *Doryphora sassafras*

Small patches of closed-forest rainforest vegetation with *Livistona australis* occur on sheltered southerly aspects in the Kurrajong area around Mountain Lagoon and Wheeny Creek.

iii) Open-forest: *Eucalyptus piperita* - *Angophora costata*

This is the widespread vegetation of gullies and sheltered slopes on sandstone with annual rainfall generally greater than 1 000 mm.

The main trees are *Eucalyptus piperita* and *Angophora costata* but *Eucalyptus pilularis* may be locally abundant on more fertile sites. *Allocasuarina torulosa* 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. Common species include *Grevillea linearifolia, Pultenaea flexilis, Acacia terminalis*, single-stemmed form of *Hakea dactyloides* and *Persoonia linearis*. There is a distinctive shrub flora along creeks, including the species *Tristaniopsis laurina, Backhousia myrtifolia, Ceratopetalum apetalum* and *Callicoma serratifolia*.

Sandstone Gully Forest of *Eucalyptus piperita* and *Angophora costata* together with *E. pilularis* occurs on sheltered hillsides in the north-eastern corner of the map sheet (Benson & Howell 1990*a*). On the lower Blue Mountains there are extensive areas of open-forest around Kurrajong Heights and along creeks flowing southward to the Grose. These are responding to the high rainfall in the area (over 1 200 mm), the deep sheltered gorges along the tributaries of the Grose and enrichment from the shale soil on the ridges. *Eucalyptus sieberi* probably indicates well-drained but poorer soils. Rodd (1987) describes open-forest of *Eucalyptus piperita, E. sieberi* and *Angophora costata* with some *E. cypellocarpa* or *E. agglomerata* as occurring over large areas of drier or less fertile (in comparison with the basalt soils) lower slopes of Mount Tomah to the west of the map sheet area and a little higher in elevation, but similar vegetation occurs on sandstone hillsides near Bilpin and Kurrajong Heights.

On the lower Blue Mountains south of the Grose, rainfall tends to be lower and gully vegetation less mesic. Rainfall at Springwood is just over 1 000 mm p.a. and at Warragamba it is 970 mm p.a. Sandstone Gully forest at Bents Basin includes *Eucalyptus pilularis* and *Syncarpia glomulifera* with *Ceratopetalum apetalum* and *Backhousia myrtifolia* along perennial creek lines (Benson, Thomas & Burkitt 1990). There is a sparse shrub understorey consisting mainly of *Bossiaea rhombifolia, Persoonia linearis* and *Leptospermum trinervium (attenuatum)*.

Map unit 10ar - Sydney Sandstone Ridgetop Woodland

i) Low open-forest: ***Eucalyptus sieberi - Eucalyptus piperita***

ii)Woodland/
open-woodland: ***Eucalyptus gummifera - Eucalyptus eximia - Angophora costata - Angophora bakeri - Eucalyptus sparsifolia***

iii) Open-forest/
woodland: ***Eucalyptus gummifera - Angophora costata - E. notabilis - E. sparsifolia - E. punctata - Syncarpia glomulifera***

iv) Open - scrub: ***Angophora hispida*** (see also Map unit 21f)

Like the Sandstone Gully Forest, the Sandstone Ridgetop Woodland is considerably variable both structurally and floristically. Structure ranges from open-forest to woodland, open-woodland, low woodland, scrub and heath. Major gradients are apparently related to rainfall and soil texture, in particular to sand and clay content. These also influence drainage conditions and add local variation to broader trends. Some tree species occur over a wide range of conditions - *Angophora costata, Eucalyptus gummifera, E. sparsifolia, E. piperita* for example are ubiquitous. Other species are more likely to indicate particular conditions - *Syncarpia glomulifera* and *Eucalyptus punctata* may indicate clay soil influence, *Angophora bakeri* and *Eucalyptus eximia,* low rainfall well drained sites, *E. sclerophylla* - damp shallow soils, *Eucalyptus sieberi*- well drained sites with higher rainfall.

Ridge and plateau vegetation has a rich, sclerophyllous, shrubby understorey with species of Proteaceae, Fabaceae, Epacridaceae and Myrtaceae. Shrub and ground cover species may be better indicators of local conditions though again there are very widespread species such as *Leptospermum trinervium, Lambertia formosa* and *Isopogon anemonifolius*. Some major species groupings can be recognised and related in particular to soil and rainfall conditions but there is considerable intergradation and local variation within them. They do however serve as a guide for understanding vegetation and landform. Detailed studies of plant response to soil and rainfall gradients are needed to confirm these exploratory hypotheses.

i) Low open-forest: ***Eucalyptus sieberi - Eucalyptus piperita***

Rodd (1987) describes low open-forest with *Eucalyptus piperita, E. sieberi, E. burgessiana* and *E. stricta* in various combinations together with scattered occurrences of *E. oblonga* and *Angophora costata* for the tops of sandstone spurs around Mount Tomah. Soils are mostly very shallow, associated with rock ledges, often poorly drained and highly infertile. Similar vegetation occurs widely north of the Grose River, but south of the Grose *Eucalyptus sieberi,* in particular, is less common. This probably relates to the higher annual rainfall in the Kurrajong area (above 1 200 mm p.a.) compared with elsewhere in the lower Blue Mountains. *Eucalyptus sieberi* occurs again on the coast where rainfall is again higher. Common shrub species listed by Rodd include *Banksia ericifolia, B. spinulosa, Lambertia formosa, Isopogon anemonifolius, Hakea dactyloides, Leptospermum trinervium (attenuatum), L. polygalifolium (flavescens), Platysace linearifolia, P. lanceolata, Dillwynia floribunda* and *Epacris microphylla.*

ii) Woodland/
open-woodland: ***Eucalyptus gummifera - Eucalyptus eximia - Angophora costata - Angophora bakeri - Eucalyptus sparsifolia***

This vegetation is found on dry hillsides and ridges on the lower Blue Mountains

generally south of the Grose River. These areas appear to be drier than those with *E. sieberi - E. piperita* low open-forest with an annual rainfall of less than 1 000 mm per annum. Soils are earthy sands or yellow earths with a depth of 50–100 cm belonging to the Faulconbridge, Hawkesbury and Gymea soil landscapes (Bannerman & Hazelton 1990). Understorey is shrubby with species such as *Leptospermum trinervium, Hakea sericea, Grevillea buxifolia, Baeckea diosmifolia, Leucopogon muticus* and *Persoonia levis.* Patches of mallee eucalypts, including the restricted species *Eucalyptus burgessiana* and *E. multicaulis,* are frequent along ridges running north from Springwood, and with *E. consideniana* along the Woodford Range.

Sandstone country drained by Cattai, O'Haras and Little Cattai Creeks in the north-eastern corner of the map sheet has woodland with *Eucalyptus haemastoma, E. sclerophylla, E. gummifera, E. eximia, E. punctata, Angophora costata* and *A. bakeri.* Sclerophyllous understorey shrubs include species of *Banksia, Grevillea, Hakea, Boronia, Leptospermum* and *Pultenaea* (Benson & Howell 1990*a*).

In the south-east corner of the sheet around East Hills and Holsworthy woodland trees include *Eucalyptus sclerophylla, E. punctata, E. piperita* and *Angophora bakeri.* The understorey has a variety of shrub species including *Acacia terminalis, Grevillea sericea, Banksia spinulosa* var. *spinulosa* and *Philotheca salsolifolia.*

iii) Open-forest/ woodland: ***Eucalyptus gummifera - Angophora costata - Eucalyptus notabilis - Eucalyptus sparsifolia - Eucalyptus punctata - Syncarpia glomulifera***

This vegetation is found on Hawkesbury Sandstone on sites with a clay influence. In the lower Blue Mountains these soils are found on ridgetops and have developed from the Mittagong Formation at the stratigraphic junction between the Wianamatta Shale and the Hawkesbury Sandstone. Soils are yellow podzolics and belong to the Lucas Heights soil landscape.

Other sites with a clay influence may be due to shale lenses in the Hawkesbury Sandstone or residual areas of Wianamatta Shale. The latter areas generally have distinctive Ironbark Forest (mapped as unit 9c).

Species such as *Syncarpia* are generally good indicators of clay soils, though other tree species may occur in a wide range of sites. Understorey species tend to be better site indicators and species such as *Bossiaea obcordata, Grevillea mucronulata, Cyathochaeta diandra* and *Entolasia stricta* are characteristic.

Woodland communities at Bents Basin are influenced by shale residuals (Benson *et al.* 1990) and a variety of species occur including *Eucalyptus gummifera, E. eximia, Angophora costata, E. pilularis* and *E. punctata. Lambertia formosa, Persoonia linearis, Leptospermum trinervium* and *Leucopogon muticus* are common shrubs.

iv) Open - scrub: Angophora *hispida* (see also Map unit 21f)

Within the ridge-top woodland, particularly shallow soils support open-scrub with *Angophora hispida;* patches are found particularly around Annangrove and Maroota. Localised areas of open-heath, open-scrub and sedgeland are mapped separately as communities 21f and 26a respectively.

Map unit 10c - Grey Box Woodland

Woodland: *Eucalyptus moluccana - Eucalyptus tereticornis*

Grey Box Woodland is found on the flat to gently undulating country that makes up much of the dry central Cumberland Plain core, between Parramatta and Penrith

with a rainfall of 700–800 mm p.a. It is part of the *Eucalyptus hemiphloia* [=*moluccana*] - *E. tereticornis* association of Pidgeon (1941) and Phillips (1947) which has been here divided into a number of units, the most important being the Grey Box Woodland (map unit 10c) and the Grey-Box-Ironbark Woodland (map unit 10d). This unit and the following map unit 10d, together with Spotted Gum Forest make up the Cumberland Plain Woodland of Benson & Howell (1990*a* & *b*).

Governor Arthur Phillip (1789) described country to the west of Parramatta in April 1788. 'The country through which they travelled was 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, which was confined to the stony and barren spots'. This description of the Grey Box Woodland indicates it to have originally been an open community of park-like appearance, with well spaced, large, spreading trees and an understorey mainly of tussock grasses and herbs, and localised patches of denser scrub. The 'stony and barren spots' with 'brushwood' are probably ironstone residuals or gullies in Hawkesbury Sandstone which would have had a dry shrubby understorey.

John White (1790), on the same expedition wrote 'The country here about [near Greystanes Hill] was pleasant to the eye, well wooded, and covered with long sour grass, growing in tufts. At the bottom of this valley or flat, we crossed another water-course, and ascended a hill, where the wood was so very thick as to obstruct our view'.

Similarly, John Hunter (1793) writes 'The country about Rose Hill, [near Parramatta], which I have formerly mentioned as requiring not much labour in clearing, from its being covered only with lofty, open woods, without any underwood, and which I then observed ran to the westward about 20 miles, [32 km] has since been travelled over by several gentlemen, who admit that that kind of country does extend near the distance above-mentioned to the westward, but in a north and south direction, it does not extend more than 3 or 4 miles, [5–6 km] when you come again into barren rocky land wholly unfit for cultivation ...'. This latter country is probably on Hawkesbury Sandstone.

In describing the central basin of the Cumberland Plain, James Atkinson (1826) writes 'In the county of Cumberland, one immense tract of forest land extends, with little interruption, from below Windsor on the Hawkesbury, to Appin, a distance of 50 miles [80 km]; large portions of this are cleared and under cultivation, and of the remainder that is still in a state of nature, a great part is capable of much improvement. The whole of this tract, and indeed all the forest in this county, was thick forest land, covered with very heavy timber, chiefly iron and stringy bark, box, blue and other gums, and mahogany'.

All these writers give the impression of open, though in some places locally dense stands of trees forming a woodland (*sensu* Specht 1970) with a grassy understorey. The nature of the understorey is clearly indicated by Atkinson who defines his use of the word 'forest'. 'It is, however, always to be understood that forest means land more or less furnished with timber trees, and invariably covered with grass underneath, and destitute of underwood'.

Estimates of canopy height in remnant stands ranged from 10 to 20m and canopy cover ranges from 10 to 73%. These figures include both woodland and open-forest formations, the latter structure being found in stands with vigorous regeneration. Most sites had been disturbed in the past and except for large, old trees which were either multistemmed and showed evidence that stems had been cut, or appeared to

be sapling regrowth. From Governor Phillip's (1789) estimates of tree spacing 'from twenty to forty feet from each other', a range of tree density from 68 trees/ha to 272 trees/ha can be calculated. The present mean tree density (378 plants/ha) (Table 5) is higher as a result of the denser regrowth following clearing or disturbance. The sites with low tree densities, sites 90 (3 trees), 73 (4 trees), 80 (5 trees) and 74 (5 trees) generally have larger trees.

Table 5. Basal area and density of major tree species from 31 sites in the *Eucalyptus moluccana - E. tereticornis* woodland.

	Basal area (m^2/ha)			Density (plants/ha)		
	mean	(± s.e.m.)	% of total area	mean	(± s.e.m.)	% of total density
Eucalyptus moluccana	5.5	1.1	39	113	21	30
E. tereticornis	4.5	1.3	32	125	29	33
E. eugenioides	1.0	0.2	7	13	7	3
Melaleuca decora	0.9	0.4	6	53	27	14
Total	14.4	1.5		378		

Other species contributing to total basal area - trees *Angophora subvelutina, Eucalyptus amplifolia* subsp.*amplifolia, E. fibrosa, E. longifolia*; small trees *Acacia decurrens, A. parramattensis, Angophora bakeri, Casuarina glauca, Allocasuarina littoralis, Melaleuca styphelioides.*

The main tree species, *Eucalyptus moluccana*, Grey Box and *E. tereticornis*, Forest Red Gum, today make up over 70% of the total basal area and 60% of the total stem density of sites examined (Table 5). The total basal areas and stem densities of the two species are about equal but they occur together in varying proportions. *E. moluccana* appears to favour the higher topographic situations of upper slopes and rises and *E. tereticornis* favours lower slopes and depressions. There was a negative correlation ($r = -0.43$, 23 d.f. $p < 0.05$) between them based on basal area data.

Less common tree species are *E. fibrosa*, which is generally found near the edge of the mapped community, perhaps on sandier sites, *E. longifolia* which occurs sporadically, its main occurrence being in the Grey Box-Ironbark Forest further east, and *E. amplifolia* and *Angophora subvelutina* which are confined to creek channels or poorly-drained sites. *E. amplifolia* replaces the very closely related species *E. tereticornis* on such sites. Small trees of *Casuarina glauca* and *Melaleuca decora* are found in similar impeded drainage situations.

The understorey may be shrubby or grassy depending on disturbance or grazing intensity. Evidently there was considerable local variation in the type of understorey even in the earliest days. John Macarthur wrote to Governor King in 1804 (Historical Records of Australia 5, 583) concerning the pasture value of land in the vicinity of Prospect. 'I have not seen any unappropriated range of 5,000 acres [2,000 ha] that contains 500 acres [200 ha] of dry pasture on which I should think it safe to feed sheep ... I carefully examined a tract from near George's River to the Nepean, and from thence to the South Creek and Prospect Hill, but entirely without success. Almost the whole is of that wet kind which has been found so fatal to sheep, or is covered with scrubby brushwood'. The 'wet kind' of land probably caused sheep

losses through liver fluke or foot rot and would have been partly covered with stands of *Casuarina glauca* or *Eucalyptus amplifolia* subsp *amplifolia*, found on poorly-drained land. 'Scrubby brushwood' here may refer to the stands of *Melaleuca decora* which are still common west of Liverpool.

The main shrub species now is *Bursaria spinosa* which grows in both dense clumps or as scattered individuals. It was found at every site and densities, recorded from a limited number of sites, ranged from 100 to 1 000 plants/ha. Density may be related to grazing or burning patterns as undisturbed sites carry the densest stands. In 1817 the botanist Allan Cunningham, on visiting the farm of a friend near Liverpool wrote, 'Like other farms in the neighbourhood it is overrun with the *Bursaria spinosa* now in fruit' (Lee 1925). Whether there was an increase in the abundance of *Bursaria spinosa* occurring at the time as a result of changes in grazing, cultivation, or fire management is not clear but the species has remained abundant.

Only one other shrub species, *Dillwynia juniperina*, occurred at more than 25% of the sampling sites though this, and the less common shrubs *Daviesia ulicifolia* and *Indigofera australis*, may have high densities on particular sites. Other less common shrubs, *Acacia parramattensis*, *A. decurrens* and *A. implexa* generally have much lower local densities.

European settlement both increased and decreased fire frequencies depending on the locality. James Atkinson wrote in 1826: 'In the unoccupied districts in the interior, and also in those tracts that are only used for the purposes of grazing, the grass in winter becomes withered by the frosts, and assumes the appearance of bad coloured hay; in this state it is refused by the cattle; and as it impedes the growth of young grass, the common practice is to set fire to it. The Natives also pursue the same system setting fire to the thick brushes and old grass every summer; the young herbage that springs up in these places, is sure to attract the kangaroos and other game; and the horned cattle are also very fond of feeding upon this *burnt ground*, as it is termed in the colony; ... In dry seasons these periodical burnings sometimes assumes a truly awful appearance, the country seems on fire in all directions, and if the weather is calm, is enveloped in dense smoke'. Many of the shrub species regenerate rapidly after a fire and their local abundance may have been increased by the early settlers' use of fire for clearing followed by longer periods of protection from fire. The small remnants of bush surviving now are probably only infrequently burnt.

Phillips (1947) described *Themeda australis* as the typical species of undisturbed sites together with *Dichelachne micrantha* and *Sorghum leiocladum* but that these were readily lost by overgrazing leaving *Bothriochloa macra*, *Chloris truncata*, *Eragrostis leptostachya* and *Danthonia* species predominating. Under trees *Bothriochloa* and *Chloris* were replaced by *Aristida vagans*, *A. ramosa* and *Microlaena stipoides*. Phillip's work was done at a time when the Cumberland Plain vegetation was heavily grazed. Recent patterns of subdivision and changing urban and rural development often leave areas temporarily ungrazed, and many sites recorded during the present survey were on areas no longer grazed. Species recorded were mainly perennial grasses particularly *Themeda australis* (recorded on 87% of quadrats) *Eragrostis leptostachya* (32%), *Aristida vagans* (39%) and *A. ramosa* (26%). Small herbs were also common, particularly *Dichondra repens* (90% of quadrats), *Brunoniella australis* (87%), *Lomandra filiformis* (35%), *Dianella laevis* (39%), *Oxalis corniculata group* (74%) and *Cheilanthes sieberi* (55%). Many of these sites have been subsequently destroyed.

Allan Cunningham mentions some of the species between Parramatta and Liverpool in 1818. 'In my route towards Liverpool, on a line of road about 9 miles [14 km], bounded by open forest-land and confined dense brush, many interesting (already described) plants were in flower, among which I gathered the following *Pomaderris*

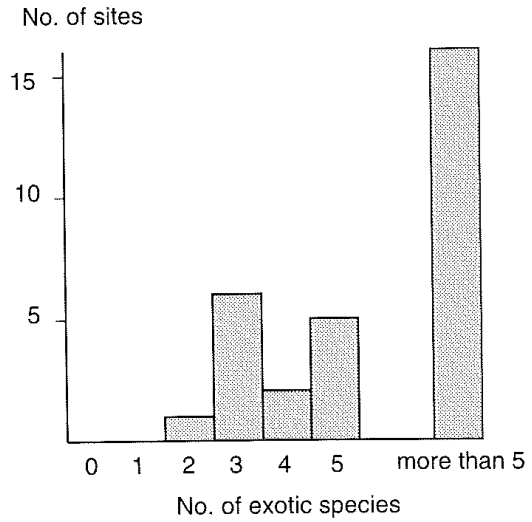
betulina, flowers panicled axillary and terminal. *Diosmeoe*, habit of *Correa*, a shrub with white flowers; also a genus of this order allied to *Eriostemon*, stamina smooth, leaves oblong, narrow obtuse. *Dampiera undulata*, a suffruticose blue flowering plant [possibly *Dampiera stricta*]. *Colletia* sp., a small tufted leaved, spinous shrub, suspected to be allied to *Cryptandra* [possibly *Cryptandra amara* or *spinescens*] is now frequent, in flower and fruit, in the vicinity of the town of Liverpool. In moist situations I gathered a small plant of the order Gentianaceae, *Erythraea australis* [*Centaurium spicatum*]. To the southward of Liverpool the country is an open forest-land of common *Eucalypti*, in which *Exocarpus cupressiformis*, and the papilionaceous tree *Jacksonia scoparia*, at this period laden with yellow flowers, are very conspicuous. *Pimelea spicata* and *P. glauca* of Mr Brown; a small *Daviesia* with cordate leaves (*D. squarrosa*, Smith); with a *Helichrysum*, allied to *H. papillosum* and prevalent in this description of country ... In situations on the roadside, more or less subject to inundation, a delicate tufted *Lobelia* (*L. inundata*) is in flower, and *Ruellia australis* [*Brunoniella australis*] is common in grassy dry spots, decorating our path throughout this days route' (Lee 1925).

Cunningham's references to the Pimeleas are interesting. *Pimelea spicata* is now extremely rare, and now only known from a few locations in western Sydney, though it was formerly more common. Similarly *Pimelea glauca* has only been recorded from a few places in the Sydney area including Cunningham's specimen, collected 'near Liverpool' in 1818; this was presumably on the journey described above and is held

Table 6. a) Number of native exotic species recorded from sites in *Eucalyptus moluccana–E. tereticornis* woodland.

	range	mean	s.e.m.
Total number of species / site	15–46	32.7	1.3
Number of native species / site	12–41	25.8	1.2
Number of exotic species / site	2–19	6.9	0.7
Total number of native species recorded	188		
Total number of exotic species recorded	46		

b) Frequency of exotic species



at the National Herbarium of New South Wales. Perhaps Cunningham's *Pimelea* specimens from Liverpool indicate original Cumberland Plain species that were quickly exterminated by the settlers' stock grazing or other associated land use change?

Land use changes have also allowed exotic species to establish. During this study between 2 and 19 exotic species were recorded on every site (Table 6). More than half the sites had more than 5 exotic species, the most common species being *Hypochaeris radicata, Conyza floribunda, Plantago lanceolata* and *Paspalum dilatatum* (Table 7).

Though much of the vegetation that now remains has been heavily disturbed, some remnants still carry quite a large number of native species. Though a number of recommendations have been made, no areas have been preserved in any national park or nature reserve. A good example at Kemps Creek is presently being considered. Some areas have been included in council reserves but in many of these the understorey has been mowed or replaced with exotic Kikuyu grass, *Pennisetum clandestinum*.

Table 7. Exotic species recorded in *Eucalyptus moluccana - E. tereticornis* woodland.

	% frequency
APIACEAE	
Apium tenuifolium	11
ASCLEPIADACEAE	
Araujia hortorum	38
Gomphocarpus fruticosus	11
ASTERACEAE	
Aster subulatus	11
Bidens pilosa	50
B. subalternans	4
Circium vulgare	38
Conyza floribunda	84
Gnaphalium purpureum	4
G. spicatum	4
Hypochaeris glabra	4
H. radicata	92
Leontodon leysseri	23
Taraxacum officinale	8
CACTACEAE	
Opuntia stricta	4
CRASSULACEAE	
Kalanchoe tubiflora	4
FABACEAE	
Lotus angustissimus	8
IRIDACEAE	
Romulea rosea	11
ASPARAGACEAE	
Asparagus densiflorus	4
A. officinalis	8
Myrsiphyllum asparagoides	8
MALVACEAE	
Modiola caroliniana	11
OLEACEAE	
Ligustrum sinense	11
Olea europea subsp. *africana*	19
PLANTAGINACEAE	
Plantago lanceolata	80
POACEAE	
Bromus catharticus	4
Cynodon dactylon	11
Digitaria violascens	4
Paspalum dilatatum	76
P. urvillei	4
Pennisetum clandestinum	4
Setaria geniculata	42
Sporobolus africana	27
POLYGONACEAE	
Rumex crispus	4
PRIMULACEAE	
Anagallis arvensis	8
ROSACEAE	
Rosa rubiginosa	4
Rubus vulgaris	4
RUBIACEAE	
Richardia stellaris	19
SOLANACEAE	
Lycium ferocissimum	11
Solanum mauritianum	4
S. nigrum	4
S. pseudocapsicum	4
S. sodomaeum	4
VERBENACEAE	
Lantana camara	8
Verbena officinalis	11

Table 8. The Grose Vale 'limestone flora' recorded by Carne (1908) indicating species recorded by Bill May in 1984 (pers. comm.). Soil types indicated by Carne, S = shale, I = intermediate, L = limestone; + = present in 1984. (Family names minus -aceae in brackets).

DICOTYLEDONS	
Abutilon oxycarpum (Malv.)	S +
Acacia decurrens (Fab.)	S +
Acacia longifolia (Fab.)	S +
Acaena novae-zelandii (Ros.)	S
Acaena ovina (Ros.)	S
Acmena smithii (Myrt.)	L
Alectryon subcinereus (Sapind.)	L +
Alphitonia excelsa (Rhamn.)	L +
Aphanopetalum resinosum (Cunoni.)	I +
Brachychiton populneus (Sterculi.)	I +
Breynia oblongifolia (Euphorbi.)	I +
Bursaria spinosa (Pittospor.)	S +
Callistemon salignus (Myrt.)	S +
Calotis lappulacea (Aster.)	S
Cassia odorata (Fab.)	L +
Cassine australis (Celastr.)	L +
Cayratia clematidea (Vit.)	L +
Cissus antarctica (Vit.)	L +
Cissus hypoglauca (Vit.)	L +
Citriobatus pauciflorus (Pittospor.)	L +
Clematis aristata (Ranuncul.)	S
Clematis glycinoides (Ranuncul.)	S
Clerodendrum tomentosum (Verben.)	I +
Croton verreauxii (Euphorbi.)	I +
Cuttsia viburnea (Escalloni.)	L
Daucus glochidiatus (Api.)	S
Desmodium brachypodium (Fab.)	S
Dichondra repens (Convolvul.)	S
Diospyros australis (Eben.)	L
Dodonaea viscosa (Sapind.)	S +
Ehretia acuminata (Boragin.)	L +
Einadia trigonon (Chenopodi.)	S +
Endiandra ? (Laur.)	L
Sambucus australasica (Caprifoli.)	L
Santalum obtusifolium (Santal.)	L
Sarcomelicope simplicifolia (Rut.)	L
Sarcopetalum harveyanum (Menisperm.)	L +
Senecio glomeratus (Aster.)	S
Sigesbeckia orientalis (Aster.)	S
Solanum prinophyllum (Solan.)	S
Solanum stelligerum (Solan.)	S +
Tasmannia insipida (Winter.)	L
Trema aspera (Ulm.)	I +
Toona ciliata (australis) (Meli.)	L +
Urtica incisa (Urtic.)	S
Vittadinia tenuissima (Aster.)	S
Wahlenbergia gracilis (Campanul.)	S +
MONOCOTYLEDONS	
Aristida vagans (Po.)	S
Bothriochloa decipiens (Po.)	S
Carex appressa (Cyper.)	S
Carex longebrachiata (Cyper.)	S
Cenchrus caliculatus (Po.)	L
Commelina cyanea (Commelin.)	S
Cymbopogon refractus (Po.)	S
Cynodon dactylon (Po.)	S
Danthonia pilosa (Po.)	S
Dianella laevis (Dianell.)	S +
Dichanthium sericeum (Po.)	S
Dichelacne sciurea (Po.)	S
Echinopogon ovatus (Po.)	S
Eragrostis leptostachya (Po.)	S
Eustrephus latifolius (Philesi.)	S +
Gahnia aspera (Cyper.)	S
Gahnia melanocarpa (Cyper.)	S
Geitonoplesium cymosum (Philesi.)	S +
Juncus ?usitatus (Junc.)	S

Epilobium billardierianum (Onagr.)	S
Eucalyptus moluccana (Myrt.)	S +
Eucalyptus tereticornis (Myrt.)	S +
Eupomatia laurina (Eupomati.)	L
Euodia micrococca (Rut.)	I +
Exocarpos cupressiformis (Santal.)	S
Ficus coronata (Mor.)	L +
Geranium solanderi (Gerani.)	S +
Glochidion ferdinandi (Euphorbi.)	I +
Glycine clandestina (Fab.)	S +
Guioa semiglauca (Sapind.)	L +
Helichrysum diosmifolium (Aster.)	S
Hibiscus heterophyllus (Malv.)	L +
Hymenosporum flavum (Pittospor.)	L +
Indigofera australis (Fab.)	S +
Legnephora moorei (Menisperm.)	L +
?*Lepidium ruderale* L. (Brassic.)	S
Leucopogon juniperinus (Epacrid.)	S +
Maclura cochinchinensis (Mor.)	L +
Marsdenia rostrata (Asclepiad.)	L +
Melaleuca styphelioides (Myrt.)	S +
Melia azedarach (Meli.)	L +
Mentha diemenica (Lami.)	S
Myoporum debile (Myopor.)	S
Neolitsea dealbata (Laur.)	L
Nicotiana suaveolens (Solan.)	S
Notelaea longifolia (Ole.)	S
Nyssanthes erecta (Amaranth.)	S
Pandorea pandorana (Bignoni.)	I +
?*Passiflora herbertiana* (Passiflor.)	L +
Phyllanthus gasstroemii (Euphorbi.)	I
Plantago debilis (Plantagin.)	S
Plectranthus parviflorus (Lami.)	S +
Pratia purpurascens (Lobeli.)	S
Pseuderanthemum variabile (Acanth.)	S +
Rapanea variabilis (Myrsin.)	I +
Rhodamnia rubescens (Myrt.)	L +
Rubus hillii (Ros.)	L
Rubus parvifolius (Ros.)	S +
Rumex brownii (Polygon.)	S
Leptochloa decipiens (Po.)	S
Libertia paniculata (Irid.)	L
Lomandra longifolia (Lomandr.)	S
Microlaena stipoides (Po.)	S
Oplismenus imbecillus (Po.)	S
Panicum pygmaeum (Po.)	S
Smilax australis (Smilac.)	S +
?*Stipa rudis* (Po.)	S

FERNS

Adiantum formosum (Adiant.)	L
Adiantum silvaticum (Adiant.)	L
Doodia aspera (Blechn.)	L
Pellaea falcata (Adiant.)	L

Additional species recorded by May in 1984

Acacia parramattensis (Fab.)
Celastrus australis (Celastr.)
Croton insularis (Euphorbi.)
Cupaniopsis anacardioides (Sapind.)
Ficus rubiginosa (Mor.)
Maytenus silvestris (Celastr.)
Morinda jasminoides (Rubi.)
Parsonsia straminea (Apocyn.)
Pittosporum revolutum (Pittospor.)
Polyscias sambucifolia (Arali.)
Stellaria flaccida (Caryophyll.)
Stephania japonica (Menisperm.)
Streblus brunonianus (Mor.)

Map unit 10d - Grey Box - Ironbark Woodland

Woodland: *Eucalyptus moluccana - Eucalyptus tereticornis - Eucalyptus crebra*

This community is similar to the previous woodland (Community 10c) but is found on more hilly Wianamatta Shale country with *Eucalyptus crebra* as a co-dominant species. It is part of the Cumberland Plain Woodland of Benson & Howell (1990*a* & *b*). The community was originally extensive around the edge of the Cumberland Plain, being abundant towards Camden and Picton, Kurrajong to Glossodia and Cattai to Prospect.

The understorey is generally grassy with patches of shrubs. Grass species include *Themeda australis, Eragrostis leptostachya* and *Aristida ramosa* and *A. vagans. Bursaria spinosa* is the most common shrub species, often forming dense thickets. Other, less common, shrub species include *Acacia implexa, A. parramattensis* and *Indigofera australis*. A small stand of this community is included in the Longneck Lagoon Field Studies Centre at Pitt Town.

Isolated stands of rainforest scrub vegetation have been recorded from Box Hill at Grose Vale (Carne 1910) (Table 8) and at the 'Native Vineyard' at Cobbitty (Woolls 1867). William Woolls writes: 'This spot [it is about 1 km south-west of Cobbitty Trig] is also remarkable for the occurrence of many plants which do not grow anywhere in the adjacent bush ... The 'Vineyard' as it is called [presumably named because of the predominance of vines and lianes] contains only a few acres, and is almost in sight of the Reverend T. Hassell's residence at Denbigh. It has the appearance of a cultivated shrubbery, rather than that of a collection of plants formed by natural causes'. Many of the native species are now extinct or still surviving as only one or two old plants, largely due to the invasion of *Olea europea* subsp. *africana* which forms dense scrub cover to 10 m high and chokes out the native species. Grazing by domestic stock and rabbits has also prevented seedling growth of many of the native species. Table 9 lists the plant species recorded by Woolls in 1867 and shows those still present in 1976, when the area was visited by the author. Such a group of species, most of which are normally restricted to rainforest, is unusual. A number are particularly rare; *Cynanchum elegans* (Asclepiadaceae), apart from the record by Woolls (it was not recorded in 1976) is known only from a few rainforest remnants near Wollongong

Table 9. Species recorded from the 'Native Vineyard' at Cobbitty by William Woolls (1867). (a, indicates also recorded by D.H. Benson in 1976 and b, recorded by Marie Kennedy in 1991).

Small trees			**Vines**		
Citriobatus multiflorus	a		*Aphanopetalum resinosum*	a	
Geijera latifolia	a	b	*Pandorea pandorana*	a	b
Alectryon subcinereus	a		*Cissus antarctica*	a	b
Guioa semiglauca			*Eustrephus latifolius*	a	
Alphitonia excelsa			*Geitonoplesium cymosum*	a	
Diospyros australis			*Sicyos australis*	b	
Streblus brunonianus	a	b	*Clematis aristata*		
Maclura cochinchinensis	a	b	*Passiflora herbertiana*		
Croton verreauxii			*Stephania japonica*		
Claoxylon australe			*Sarcopetalum harveyanum*	b	
Coelebogyne ilicifolia			*Cynanchum elegans*		
Euodia micrococca	b		*Marsdenia flavescens*	a	b
			Parsonsia straminea		
			Leichhardtia leptophylla		
			Convolvulaceae (2 species)		

and scree slopes of Mount Dangar in the Hunter Valley. Similarly the nearest localities to the Native Vineyard for *Geijera latifolia* (Rutaceae) are Albion Park to the south and Pokolbin to the North. Similar vegetation is associated with the more rugged escarpments of Razorback Range between Camden and Picton on outcrops of the sandstone strata of the Bringelly Shale, particularly the Razorback and Mount Hercules Sandstone Members along gullies and cliff lines on sheltered northeast to southeast aspects. Phillips (1947) described a *Brachychiton-Bursaria* shrub stratum group found on outcrops of ostracod sandstone (possibly the Potts Hill Sandstone Member of the Minchinbury Sandstone). At the time these areas were mostly cleared and cultivated with only isolated specimens of *Brachychiton populneus*. Since then most of these have disappeared but it is probable that their original vegetation included 'rainforest type' shrubs.

Very little is known about the local ecological relationships between the three species *Eucalyptus moluccana*, *E. tereticornis* and *E. crebra*. *Eucalyptus tereticornis* may be found on more poorly drained sites than the others, though it also occurs on well-drained hill tops. *E. crebra* is found on dry hilly country, but often interspersed with the other species. It is probably slower growing than the other species. Locally pure populations of any of the species may be found, often in close proximity, suggesting different recruitment requirements may be involved. Past management practices such as the selective cutting of *E. crebra* for fence posts etc. may have led to local loss of this species.

Map unit 14a - Castlereagh Scribbly Gum Woodland

Low woodland: *Eucalyptus sclerophylla - Angophora bakeri*

This unit and the following map units 14b and 14c are part of the Castlereagh Woodlands of Benson & Howell (1990*a*), the characteristic vegetation of the Tertiary alluvial deposits of western Sydney with a very rich but poorly conserved flora.

Low woodland is found on sandy soils of the Tertiary alluvium around Castlereagh-Londonderry and at Holsworthy. It ranges from low woodland to woodland structure, with estimated canopy height ranging from 8 to 12 m. Projected foliage cover ranges from 20–32%. This structure probably approaches the original pre-settlement structure as neither of the main tree species has been cut to any great extent. This is also indicated by the mean basal area for the community (15.4 m^2/ha) (Table 10), which is much higher than the *E. fibrosa* open-forest 11.5 m^2/ha), a community that has been heavily logged. Fire, however, appears to have been frequent in recent times and may have increased the proportion of multi-stemmed plants. The understorey is variable, a 2 m high shrub layer being present at some sites but being replaced by sedges or grassed under conditions of poor drainage or frequent burning.

Eucalyptus sclerophylla, Scribbly Gum, is the most distinctive tree species, occurring as large spreading trees 8 to 12 m high. The most common species, however, is *Angophora bakeri*, generally a small tree with characteristically twisted branches. This species makes up to 70% of the basal area and 82% of stem density compared with 13% basal area and 6% stem density for *E. sclerophylla* (Table 10). Other tree species which may be present are *E. fibrosa*, *E. gummifera*, *E. eugenioides*, and in places with poorer drainage *E. parramattensis* subsp. *parramattensis*, *E. sideroxylon* and *Melaleuca decora*. A small group of *E. eximia* trees were found at the southern end of Castlereagh State Forest and may be a chance colonisation from the lower Blue Mountains. *Angophora bakeri* seems to be very tolerant of a wide range of drainage conditions and is equally common with *E. sclerophylla* on well drained sites, and *E. parramattensis* on poorly-drained ones.

Table 10. Basal area and density of major tree species from 6 sites in Castlereagh Scribbly Gum Woodland.

	Basal area (m^2/ha)			Density (plants/ha)		
	mean	(± s.e.m.)	% of total area	mean	(± s.e.m.)	% of total density
Angophora bakeri	10.84	2.0	70	496	139	82
Eucalyptus sclerophylla	2.06	1.4	13	38	17	6
Total	15.42	1.7		604	132	

Other species contributing to total basal area are *Eucalyptus fibrosa*, *E. gummifera*, *E. parramattensis* subsp. *parramattensis* and *Melaleuca decora*.

The understorey is of sclerophyllous shrubs. These may form a continuous cover or be more open, with grasses in between. Common shrub species are *Banksia spinulosa* var *spinulosa*, *Grevillea mucronulata*, *Hakea sericea*, *Leptospermum trinervium* and *Melaleuca nodosa*. At least two nationally rare shrub species endemic to the Tertiary alluvium of western Sydney, *Micromyrtus minutiflora* and *Persoonia nutans*, are found in this community. Recently a new species of *Allocasuarina*, *Allocasuarina glareicola* was discovered and described in Castlereagh State Forest in this community. There are only two small populations so far known.

The more open communities often result from frequent burning which favours the grasses and sedges at the expense of the shrub species. Common species are *Themeda australis*, *Eragrostis brownii*, *Patersonia sericea* and *Cyathochaeta diandra*. At certain times in the year ground orchids may be conspicuous.

This community usually grades gently into the adjacent *E. fibrosa* open-forest or *E. parramattensis* subsp. *parramattensis* low woodland. Where it adjoins communities on Wianamatta Shale the transition may be much more abrupt.

Soils on sites occupied by Scribbly Gum Woodland are very poor and until recently this community remained essentially undisturbed. However, extensive extraction of sand and gravel is now resulting in the removal of much vegetation, whilst the subdivision of much of the remainder into small holdings for suburban development, hobby farms, poultry farms etc. is also decreasing its extent. No examples have been reserved by the National Parks and Wildlife Service though proposals to make Castlereagh State Forest a Nature Reserve or Flora Reserve would ensure good conservation of this community. In general the future for the community appears to be poor. Hobby farm development results in the removal of understorey species and their replacement with exotic grasses, whilst council reserves are generally mown with similar results. The latter is regrettable for with care such remnants could be preserved in many areas as local examples of the original vegetation.

As far as disturbance, viability and management are concerned, similar comments to the Castlereagh Ironbark Forest, apply to this community. It is a well-drained community, on a nutrient poor soil which acts as a buffer to exotic weed invasion. Only three exotic species were recorded in this survey. The apparent uselessness of this soil type for agriculture and the unspectacular nature of the flat terrain make it appear as 'useless scrub', but if efforts are made to retain small stands in reserves etc., the richness and nature of the species in them could be successfully conserved.

Map Unit 14b - Agnes Banks Woodland

Low woodland/open-scrub: *Eucalyptus sclerophylla - Angophora bakeri - Banksia serrata.*

At Agnes Banks, south-west of Richmond, is a deposit of windblown sand of Pliocene-Pleistocene Age (Gobert, 1978) that supports an interesting shrub-dominated community, floristically similar to that found on coastal sand dunes such as those near Myall Lakes.

Soil depth varies from very thin at the edges, where the sands overlie the clay soils of the underlying Tertiary alluvium, to up to 7 m thick at the dune crests. On crests and ridges a 'coffee-rock' pan (<5 cm thick) occurs about 80 cm below the surface. On footslopes and in swales this pan is missing or may be discontinuous (Bannerman & Hazelton 1990). This pan may direct water into the swales increasing the differences in moisture between crests and swales. The relationship of vegetation to drainage conditions and the effects of a perched water table above a 'coffee-rock' horizon are shown in Figure 5.

Community structure is predominantly woodland to low woodland, but ranges from low open-forest to sedgeland. The characteristic tree species on well-drained sites are E. *sclerophylla* and *Angophora bakeri* and on poorly-drained sites *E. parramattensis*. *Banksia serrata* is generally a smaller but very distinctive tree species. Benson (1981) describes the vegetation in terms of five plant communities which occur in a sequence along a drainage gradient. These are:

a) **Low open-forest of *Banksia serrata* and *Angophora bakeri*.** A community apparently originally confined to the well-drained crests of the large dunes, most of which have been completely removed by sand extraction. The main trees are *Banksia serrata* and *Angophora bakeri*, up to 10 m high but the community may have occasional large, emergent trees of *Eucalyptus sclerophylla* up to 13 m. There is an open understorey of *Pteridium esculentum* and *Imperata cylindria* and scattered shrubs including *Ricinocarpos pinifolius*, *Eriostemon myoporoides* and *Bossiaea rhombifolia*.

b) **Woodland of *Eucalyptus sclerophylla, Angophora bakeri* and *Banksia serrata*.** This is the most widespread community, found on well-drained sites. It is dominated by trees of *Eucalyptus sclerophylla* 10 to 15 m high, together with smaller trees of *Angophora bakeri* and *Banksia serrata*. A large number of sclerophyllous shrub species is characteristic of the understorey, common species being *Leptospermum trinervium, Conospermum taxifolium, Ricinocarpos pinifolius* and *Isopogon anemonifolius*.

c) **Woodland of *Eucalyptus sclerophylla, E. parramattensis* subsp. *parramattensis* and *Banksia aemula* [previously *B. serratifolia*].** At the southern end of the sand deposit is woodland dominated by *Eucalyptus sclerophylla* but which appears to be restricted to shallower or less well-drained sand than Unit (b). Small trees of *E. parramattensis* up to 10 m high and large shrubs of *Banksia aemula* up to 7 m high are generally present. An understorey of sclerophyllous shrubs, similar to that in (b) above, is usually present. *Banksia aemula* may indicate more podsolised soils than Unit (b) with *B. serrata*, a situation reported for Myall Lakes (Myerscough & Carolin 1986).

d) **Low open-woodland of *Eucalyptus paramattensis* subsp. *parramattensis*.** This community is confined to poorly-drained situations. Small trees of *E. parramattensis* less than 10m high, either in clumps or as scattered individuals, are dominant though *E. sclerophylla* and *Angophora bakeri* may be present occasionally. The understorey is dominated by *Banksia oblongifolia*, which is in the most low-lying sites form a low shrubland, devoid of trees. Large tussocks of sedges and rushes are common. One sedge species, *Restio pallens*, common on the north coast of NSW and in southern Queensland reaches its southern limit at Agnes Banks.

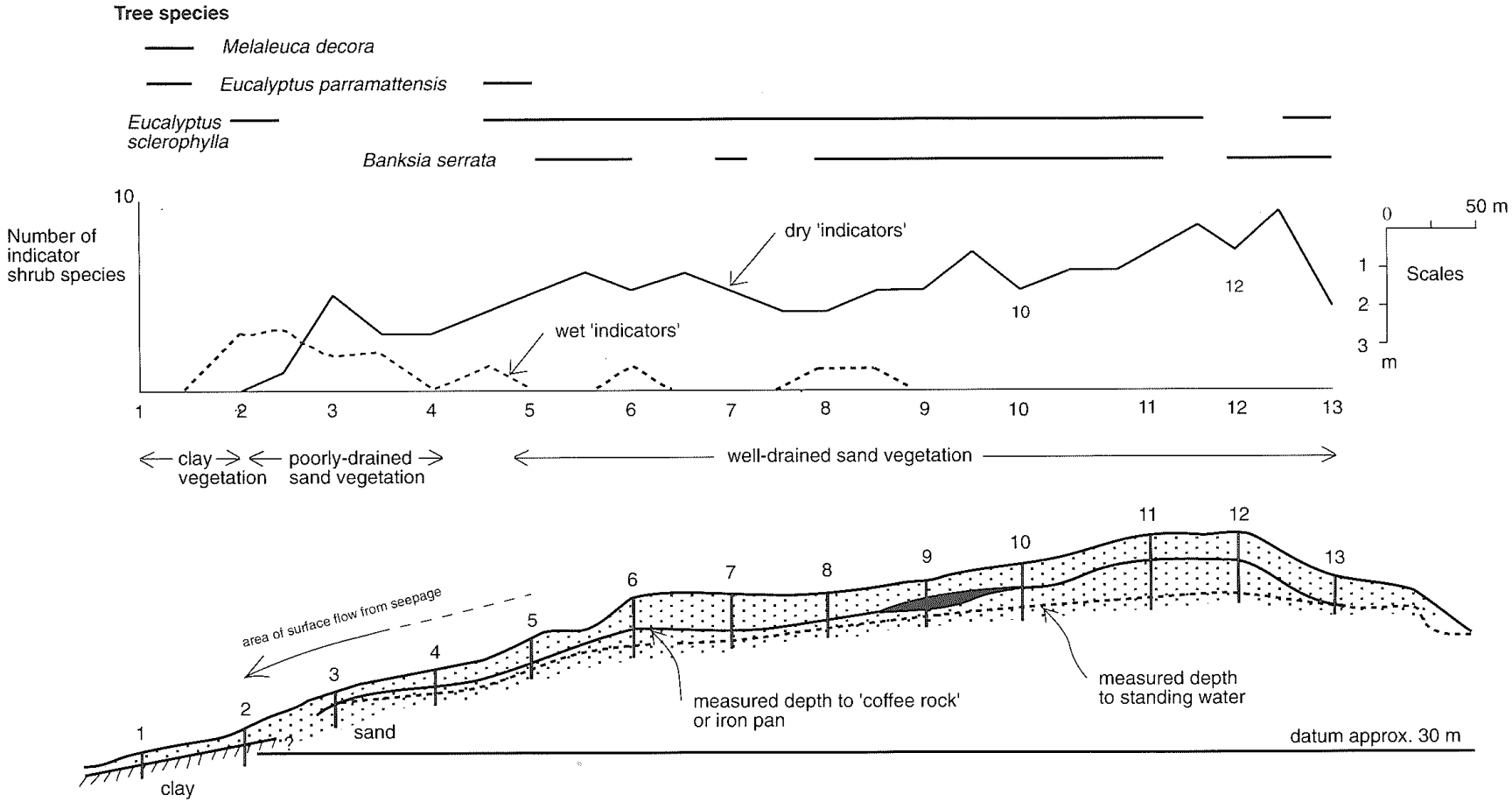


Figure 5. Occurrence of characteristic species along transect across sand dune at Agnes Banks showing relationship between topography and depth of iron pan. 'Wet' and 'dry' indicator species are those known from previous experience to be confined to particular moisture conditions.

e) **Sedgeland of *Lepidosperma longitudinale*,** with the small shrub *Melaleuca thymifolia*, occurs in a limited area in depressions between the main dunes where drainage is severely impeded. This vegetation has now been completely destroyed by mining and *Lepidosperma longitudinale* no longer occurs in western Sydney.

The vegetation on the sand deposit contrasts markedly with the surrounding vegetation and the boundary between the sand and the clay soils of the Tertiary alluvial deposits is very distinct. On the clay the dominant tree species becomes *Eucalyptus fibrosa* and the rich shrub understorey is replaced by a more open one predominantly of *Melaleuca decora* and *Bursaria spinosa* with a dense ground cover of grasses.

Part of this community is conserved by the Agnes Banks Nature Reserve but the area represented, 16 ha, is inadequate. Because it is on the shallowest sand, it preserves only a limited number of the characteristic species of the sand, and does not include examples of the low open-forest of *Banksia serrata - Angophora bakeri*, or the sedgeland of *Lepidosperma longitudinale*, or very much of the woodland of *E. sclerophylla - Angophora bakeri - Banksia serrata*. A Commission of Inquiry (Cleland 1988) found a further adjoining area to the north, to be of significance and a Permanent Conservation Order was recommended and later imposed by the Minister. The remaining sand area is proposed to be mined for construction sand.

Map unit 14c - Swamp Woodland

Low woodland: *Eucalyptus parramattensis* subsp. *parramattensis - Melaleuca decora*

Along creeklines, particularly Rickabys Creek, and in poorly-drained depressions on Tertiary alluvium near Castlereagh and Londonderry, is low woodland of *Eucalyptus parramattensis* subsp. *parramattensis* and *Melaleuca decora*. Occasional tree species include *Eucalyptus sideroxylon* and *E. sclerophylla*. Tree height at recorded sites ranged from 8 to 12 m and projected foliage cover from 8 to 18%. Basal area and plant density are much lower than the associated Castlereagh Ironbark and Scribbly Gum woodland (Table 11), but are probably indicative of the original structure, as the community has suffered little disturbance because of the poor agricultural soil and poorly-drained sites where it occurs. The main tree species, *E. parramattensis* subsp. *parramattensis* makes up about 31% of basal area and 44% of plant density (Table 11). Stem diameters are generally small and almost always less than 25 cm d.b.h. The associated tree species *Melaleuca decora* and *E. sclerophylla* may both have larger stem

Table 11. Basal area and density of major tree species from 3 sites in *Eucalyptus parramattensis* subsp. *parramattensis* low woodland.

	Basal area (m^2/ha)			Density (plants/ha)		
	mean	(± s.e.m.)	% of total area	mean	(± s.e.m.)	% of total density
Eucalyptus parramattensis	1.96	0.8	31	166	74	44
Melaleuca decora	1.76	1.7	28	83	71	22
E. sclerophylla	1.20	0.6	19	75	43	20
Total	6.39	0.7		375	80	

Other species contributing to total basal area are the tree *Eucalyptus sideroxylon* and the small tree *Angophora bakeri*.

diameters, though *E. sclerophylla* is generally a smaller tree than where it is found in Scribbly Gum Woodland.

The understorey is grassy and herbaceous with many annual or ephemeral species which respond to wet conditions. Density varies with the frequency and period since the last fire. The shrub layer may be mid-dense to open. Common species are *Banksia oblongifolia, Kunzea capitata, Hakea sericea* and *Melaleuca thymifolia.* The ground cover may be grassy and herbaceous or up to 60% bare. Common ground species are *Themeda australis, Imperata cylindrica, Dianella revoluta* and *Lepyrodia* species. Many species are annual or perennial and respond to wet conditions. These include *Isotoma fluviatilis* subsp. *fluviatilis, Gratiola pedunculata, Elatine gratioloides, Nymphoides geminata, Haloragis heterophylla, Lythrum hyssopifolia* and *Boronia polygalifolia.* Other species are particularly conspicuous after fire including *Ptilanthelium deustum* and terrestrial orchids including *Caladenia caerulea, C. carnea, Diuris maculata* and *Lyperanthus suaveolens.*

Depending on drainage Swamp Woodland may grade either gradually or abruptly into the associated Scribbly Gum Woodland (community 14a).

Many of the swamp woodland species have narrow habitat requirements and although widespread in distribution, are now rare or vulnerable because of loss of habitat, particularly on the Cumberland Plain, where most creeks and wet areas have been severely disturbed. For many of these species at least over half of herbarium collection sites on the Central Coast botanical subdivision are now likely to have been destroyed. One species *Hypsela sessiliflora,* originally collected from wet sites on the western Cumberland Plain has now been declared extinct (Briggs & Leigh 1988).

Swamp Woodland is potentially viable in the long-term. Because of the low nutrient status and poor agricultural value, it has remained essentially undisturbed, the low nutrient status and somewhat sandy nature of the soil being a buffer to exotic weed invasion except perhaps for *Andropogon virginicus.* Its poor drainage and occurrence in depressions and drainage channels, however, makes it susceptible to nutrient inflow and sedimentation, both of which facilitate weed invasion. Furthermore, it is now threatened by extensive clay-shale extraction proposals and hobby farm and suburban subdivision. No examples of this community have been reserved by the National Parks and Wildlife Service though a proposal to enlarge Agnes Banks Nature Reserve to the south, thereby including a good example of this community is now being considered. Castlereagh State Forest also includes some areas of this community.

Map unit 21f - Lower Blue Mountains Heath

Open-heath: *Eucalyptus stricta - Allocasuarina nana*

Open-scrub: *Angophora hispida*

Open-heath and open-scrub form part of the Sydney Sandstone Complex (in particular part of the Sydney Sandstone Ridgetop Woodland map unit 10ar). Open-heath is extensive enough to be mapped separately south of Woodford. Here it occurs on a series of rocky ridgetops along the Woodford Range. Characteristic species are the mallees of *Eucalyptus stricta* which here may have intergrading characteristics with *E. apiculata,* also *E. multicaulis, E. consideniana* and *E. oblonga.* A variety of shrub species is common including *Banksia ericifolia, Dillwynia floribunda* and *Petrophile pulchella,* together with ground species including *Lepidosperma flexuosum, Schoenus villosus, Restio fastigiatus, Patersonia glabrata* and *Lepyrodia scariosa. Allocasuarina distyla* is generally more common than *Allocasuarina nana.*

Small patches of open-scrub with *Angophora hispida* are found around Annangrove and Maroota, and in the former Maroota State Forest. Here rock platforms may have heathy 'islands' of shrubs growing in shallow soil in hollows in the rock. A rare shrub species endemic to those sites in the Maroota area is *Kunzea rupestris*. Characteristic species of these sites include *Calytrix tetragona, Dillwynia floribunda, Grevillea buxifolia, Petrophile pulchella* and *Platysace ericoides*. This vegetation probably represents a lower rainfall variant (annual rainfall about 800 mm) of the more coastal sandstone heath (annual rainfall 1 000-1 200 mm) found in Ku-ring-gai Chase and Marra Marra National Parks, rather than being Lower Blue Mountains Heath. Such areas are too small to show on the Penrith Map.

Map unit 26a - Blue Mountains Sedge Swamps

Closed-sedgeland: *Gymnoschoenus sphaerocephalus - Lepidosperma limicola - Xyris ustulata - Baeckea linifolia*

This community, part of the Hawkesbury Sandstone Complex, is restricted to a number of poorly-drained sites on the Hawkesbury Sandstone plateau north of Springwood. These are generally related to impervious shale strata which collect the water and direct it out along springs and soaks which often follow topographic contours. Floristic composition is related to moisture availability and sediment depth. With deep sediment and permanent moisture the characteristic species are *Gymnoschoenus sphaerocephalus, Lepidosperma limicola, Xyris ustulata* and *Baeckea linifolia*. Where moisture is ephemeral, *Lepyrodia scariosa* predominates (Holland, Benson & McRae 1992). The main occurrence of sedge swamp however is in the higher Blue Mountains further west, from Wentworth Falls to Clarence where sedgeland and swamps are a characteristic feature of the landscape (Keith & Benson 1988).

Map unit 28a - Freshwater Wetlands

Open-sedgeland: *Eleocharis sphacelata - Juncus usitatus - Persicaria* spp.

Shrubland: *Melaleuca linariifolia*

Freshwater wetland and swamp communities were once a feature of the Nepean–Hawkesbury floodplain. In the lower Hawkesbury between Pitt Town and Wisemans Ferry, these wetlands or 'backswamps' form in the depression between the levee bank along the River edge and the sandstone hillsides of the main river valley. Below Wisemans Ferry, wetlands are estuarine and influenced by salinity (see map unit 4a). Upstream of Pitt Town wetlands are less frequent and occur as depressions on the river floodplain. Most have now been cleared or drained. Indeed remnant wetlands vary considerably in terms of floristic composition, drainage and flooding conditions and water quality, and it is difficult to generalise on wetland behaviour.

Zonation patterns may be recognised in particular wetlands and related broadly to differences in water depths and periods of inundation. Floodplain wetlands may have areas that are permanently wet, semi-permanent with water present most of the year, or seasonal, which are dry for the greater part of the year depending on local rainfall conditions. Permanent and semi-permanent wetlands may have emergent reedland of *Eleocharis sphacelata*, which may grow to 1–2 m above the water level. *Typha* spp. may indicate higher-nutrient conditions or brackish water. Common smaller species are *Ludwigia peploides* subsp. *montevidensis, Triglochin procera, Myriophyllum* spp. and *Philydrum lanuginosum*. Death of above-ground vegetation during winter may result from severe frosts. Permanent wetlands often have extensive areas of open water sometimes with floating or submerged vegetation, depending on water depth or seasonal conditions.

Seasonal wetland zones do not usually have standing water, except following rain or during flooding, but the soil is often waterlogged or very moist. They may have rushland with tussocks of *Juncus usitatus* or herbland with scrambling *Persicaria* spp. (*P. decipiens, P. hydropiper, P. lapathifolia, P. praetermissa*). Less common are *Myriophyllum, Marsilea* and *Ranunculus* spp. There may be scattered individual shrubs where stock grazing has prevented regrowth or tall shrubland with *Melaleuca linariifolia, M. styphelioides* or *Casuarina glauca*. Depending on the topography the tall shrubland may grade into *Eucalyptus robusta* swamp woodland or, more commonly give way to *E. amplifolia* subsp. *amplifolia* - *Angophora subvelutina* River-flat Forest or Grey Box Woodland. In general the forest or woodland near wetlands has been cleared.

Remaining floodplain wetlands are concentrated in the area between Richmond and Sackville. Adam & Stricker (1989) record 25 floodplain wetlands for the 1:25 000 Wilberforce map sheet area that covers this area. These cover about 860 ha or over 80% of the total area of remaining floodplain wetland for the Penrith map sheet area (Figure 6). Sites with high conservation capability ratings include Wheeny Lagoon, Broadwater/Little Cattai Creek, Portland Head Farm, Reedy Swamp, Hawkesbury Campus of the University of Western Sydney and Castlereagh State Forest.

By their nature, many wetlands are narrow strips too small to show at the 1:100 000 scale of the Penrith map. Their absence does not indicate lack of importance, merely

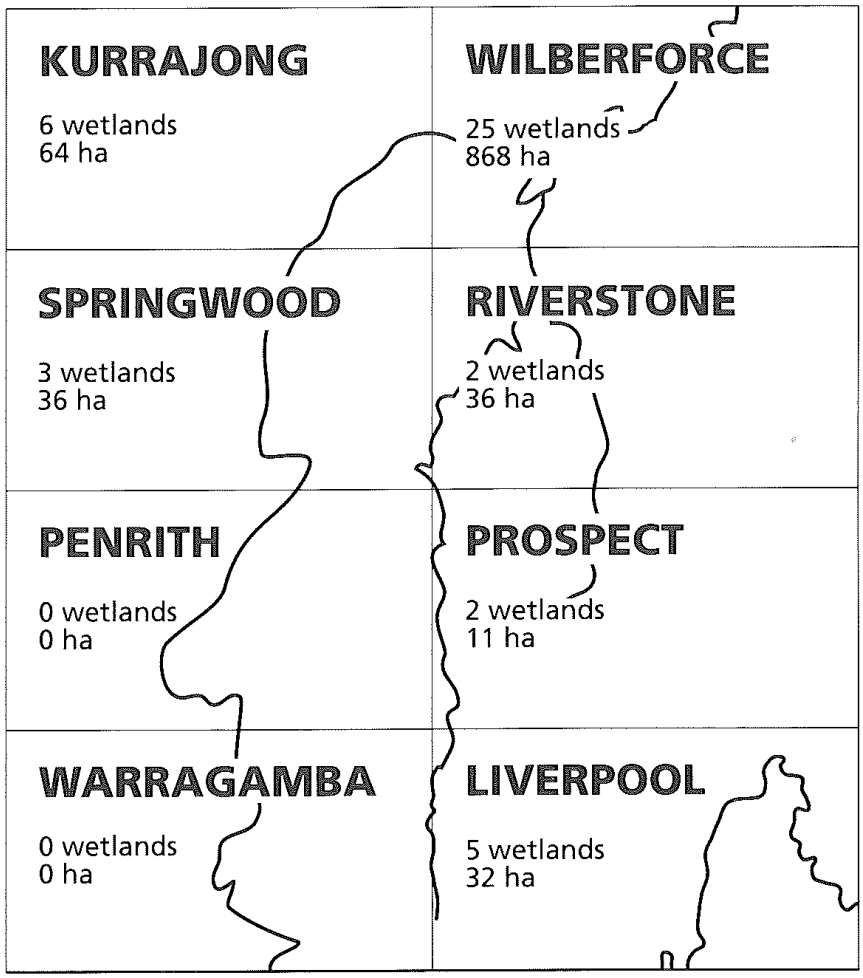


Figure 6. Area (ha) and number of floodplain wetlands within 1:25 000 map areas of the Penrith sheet. Data from Adam & Stricker (1989).

technical limits to their representation. Examples are Reedy Swamp in Mitchell Park, Pughs Lagoon near Richmond, backswamps between Yarramundi and Lowlands and at McGraths Hill.Though much freshwater swamp has been drained and replaced with improved pasture, indications of the original swamp vegetation may remain. *Juncus* spp. particularly *J. usitatus*, are of low palatability to stock and may persist.

Floodplain wetlands on the Georges River include Horseshoe Pond, New Brighton, Deepwater Park, Stockade Reach and Voyager Point. Voyager Point has an extensive wetland in very good condition. It is cut off from the Georges River by a levee bank and consequently fresh, rather than estuarine. In its upper parts the vegetation is low woodland and scrub with shrubs of *Melaleuca nodosa* and small trees of *Eucalyptus parramattensis* subsp. *parramattensis*. This is on very low nutrient soils derived from Tertiary alluvium. Further down tall shrubs of *Melaleuca ericifolia* and *M. decora* predominate, while at the northern end is an extensive area of sedgeland, with *Eleocharis sphacelata, Triglochin procera* and *Typha orientalis*. At the time of inspection there were extensive areas of open-water with a variety of small floating water plants such as *Myriophyllum, Utricularia* and *Nymphoides*. There is considerable fluctuation in the water level over the seasons. For example in August 1986 there was very little water. The vegetation here is extremely good condition with healthy native vegetation and very few weeds.

Wetlands in the Lower Blue Mountains are not floodplain wetlands but generally associated with deep sandy soils, very low nutrient status and impeded drainage. Burralow Swamp at Kurrajong on the margin of Blue Mountains National Park is an isolated wetland draining south to the Grose River. It is part of Burralow Swamp Soil Landscape (Bannerman & Hazelton 1990) and has a more sandy substrate than the floodplain wetlands, a very low fertility status (compared with the moderate fertility of the floodplain wetlands), very little standing water and a predominance of shrubs and ferns. Species include *Leptospermum polygalifolium, Hakea salicifolia, Hypolepis muelleri, Gleichenia dicarpa, Eleocharis sphacelata* and *Gahnia clarkei*. Other creeks in the Lower Blue Mountains, with deep sandy alluvium, such as Long Angle, Frasers and Fitzgeralds Creeks have similar vegetation often with *Melaleuca linariifolia* and forest of *Eucalyptus deanei*. Glenbrook Lagoon is a permanent open-water wetland of similarly low nutrient status with important sedgeland of *Lepironia articulata*, one of very few occurrences of this species in the Sydney area.

Seasonal wetlands have probably suffered the most from disturbance from draining, damming or grazing. Species in these sites probably depend on fluctuating water levels to promote growth and flowering. Alterations such as draining or damming stop seasonal levels from fluctuating and reduce sites for seasonal wetland species. Many of these are becoming rarer, but because we have limited data on their distributions, changes are difficult to quantify. At Longneck Lagoon, long term higher water levels and possible changes in water quality have occurred with a loss of wetland species and the growth of previously less common species.

Though there have been several general surveys of the extent of swamps along the Nepean–Hawkesbury system (Royal Botanic Gardens, 1986; Adam & Stricker 1989), there has been very little work on the plant ecology of the swamps themselves, despite the changes that are evident in lagoons like Longneck where past disturbance from stock grazing, draining and, most recently, partial damming by roadworks has altered the relative extent of vegetation zones and introduced a large number of exotic species. The task of separating the changes resulting from human activities - catchment disturbance and hydrological alterations - from climatically induced change, is difficult. However more information on these aspects is needed if adequate management of surviving wetlands is to be undertaken (Figure 7).

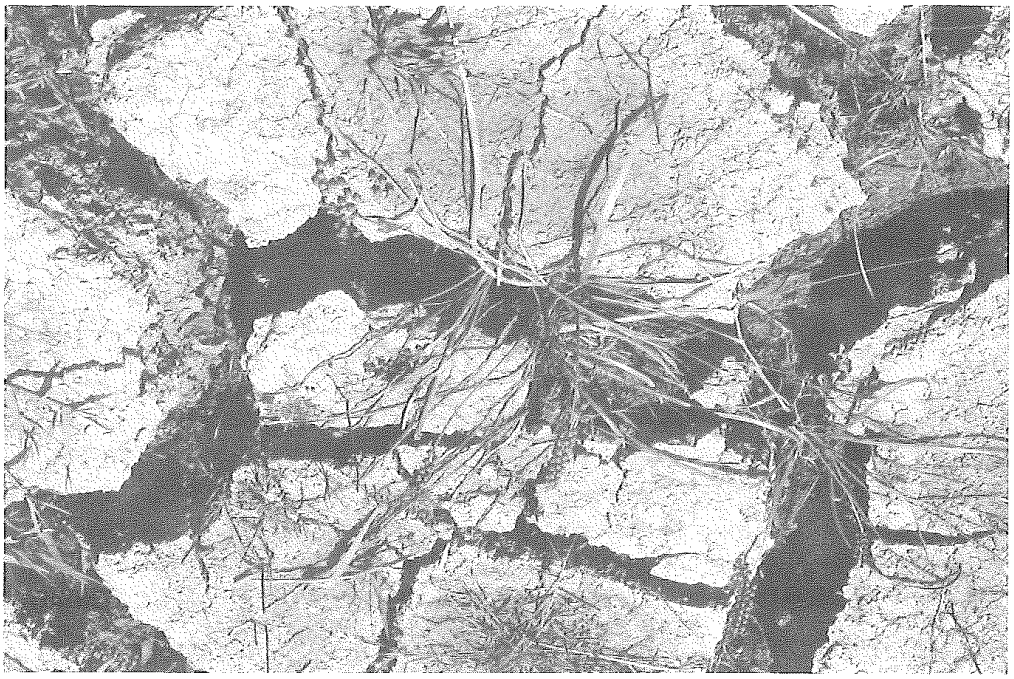


Figure 7. Floodplain wetland plants are adapted to fluctuating water levels; short periods of dryness can promote germination and establishment of new plants, such as *Triglochin procera* shown in mud cracks here at Reedy Swamp, Cattai, following a dry spring.

Cleared areas

Agricultural development and urban settlement have generally followed the more fertile soils of the alluvial flats and the Wianamatta Shale of the Cumberland Plain. The low nutrient soils of the Hawkesbury Sandstone and Tertiary alluvium have frequently survived with natural vegetation though extensive areas of Tertiary alluvium are now being cleared for extraction of sand and gravel. The major wildlife reserves are all on Hawkesbury Sandstone.

Discussion

Vegetation patterns

Vegetation patterns shown on the map sheet are limited by the scale of the final work. At 1:100 000 scale areas less than about 200 m across, for example, cannot be reproduced. Mapping conventions use lines to indicate boundaries, which may in reality be ecotones or gradations. Plant communities themselves may vary in composition in a much more complex way than can be indicated by assigning dominant species which may or may not be present at any particular place. The mapping units recognised here are subjective and result from observation and correlation of landform and floristic features. These correlations have not been experimentally confirmed though many of the patterns recognised have been proposed by earlier writers and confirmed by the extensive field observations of the present writer.

The close relationship between vegetation and geology in the Sydney area was recognised by the early explorers and settlers and used to assess potential land use (see earlier quotations). Many of their observations were confirmed later by scientists; Barwick (1903) and Carne (1908) describe the characteristic flora associated with volcanic necks. Cambage (1905) describes species restricted to areas of Narrabeen Group geology, and differences between the vegetation of the Wianamatta Shale and Hawkesbury Sandstone. Pidgeon (1937, 1941) described the major vegetation types confined to these geologies and Phillips (1947) discussed the differences between the vegetation on Wianamatta Shale, Tertiary alluvium and Holocene alluvium, respectively. Pidgeon described vegetation in terms of climax communities with the Precipitation/Evaporation index as a measure of the principal factor determining the distribution of vegetation. She stated that on shale the climate factor, and on sandstone the soil factor, is limiting. Phillips pointed out, however, that the soil and climate are interacting factors. Beadle (1962) demonstrated that nutrients, particularly soil phosphate are important in the distribution of vegetation types, and that the introduction of nutrients in the normally low nutrient soils both inhibits growth of native species and promotes the invasion of exotic weed species. Current thinking rejects the earlier concepts of climax communities (e.g. Clements 1936) and interprets vegetation patterns in terms of responses of species to variations in geology, soil texture and fertility, soil moisture relations and local climate.

That soil fertility alone is not a sufficient indicator of vegetation is shown in Table 12. Here soil fertility groups (in terms of chemical composition) as determined for the soil landscapes of Bannerman & Hazelton (1990) are related to vegetation. The findings follow the general trends with vegetation on volcanic soils being most mesic and the scleromorphic heaths being found on very low-nutrient soils. The Floodplain

Table 12. Soil fertility (from Bannerman & Hazelton 1990) for various plant communities.

Soil fertility	**Plant community**	**Map code**
Moderate:	Glen Forest	6c
	Freshwater Reed Swamps-floodplain wetlands only	28a
Moderate-low:	Spotted Gum Forest	9b
	Turpentine - Ironbark Forest	9o
	Grey Box Woodland	10c
	Grey Box - Ironbark Woodland	10d
Low:	Shale Cap Forest	9a
	Ironbark Forest	9c
	Shale/gravel Transition Forest	9d
	Castlereagh Ironbark Forest	9e
	River-flat Forest	9f
	Sydney Sandstone Gully Forest	10ag
	Castlereagh Scribbly Gum Woodland	14a
	Swamp Woodland	14c
Low-very low:	Camden White Gum Forest	6d
	Agnes Banks Woodland	14b
Very low:	Estuarine Complex	4a
	Sydney Sandstone Ridgetop Woodland	10ar
	Lower Blue Mountains Heath	21f
	Blue Mountains Sedge Swamps	26a
	Freshwater Reed Swamps-Lower Blue Mtns wetlands	28a

Forests, however, presumably with some of the biggest trees, and certainly the areas sought for cultivation by the early settlers, occurred on low nutrient soils according to Bannerman & Hazelton (1990). It would appear that soil texture, a permanent water supply and periodic flooding probably compensated for the low soil nutrients, which are indeed lower than for the nearby shale soils.

Regional affinities

The Penrith Map Sheet Area includes the largest areas of the Wianamatta Shale and Tertiary alluvial soils in the Sydney area. The Cumberland Plain Woodlands (Map Units 9b, 10c, 10d) are part of the Box Woodlands of the East and South-East described by Beadle (1981), in particular, part of his *Eucalyptus moluccana* Alliance. This occurs in rainshadows near the coast, e.g. the Cumberland Plain and the floors of the Hunter and Clarence River valleys, as well as patchily in the intervening areas, with outliers in the south, the drier parts of the Illawarra Plain, the Araluen and Bega valleys and a northern extension in small isolated stands as far as the Tropic of Capricorn. Beadle gives a number of grass and herb species for the Cumberland Plain and Hunter Valley though it is apparent that associated species are quite different as the Tropic is approached.

The Castlereagh Woodland is part of Beadle's Ironbark Forests and Woodlands of the East, and is referred to under his *Eucalyptus crebra* Suballiance, though the communities at Castlereagh contain more *Eucalyptus fibrosa* and even *E. sideroxylon* than *E. crebra*. The *E. crebra* Suballiance occurs throughout a large area of Queensland from north of the Tropic, through south-eastern Queensland onto the coastal lowlands of N.S.W. The communities form ecotonal associations with the low fertility coastal assemblages (i.e. the sandstone flora), according to Beadle.

Differences between shale, sandstone and alluvial floras have been recognised for many years, both in the observations of early settlers as they searched for indicators of better agricultural land, and in the work of Pidgeon, Phillips, Beadle etc. The distinctiveness of the flora on Tertiary alluvium was recognised by Phillips but only became more generally known in the 1970s. The need for representative areas of communities of soils other than sandstone is discussed in Benson & Howell (1990*a* & *b*).

Regional resemblances of the floras on the different soil types are interesting. During a study of the rare plants of Western Sydney, total floristic lists for the Cumberland Plains Woodland (439 species) and the Castlereagh Woodland (242 species) were compiled. Using distributional data from an updated version of Jacobs & Pickard (1981) we compared these floras with the total floras for the Botanical divisions and subdivisions of New South Wales (Table 13). We also compared the sandstone flora of Ku-ring-gai Chase National Park (313 species). The results show that whilst the flora of the Cumberland Plain Woodlands and the Castlereagh Woodlands has strongest resemblances with the Coastal subdivisions, nearly 75% of the Cumberland Plain flora also occur on the Western Slopes and nearly 45% on the Western Plains. The figures for the Castlereagh Woodlands are slightly lower at 66% and 37% respectively. This is much higher than for the Hawkesbury Sandstone flora, where only 34% of species occur on the Western Slopes and 10% on the Western Plains. It is also worth noting that, as well as having a similar floristic composition to the flora of the Cumberland Plain, that of the Western Slopes has been subjected to similar clearing and grazing pressures and is also poorly conserved (Figure 8).

In examining the current distribution of the vegetation it should also be borne in mind that species distributions have varied in response to fluctuating past climatic change. About 20 000 years ago, during the coldest part of the last of the Pleistocene

Table 13. Comparison of western Sydney flora with other botanical subdivisions of New South Wales.

Vegetation type*	No. of species	Percentage of species also occurring in				
		NC,SC	NT,CT,ST	WS	WP	FWP
Cumberland Plain Woodlands	439	94	87	74	44	17
Castlereagh Woodlands	242	92	87	66	37	10
River-Flat Forests	216	95	92	70	39	12
Hawkesbury Sandstone (Ku-ring-gai Chase NP)	313	85	81	34	10	2

*from Benson & Howell (1990*a*)
NC-North Coast, **SC**-South Coast
NT-Northern Tablelands, **CT**-Central Tablelands, **ST**-Southern Tablelands
WS-Western Slopes
WP-Western Plains
FWP-Far Western Plains

ice ages, the sea fell to its lowest level, 120–140 m below the present level (Benson & Howell 1990*a*). Given the close correlations of many species with climate today it is not unreasonable to speculate on vegetation patterns at this time. Many of the species on the Cumberland Plain are also found in the Tablelands and Slopes and are likely to have been able to cope with the colder and drier conditions. The Floodplain forests are likely to have migrated further down the Hawkesbury into the sheltered protection offered by the unflooded valleys of Broken Bay and Port Jackson. The coastal plain, beyond todays coastline, may have had sand dunes and alluvial soils perhaps with *Eucalyptus pilularis* - *Angophora costata* forests and associated vegetation similar to that found on the coastal lands at Myall Lakes. As sea level rose again to reach its present level about 6,000 years ago, it drowned the coastal river valleys of the Hawkesbury and formed the present floodplain. Coastal species including *Banksia aemula* and *Restio pallens*, another 'wallum' species, could have been dispersed inland to colonise suitable sandy substrates such as at Agnes Banks. A number of other Cumberland Plain species have disjunct coastal occurrences today - *Pimelea spicata*, *Thesium australe*, *Melaleuca nodosa* - possibly remnants of past migration patterns.

Such comments are speculative - more research into pollen studies, variation patterns within species and ecology and physiology is needed. However if we are to retain the raw material for these studies, conservation of adequate in situ populations across the area, not contaminated by genetic material transplanted from other areas, is necessary.

Rare or endangered species

A list of the native flora of western Sydney - covering most of the Penrith Sheet - has been recently prepared (Benson & McDougall 1991). This lists nearly 1 000 native species for the area with their conservation status. Many of these species are now very rare; 373 are regarded as vulnerable in a regional context. Of a list of 84 species, regarded as having particular conservation significance in western Sydney, 44% were

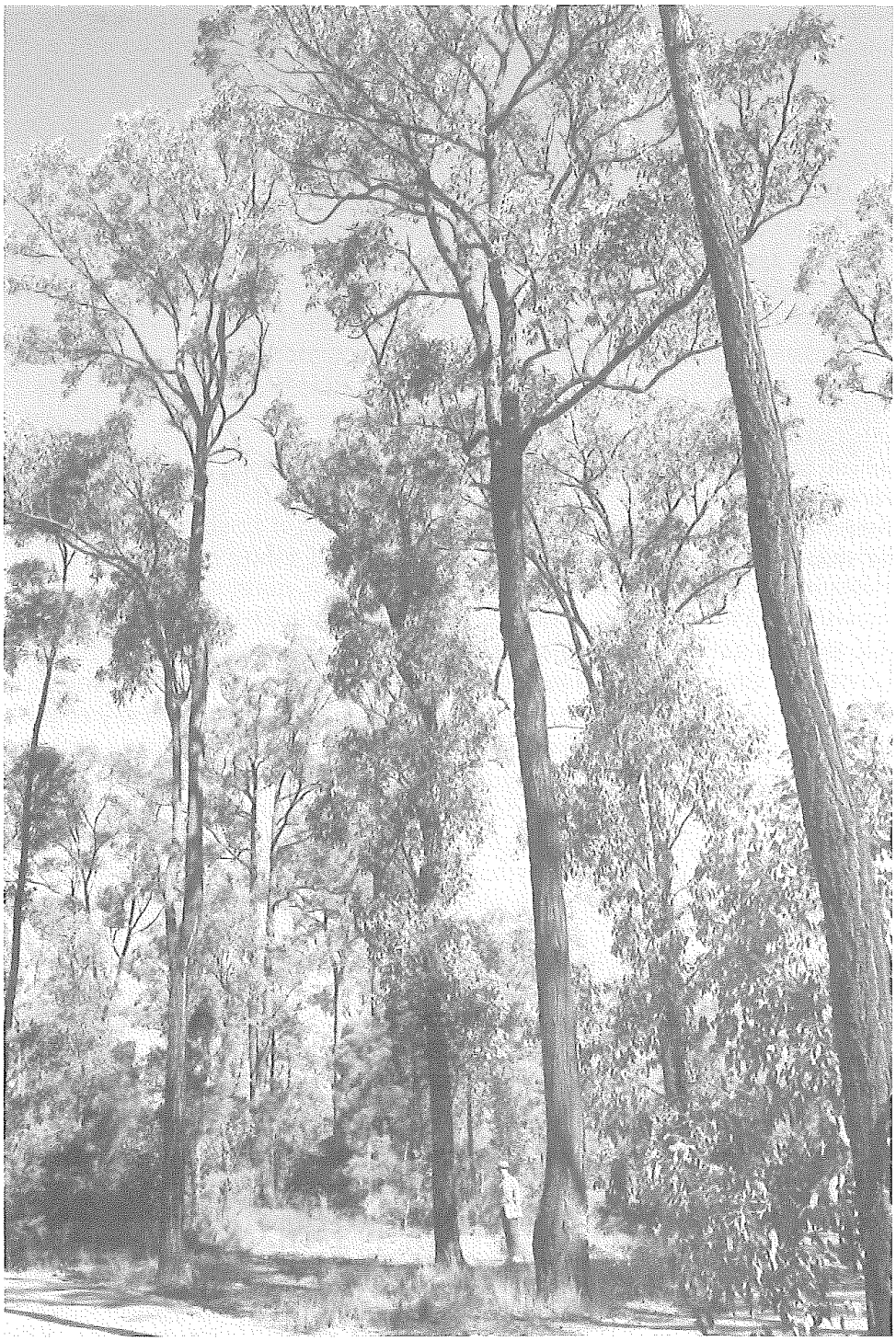


Figure 8. Some of the species found in the Castlereagh Woodland, such as the ironbarks *Eucalyptus fibrosa* and *Eucalyptus sideroxylon* also occur on the Western Slopes of New South Wales, under similar rainfall and soil conditions. Genetic differences between coast and inland populations provide potential scientific research material.

recorded in the Cumberland Plain Woodlands and 36% in the River-flat Forests (including freshwater wetlands), highlighting the need for better conservation of remnants of these vegetation types. Species of particular conservation significance within the Lower Blue Mountains region (not covered by Benson & McDougall) are given in Table 14.

At the very least, conservation plans for all those on the national list (Briggs & Leigh 1988) such as *Pultenaea parviflora, Micromyrtus minutiflora, Persoonia nutans, Acacia pubescens* (the largest remaining population, at Prestons, is currently threatened) and *Pimelea spicata* should be carried out urgently.

Conservation of vegetation

Long-term conservation strategies to conserve and enhance natural vegetation in the Penrith sheet area are needed. These should include:

1. Protection of major reserves and their catchments

Table 15 and Figure 9 show the conservation reserves for plant communities on the Penrith Sheet. Though large areas of sandstone country on the Lower Blue Mountains are protected, it is clear that conservation of the western Sydney vegetation, and in particular the Cumberland Plain and Castlereagh Woodlands is inadequate. Conservation of these areas has been actively sought since the early 1970s, but increasing land prices and the tendency to put off difficult land use decisions, has impeded progress. Recommended major conservation areas given in Benson & Howell (1990*a*) are:

- The catchment of Longneck Lagoon which includes important areas of Grey Box woodland and protects the catchment of this important wetland;
- The southern additions to Agnes Banks Nature Reserve; these would protect significant areas of Castlereagh Woodland on poorly drained sites;
- Castlereagh State Forest, which needs permanent protection as a flora reserve for its important ironbark forests and diverse flora;
- Commonwealth land at Shanes Park, which should be acquired to protect intergrading vegetation on shale and Tertiary alluvium;
- The Mulgoa Nature Reserve proposal with its interesting shale cliff-line habitat;
- The Kemps Creek Nature Reserve proposal, which should be established to protect low-lying Cumberland Plain Woodland;
- Water Board land around Prospect Reservoir, needing permanent protection for its important woodlands.

To date (February 1992) none of these areas have been formally protected.

2. Identification and protection of small remnants

Much of the long-term conservation of the flora of western Sydney will depend on the conservation and management of small reserves by a number of different authorities including the N.S.W. National Parks and Wildlife Service, Forestry Commission, Water Board, and about 10 local councils. Success will be patchy and depend in the long term on availability and application of specific information on the nature of the particular reserve, together with a general increase in education in environmental management.

Table 14. Species of particular conservation importance within the Lower Blue Mountains region of the Penrith 1:100 000 map sheet. For significant species of the western Sydney and Cumberland Plain region, see Benson & McDougall (1991).

Species listed here are either rare or threatened (from Briggs & Leigh 1988) or of significance in terms of geographic distribution, or localised populations disjunct from other occurrences.

DICOTYLEDONS

CHLOANTHACEAE
Chloanthes glandulosa- Springwood to Kurrajong, main population, (one record for South Coast)

CUNONIACEAE
Acrophyllum australe- Woodford to Faulconbridge, 2VCi, local endemic

DILLENIACEAE
Hibbertia hermanniifolia- Bents Basin, Wallacia, 3RCa, disjunct local pop. Nth-limit

EPACRIDACEAE
Epacris sparsa- Avoca Vale, very rare local endemic
Leucopogon fletcheri- Springwood, Blaxlands Ridge, 3RC-, local pop.
Monotoca ledifolia- Sublime Point, Leura, 3RC-, locally restricted with small populations

MYRTACEAE
Eucalyptus benthamii- Nepean R. Wallacia- Camden, Kedumba Ck, 2VCi, local endemic
Eucalyptus burgessiana- Faulconbridge, Linden, 2RCa, local endemic
Leptospermum emarginatum- Nepean River, Penrith; Bents Basin, local pop. Nth-limit

PROTEACEAE
Grevillea longifolia- Lawson-Springwood, 2RC-, disjunct local pop.
Persoonia hirsuta- Springwood-Glenbrook, 3KCi, local pop.

RUBIACEAE
Canthium coprosmoides- Avoca Vale, local pop.
Psychotria loniceroides- Avoca Vale, local pop.

RUTACEAE
Zieria involucrata- Springwood, Burralow Swamp, 2VC-
Zieria murphyi- Tomah Saddle, 2VC-

SOLANACEAE
Cyphanthera scabrella- Glenbrook Gorge, Erskine Ck, Bowen Ck, 2RC-, restricted local endemic

TREMANDRACEAE
Tetratheca neglecta- Yerranderie, 2RC-

MONOCOTYLEDONS

CYPERACEAE
Carex neurochlamys- Avoca Vale local pop., Sth limit

IRIDACEAE
Libertia paniculata- Avoca Vale, local pop.

LOMANDRACEAE
Lomandra fluviatilis- Bents Basin, Nortons Basin, Glenbrook Creek, 3RC-

(pop = population, Sth - southern, Nth = northern; codings from Briggs & Leigh)

Table 15. Major conservation reserves in the area covered by the Penrith 1:100 000 map sheet.

Reserve	Approx area on map sheet (ha)
Agnes Banks Nature Reserve	64
Windsor Downs Nature Reserve	330
Bents Basin State Recreation Area	399
Georges River State Recreation Area	part only
Cattai (incl. Mitchell Park) State Recreation Area	116
Blue Mountains National Park	part only
Wollemi National Park	part only
Castlereagh State Forest (Demonstration Forest)	448

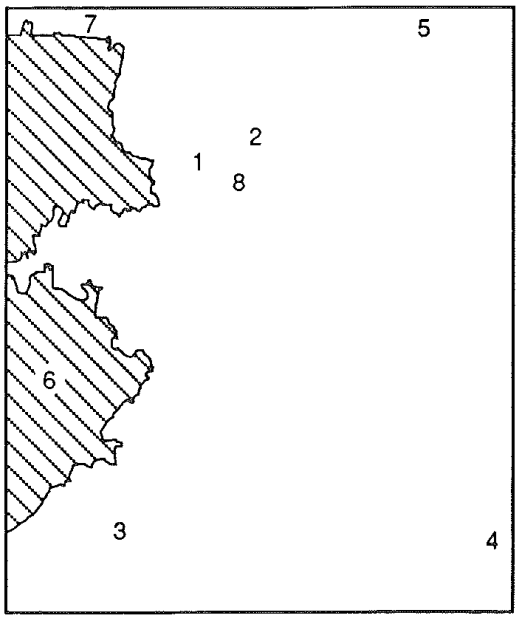


Figure 9. Location of conservation reserves for Penrith map sheet area. 1 Agnes Banks Nature Reserve; 2 Windsor Downs Nature Reserve; 3 Bents Basin State Recreation Area; 4 Georges River State Recreation Area; 5 Cattai State Recreation Area; 6 Blue Mountains National Park (hatched); 7 Wollemi National Park; 8 Castlereagh State Forest.

In particular, the importance of the role of local councils should not be overlooked. The now disparate occurrences of many of the plant species in western Sydney mean that many are not included within the National Parks and Wildlife Service reserves system and occur in small areas under council control (Figure 10).

Whereas local plant populations in the small reserves in the sandstone areas are generally backed up by larger populations in the surrounding National Parks, there are no large reserves for the Wianamatta Shale, Tertiary and Holocene alluvium plant communities of Western Sydney. The potential for future losses in reserves in these areas is therefore of far greater significance. Such areas will gradually become even more fragmented than they are now and the tendency to tidy up wild areas, using lawn mowers, herbicides, etc., along margins, fences, roads, paths, reduces irrevocably a little more of the natural diversity each time .

A long-term trend that should be recognised is the increasing amount and quality of run-off water being directed into remnant natural areas. The addition of nutrient and

Figure 10. Lansdowne Park contains extensive areas of Cumberland Plain Woodland, many of the species of which respond well to periodic fires. Fortunately it is large enough to support a managed fire regime, despite its suburban context.

promotion of weed invasion is now widely recognised (e.g. Buchanan 1989) and threatens, in particular, the low-nutrient habitats. Increasing volumes with increased nutrients result from the large scale paving of hard surfaces in built-up areas, the loss of trees, the greater use of water in gardens, car washing, sewer discharges, pet excrement (pets may add 3–10 kg/ha/year of phosphorus to suburban areas - Benson & Howell 1990*b*), and the increasing concentration of run-off in fewer creek lines and channels. As discussed earlier, the Cumberland Plain vegetation is adapted to conditions of low rainfall and is therefore capable of sustaining periods of drought. Increased soil moisture, however, is more likely to eliminate native species by favouring rank growing exotic species. Apart from the well publicised dangers of Privet, *Ligustrum* spp. *Lantana camara, Tradescantia albiflora* etc., the spread of Kikuyu, *Pennisetum clandestinum*, is a danger. This grass is being used more frequently in recreation areas and disturbed sites and is a vigorous invader of native bush where the conditions are suitable.

3. Identification of corridors, regeneration and planting

Corridors linking the major conservation reserves and smaller remnants need to be designated and enhanced. The main north-south creek systems, Eastern Creek, South Creek and Kemps Creek, together with the Hawkesbury-Nepean and Georges Rivers should be the skeleton, together with interconnections across catchment divides. Some of these corridors, for example Eastern Creek, are already recognised by the Department of Planning, but plans for encouraging natural tree regeneration and planting need to be developed. Regeneration should be encouraged where residual native vegetation remains as this retains the scientific values of local genetic provenances. Any planting in a natural site should be propagated from local material.

4. Treatment of flood-prone areas and wetlands

Remnant vegetation often survives in floodprone areas. Wetlands, in particular, are important and should be protected from drainage or other alteration. Although such sites are not suitable for urban development, they are highly susceptible to changes and increasing volumes of run-off from adjacent urban areas. In some areas the increased run-off has led to the native creek vegetation being replaced by broad concrete stormwater channels. Since this creekside vegetation is often the only remaining vegetation, its destruction is a major loss of local biodiversity. There may also be cases where wetlands should be rehabilitated. Pitt Town Nature Reserve has been heavily grazed and most native species except for some *Juncus usitatus*, *Carex appressa*, *Triglochin procera* and *Persicaria lapathifolia* have gone. It is an important site for birds and provides scope for rehabilitation.

5. Identification of buffer zones

Because many of the conservation areas and bushland remnants are small and will soon be surrounded by increasingly dense urban populations, buffer zones will be needed and should be developed now. Such areas should be established with appropriate local native trees and shrubs to provide semi-natural bush to take intensive recreational use out of the intact bushland remnants.

6. Maintaining diversity of other wildlife, particularly birds and invertebrates

In areas planned for future urban development, tree planting, where it is appropriate, rather than preservation or regeneration, should be carried out in advance of building, since established trees will greatly enhance the new suburb's environment. Plantings need to recognise the needs of local fauna, particularly birds and invertebrates. Birds of the dry woodlands of western Sydney should be encouraged by planting woodland and forest groves, of local eucalypt species together with local understorey species including grasses and herbs. The use of non-local but colourful species such as grevilleas, whilst suitable for home gardens, should not be used in large-scale plantings as these favour the common garden birds, rather than providing suitable conditions for the specific local birds of western Sydney.

Acknowledgments

I would like particularly to thank Helen Bryant, David Keith, Jocelyn Howell and Lyn McDougall for help with fieldwork, data collection, air photo interpretation and map and manuscript preparation, Dr Elizabeth Brown for the topographic diagram, Teresa James for access to her species lists, Herbarium staff, especially Bob Coveny for identification of many of the plant specimens, Dr Lawrie Johnson for comments on the manuscript and Angela Benn, Belinda Crews and Alice Cheung for typing.

References

Adam, P. & Stricker, J. (1989) *Wetlands of the Sydney region*. Report prepared by Nature Conservation Council of NSW.

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

Baker, M., Corringham, R. & Dark, J. (1984) *Native plants of the Upper Blue Mountains*. (Three Sisters Productions: Winmalee).

Baker, M., Corringham, R. & Dark, J.(1985) *Native plants of the Lower Blue Mountains*. (Three Sisters Productions: Winmalee).

Bannerman, S.M. & Hazelton, P.A. (1990) *Soil landscapes of the Penrith 1:100 000 sheet*. (Soil Conservation Service of NSW: Sydney).

Barwick, A.C. (1903) The botany of the 'clears' and 'basalt masses', County of Hunter, N.S. Wales. *Proceedings of the Linnean Society of New South Wales* 28: 932–943.

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

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.

Bennett, G. (1860). *Gatherings of a naturalist in Australasia*. Facsimile edn. (Currawong Press: Sydney).

Benson, D.H. (1974). Survey of the natural vegetation of the floodplain of the Hawkesbury River and its major tributaries. Chapter 3 in *Geomorphology of New South Wales Coastal Rivers* H.A. Scholer (ed) University of N.S.W. Water Research Laboratory Report No. 139.

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

Benson, D.H. (1985). Aspects of the ecology of a rare tree species, *Eucalyptus benthamii* at Bents Basin, Wallacia. *Cunninghamia* 1(3): 371–383.

Benson, D.H. (1986) The vegetation of the Gosford and Lake Macquarie 1:100 000 vegetation map sheet. *Cunninghamia* 1(4): 467–489.

Benson, D.H. (1989). Notes on native vegetation of Prospect Reservoir. (Unpubl. report). Royal Botanic Gardens, Sydney.

Benson, D.H. & Howell, J. (1990*a*). *Taken for granted: the bushland of Sydney and its suburbs*. (Kangaroo Press: Sydney).

Benson, D.H. & Howell, J. (1990*b*). Sydney's vegetation 1788-1988: utilization, degradation and rehabilitation. *Proceedings of the Ecological Society of Australia* 16: 115–127.

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. (1991) *Rare bushland plants of western Sydney*. (Royal Botanic Gardens: Sydney).

Benson, D.H., Thomas, J. & Burkitt, J. (1990). The natural vegetation of Bents Basin State Recreation Area, New South Wales. *Cunninghamia* 2(2): 223–262.

Briggs, J. & Leigh, J. (1988) *Rare or threatened Australian plants* Revised edn. Special Publication no 14. (Australian National Parks & Wildlife Service: Canberra).

Bryant, H.J. & Benson, D.H. (1981) Recent floristic lists of New South Wales. *Cunninghamia* 1(1): 59–77.

Buchanan, R.A. (1989) *Bush regeneration: recovering Australian landscapes* (TAFE, Sydney).

Bureau of Meteorology (1979) *Climatic survey - Sydney, region 5, New South Wales*. (Department of Science and the Environment: Canberra).

Cambage, R.H. (1905). Notes on the native flora of New South Wales, Part IV. The occurrence of *Casuarina stricta* Ait., on the Narrabeen Shales. *Proceedings of the Linnean Society of New South Wales* 30: 376–391.

Carne, J.E. (1908). The geology and mineral Resources of the Western Coalfields. *Memoirs of the Geological Survey of New South Wales* 6: 64–152.

Cleland, K. (1988). *The natural area, Agnes Banks*. Report to the Honourable David Hay Minister for Local Government and Minister for Planning. (Commissioners of Inquiry for Environment and Planning: Sydney).

Clements, F. E. (1936). Nature and structure of the climax. *Journal of Ecology* 24: 252-283.
Crawford E., Herbert, C., Taylor, G., Helby, R., Morgan, R. & Ferguson, J. (1980). Diatremes of the Sydney Basin, in Herbert, C. & Helby, R. (eds.). *A guide to the Sydney Basin* Geological Survey of N.S.W. Bulletin No. 26.
Cunninngham, Allan (1816) Journal. (State Archives of NSW: Sydney).
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).
Edwards, K. (1979) *Rainfall in New South Wales with special reference to soil conservation.* Soil Conservation Service Technical Handbook No. 3. (Soil Conservation Service: Sydney).
Forestry Commission of NSW (1984). *Management plan for Cumberland Management area.*
Forster, G.R., Campbell, Desnee, Benson, D.H. and Moore, R.M. (1977). Vegetation and soils of the western region of Sydney. Division of Land Use Research Technical Memorandum 77/10 (CSIRO: Canberra).
Gobert, V. (1978). Proposed nomenclature for the Cainozoic sediments of the Penrith - Windsor area. *Quarterly Notes of the Geological Survey of New South Wales* 32: 1–9.
Harden, G. (ed.) (1990-91). *Flora of New South Wales Volumes I & 2.* (New South Wales University Press: Kensington).
Holland, W.N., Benson, D.H. & McRae, R.H.D. (1992). Spatial and temporal variation in a perched headwater valley in the Blue Mountains: geology, geomorphology, vegetation, soils and hydrology. *Proceedings of the Linnean Society of New South Wales* 113: 271–295
Hunter, John (1793) *An historical journal of events at Sydney and at sea 1787-1792.* (Angus & Robertson: Sydney 1968).
Jacobs, S. & Pickard, J. (1981). *Plants of New South Wales.* (Government Printer: Sydney).
Jacobs, S. & Lapinpuro, L (1986) Alterations to the census of New South Wales plants. *Telopea* 2: 705–714.
Keith, D.A. (1988). Floristic lists of New South Wales (III). *Cunninghamia* 2(1): 39–74.
Keith, D.A. & Benson, D.H. (1988) The natural vegetation of the Katoomba 1:100 000 map sheet. *Cunninghamia* 2(1): 107–143.
Lee, I (1925) *Early explorers in Australia* (Methuen: London).
McLoughlin, L. (1985). *The Middle Lane Cove River, a history and a future.* Monograph No. 1, Centre for Environmental and Urban Studies, Macquarie University.
Mitchell, M.L. (1988). *Mangrove and saltmarsh boundaries along the Georges River, New South Wales.* B.Sc. Hons. Thesis, Biological Science (Botany) University of New South Wales.
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.
New South Wales Department of Mines (1966). *Sydney 1:250 000 Geological Series Sheet.* Edition 3.
Old, A.N. (1942) The Wianamatta Shale waters of the Sydney district; their salinity and a suggested geological explanation. *Agricultural Gazette of New South Wales* 53: 215–221.
Phillips, M.E. (1947). Vegetation of the Wianamatta Shale and associated soil types. M.Sc. Thesis, University of Sydney.
Phillip, Arthur (1789) *The voyage of Governor Phillip to Botany Bay.* Facsimile Edn. (Hutchinson Group (Australia), Melbourne 1982).
Pickard, J. (1972). Annotated bibliography of floristic lists of New South Wales. *Contributions from the N.S.W. National Herbarium* 4: 291–317.
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. (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.
Rodd, A.N. (1987). Vegetation of Mount Tomah. In *The Mount Tomah Book.* (The Mount Tomah Society and Royal Botanic Gardens: Sydney).
Royal Botanic Gardens (1986). *The conservation value of natural vegetation along the Hawkesbury-Nepean River.* Report prepared for Department of Planning and Environment.
Specht, R.L. (1970). Vegetation. In *The Australian Environment* (G.W. Leeper, Ed.) pp. 44–67. Edition 4. (CSIRO - Melbourne University Press: Melbourne).

White, John (1790) *Journal of a voyage to New South Wales.* (Angus & Robertson: Sydney 1962).
Woolls, W. W. (1867). *A contribution to the flora of Australia.* (F. White: Sydney).
Woolls, W. W. (1880). Eucalypts of the County of Cumberland Part III. *Proceedings of the Linnean Society of New South Wales* 5: 463–469.

Manuscript received 25 November 1991
Manuscript accepted 4 May 1992