

The effect of 200 years of European settlement on the vegetation and flora of New South Wales

John Benson

Abstract

Benson, J.* (New South Wales National Parks and Wildlife Service, P.O. Box 1967, Hurstville, NSW, Australia 2220) 1991. *The effect of 200 years of European settlement on the vegetation and flora of New South Wales*. *Cunninghamia* 2(3): 343-370. The vegetation of New South Wales is dominated by *Eucalyptus* (and other Myrtaceous genera) and *Acacia* and reflects adaptations to climatic change during the late Tertiary and Quaternary and to 38-45,000 years or more of Aboriginal burning. Of the ca. 6000 vascular plants in NSW, 1198 are alien and naturalised originating from Europe, Asia, the Americas, South Africa and the Mediterranean. At least 532 native species are rare or threatened. The native flora has been previously tentatively classified into 432 associations in 18 major community groups. Grazing and cropping have been the major causes of decline in the distribution and abundance of these associations and of rare or threatened species, but additional factors are urban expansion, forestry and invading weeds. Examples are *Rutidosia leptorhynchoides*, an endangered plant threatened by grazing and urban expansion, the recently cleared *Acacia harpophylla* forests, and coastal vegetation threatened by the invasive weed *Chrysanthemoides monilifera*.

Of the total area of NSW, 4.86% is reserved for conservation as of 1990; an estimated 42 per cent of plant associations and 49 per cent of rare or threatened species are adequately conserved as of 1990. Further survey and reservation is needed, particularly in tall open forests, wetlands, semi-arid and agricultural lands. Further research is required into endangered species, their habitats and the processes causing decline in populations.

Introduction

While Dutch and English sailors landed on the western and northern shores of Australia in the 17th century, it was Captain James Cook's voyage in 1770 that led to the first European settlement of Australia in 1788 on the east coast, where the city of Sydney now stands.

In the ensuing 200 years of European settlement of Australia, much of the vegetation has been greatly altered in abundance and distribution. Species have become extinct due to the activities of man, alien plants have been introduced, many becoming weeds in competition with native species, and some ecosystems are under severe threat because of over-exploitation. Adamson and Fox (1982) go so far as to suggest that no other continent has experienced such a rapid change.

Wells et al. (1984) estimate that forests, woodlands and tall shrubs covered 77-88% of New South Wales in 1788. Over half of this vegetation has been cleared, primarily for agriculture (Department of Arts, Heritage and Environment 1986, Reed 1990); During the first 130 years of European settlement 35.3 million hectares (44% of New South Wales) were ring-barked or partially cleared (Reed 1990). Furthermore, during a five year period in the 1980s, at least 2.2 million hectares were cleared. This repre-

* Present address: National Herbarium of New South Wales, Royal Botanic Gardens, Sydney, NSW, Australia 2000.

sents a rate of 1183 hectares/day (Reed 1990). Land-clearing continues today in most parts of the State with indifference to contemporary views about the causes of land degradation, for example, the views expressed in the Murray-Darling Basin Natural Resources Management Strategy (Murray-Darling Basin Ministerial Council 1989).

Pre-European history of the vegetation of south-east Australia

The history of Australia's vegetation is well documented by Beadle (1981), Barlow (1981), Groves (1981), Smith (1982) and White (1986). It is briefly discussed here to establish the environmental factors and previous human impact that have affected the vegetation.

After long periods of relative stability of climate and vegetation formations over most of the Tertiary, climate became more unstable in the Pliocene-Pleistocene epochs (Singh 1982). Rainforests covered much of Australia in the mid-Tertiary but retracted with the onset of cooler and drier climatic trends. Pollen diagrams from Lake George in south-east New South Wales (Singh, Kershaw & Clark 1981), and Lynch's Crater in north-east Queensland (Kershaw 1978) detail changes in vegetation during the latter parts of the Pleistocene. These changes principally comprise oscillations between rainforest plants and dry sclerophyll plants.

A tentative reconstruction, based on somewhat limited data, is given by Ross (1984) who describes the major environmental changes in south-east Australia over the late Quaternary. By about 32,000 years ago south-east Australia experienced interstadial conditions that were cooler and wetter than today. Rainforests had retreated to refugia and grasslands dominated high country and semi-arid regions of the continent. During the last ice age between about 25,000 and 12,000 years ago the vegetation adapted to dry, cool conditions. Grasslands were common and forests became more sparse in their structure. When the ice age ended the treeline rose and forests once again expanded, with *Casuarina* invading many areas. Rainforest also expanded from its refugia (Webb & Tracey 1982). This corresponded with a relatively wet period up to 5000 years ago. During a slightly drier period between 3000 and 1000 years ago some areas reverted to more grass-dominated vegetation (Ross 1984). The present-day slightly less xeric vegetation types were established during the last 1000-1500 years (Ross 1984).

The impacts of Aborigines on Australian vegetation

It is difficult to specify the effect of 45,000 (Nanson, Young & Stockton 1987) to 60,000 (Wright 1986) years of Aboriginal practices on Australia's vegetation because they occupied the continent simultaneously with great changes in climate.

The most significant way in which Aborigines may have altered their environment would have been through the use of fire. The reasons attributed to Aborigines using fire include: flushing game (Barrallier 1802, Hunter 1793); to stimulate seed production of edible plants, for example cycads (Beaton 1982); to stimulate the growth of young shoots, thereby increasing the amount of food for game in an area (Lewis 1982); easing travel through the countryside; signalling; and frightening enemies.

Over the last few decades there has been a good deal of debate over the extent of change to the Australian vegetation caused by Aboriginal burning. Tindale (1959) followed by Jones (1969) suggests that Aborigines had radically altered the environment through their use of fire. Alternatively, Horton (1982) postulates that Aborigines were conservative when using fire and merely maintained natural fire patterns in vegetation.

Bowman and Brown (1986) reject Horton's model of fire-vegetation relations by citing data that support the view that frequent burning favours plants adapted to fire and increases the probability of fire. They maintain that Aborigines were capable of burning mature forests in regions of low fire frequency thus causing changes to the vegetation e.g. from *Nothofagus* forests to sedgelands. However, the survival of the fire-sensitive pencil pine *Arthrotaxis cupressoides* during Aboriginal occupation in the Alpine zone of Tasmania, and its subsequent decline due to European firing, indicates that Aborigines used fire differently from Europeans or did not occupy and burn all regions (Bowman & Brown 1986).

Although evidence is lacking, it is likely that some plant species are now threatened because they were favoured by Aboriginal burning regimes which are now absent. Examples include species of *Swainsona* (Fabaceae) (Parsons & Browne 1983). Conversely, some species may have become rare primarily due to Aboriginal burning.

A general agreement beginning to emerge about the level of Aboriginal impact on Australian vegetation through their use of fire (Clark 1983, Bowman & Brown 1986), lies somewhere between the views of Horton (1982) and Jones (1969). Clark (1983) concludes that 'it is likely that Aborigines played a maintenance role to the major determinant of vegetation, climate'. There are certainly numerous records in the journals of early European explorers such as Mitchell in New South Wales (1848) and Robinson in Tasmania (1829-1834) describing the common Aboriginal practice of firing the vegetation but it is difficult to weigh the relative importance of Aboriginal use of fire against climatic change. Also, we do not have enough knowledge of the differences in Aboriginal use of fire between different groups and in different parts of Australia. Whatever the causes, the vegetation that was present in most regions when Europeans arrived was well adapted to fire (Gill 1975).

The present vegetation of New South Wales

New South Wales contains a range of plant associations as a consequence of steep north-south and east-west environmental gradients. This diversity in associations is reflected in the richness of plant species (Table 1).

Table 1. Number of vascular plant species in New South Wales (from Jacobs & Pickard 1981)

Plant group	No. native species	No. naturalised species (%)	Total
Pteridophyta	199	5 (3)	204
Gymnosperms	25	3 (11)	28
Angiosperms (monocots)	1171	314 (21)	1485
Angiosperms (dicots)	3569	876 (20)	4445
Total	4964	1198 (19)	6162

The majority of the plant associations present today are dominated by *Eucalyptus* or other trees and shrubs in the Myrtaceae, or *Acacia* in the Fabaceae. Exceptions are alpine and rainforest plant associations and chenopod shrublands of the interior. With the exception of rainforest flora, most of the flora in New South Wales displays xeromorphic characteristics. Xeromorphism has evolved as an adaptation to infertile soils and/or lack of water (Beadle 1981). Many xeromorphic genera and species have evolved from rainforest species (Andrews 1916, cited in Beadle 1981; Webb & Tracey 1982). Proteaceae has rainforest genera such as *Stenocarpus*, *Orites*, and *Macadamia* but also xeromorphic genera such as *Hakea*, *Grevillea* and *Banksia*.

The distribution of plant species in New South Wales is skewed towards the eastern, moister and more complex (in terms of substrates and topography) botanical divisions of the State. The drier western plains that cover more than half of the state contain far fewer plant species than do the eastern ranges and coast. Cunningham et al. (1981) list approximately 2000 taxa of plants occurring in western New South Wales, yet a comparable number of plant taxa are present within the Sydney region on the east coast (Beadle, Evans & Carolin 1982).

Localised endemism is also more common in the eastern parts of New South Wales where varied geologies, greater variation in local climate and isolated tablelands or mountains have favoured the evolution of distinctive floras. Such areas include: the alpine zone of Kosciusko National Park on the Southern Tablelands with 21 endemic species of vascular plants (Costin et al. 1979); the southern escarpment overlooking the Jamieson Valley in the Blue Mountains (Keith & Benson 1988); outlying mountains on the South Coast and the Northern Tablelands; and the subtropical rainforest remnants of the 'Big Scrub' area on the far North Coast.

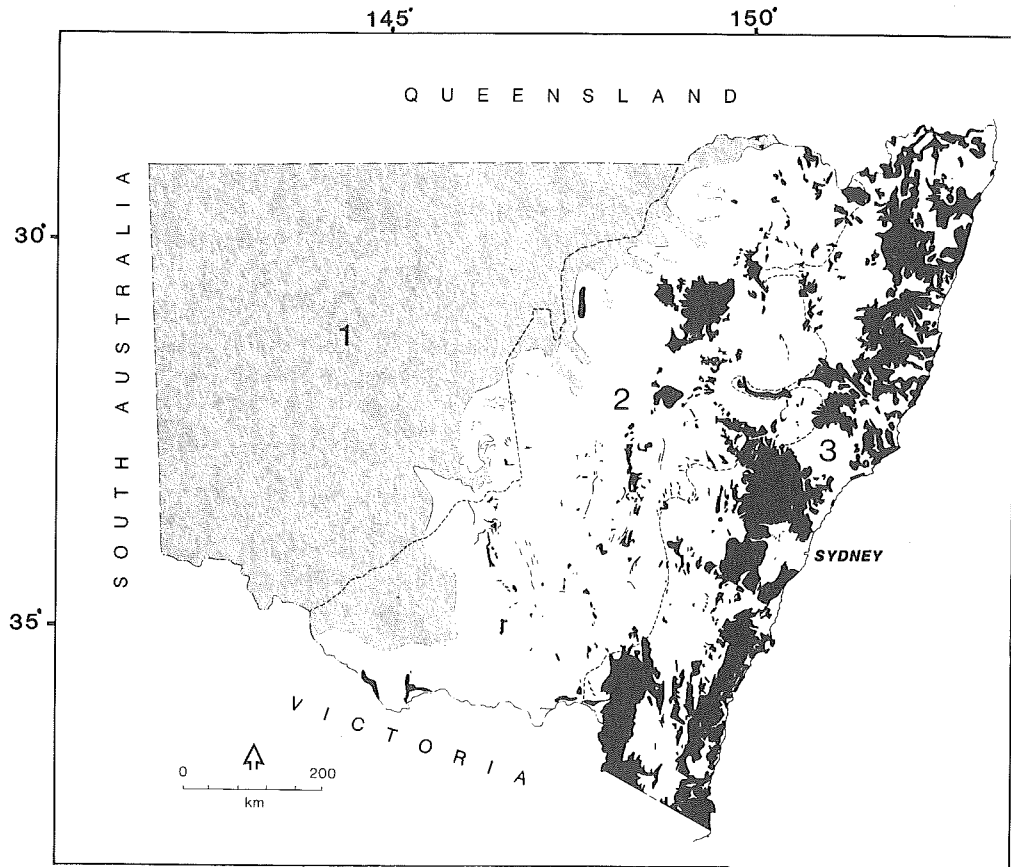
Beadle (1981) erected a floristic classification for Australia's vegetation. This has been refined by Benson (1989) for New South Wales, in which 432 plant associations are listed. These associations are allocated to 18 vegetation groups (based on the Beadle 1981 classification) reflecting the major biogeographic provinces of the State. This classification is currently being revised (Hager & Benson 1990; Robinson & Benson 1990).

Effect of European settlement on the vegetation of New South Wales

Most of New South Wales has either been moderately or highly modified by humans since European settlement 200 years ago (Adamson & Fox (1982), Leigh et al. (1984), (Figure 1). The regions that have been most markedly altered (besides urban centres) are those that contain better soils on flat to undulating topography. They include the coastal alluvial valleys and plains, basalt plateaux, the less steeply sloping tablelands and the Central Division of the State incorporating the Western Slopes and eastern parts of the Western Plains.

At the time of European settlement rainforest covered about 1% of New South Wales, but because it occupied rich soils, some of the largest expanses (for example the Big Scrub and on the Illawarra) were cleared by the mid 19th century (Frith 1977; Strom 1977). Today, only about one quarter of the original rainforest (192,000 hectares) remains structurally intact (Floyd 1990). The largest remaining stands are now protected in reserves and are registered on the World Heritage List.

Very little of the various associations of tall moist forest occurring on higher nutrient soils on the eastern tablelands and coast remain undisturbed. Initially clearing for settlement and agriculture eliminated much of this habitat from the coastal valleys and flatter parts of the tablelands. With the exception of some relatively small stands



- uncleared forests, woodlands and shrublands
(unmodified to highly modified)
- uncleared arid woodlands, shrublands, grasslands
and riverine forests *(highly modified)*
- cleared lands *(completely modified)*

DIVISION BOUNDARIES

- 1 WESTERN (leased lands)
Western Plains
- 2 CENTRAL (includes the 'Wheatbelt')
Slopes and Eastern Plains
- 3 EASTERN
Coast, Ranges and Tablelands



Figure 1. Modification of the native vegetation of New South Wales since European settlement in 1778.

in conservation reserves, most of the remaining tall forest has been or is presently being logged and subject to changed fire regimes, including frequent control burning. This has significantly changed the age/size structure of these forests and the composition of the understorey. Regenerating forests on both public and private land are coming under increasing pressure for exploitation as timber resources run low and alternative uses of timber are being proposed for supplying woodchip exports, pulp mills and export firewood (NSW Department of State Development 1989; National Parks and Wildlife Service of NSW 1990).

Even in areas where woodlands or forest were left uncleared, subsequent grazing produced a series of changes in the understorey which are hard to assess today because very few detailed descriptions of the flora were made by early explorers or settlers. The *Eucalyptus albens* and *E. melliodora* – *E. blakelyi* woodland associations on the Central Western Slopes were drastically affected by early settlement; probably over 90% of these woodlands have been lost. Those areas not cleared have been subject to heavy grazing pressures. Moore (1966) describes some of the changes to understorey plant species over time due to grazing in these woodlands. Beginning with tall warm-season perennial grasses such as *Themeda australis* and *Poa caespitosa*, sheep grazing led to these being replaced by short, cool season perennials (other native species) and herbs. Further grazing led to the influx of cool-season annuals, mainly introduced species with Mediterranean origins. Superphosphate application further favoured annuals over perennial species of plants.

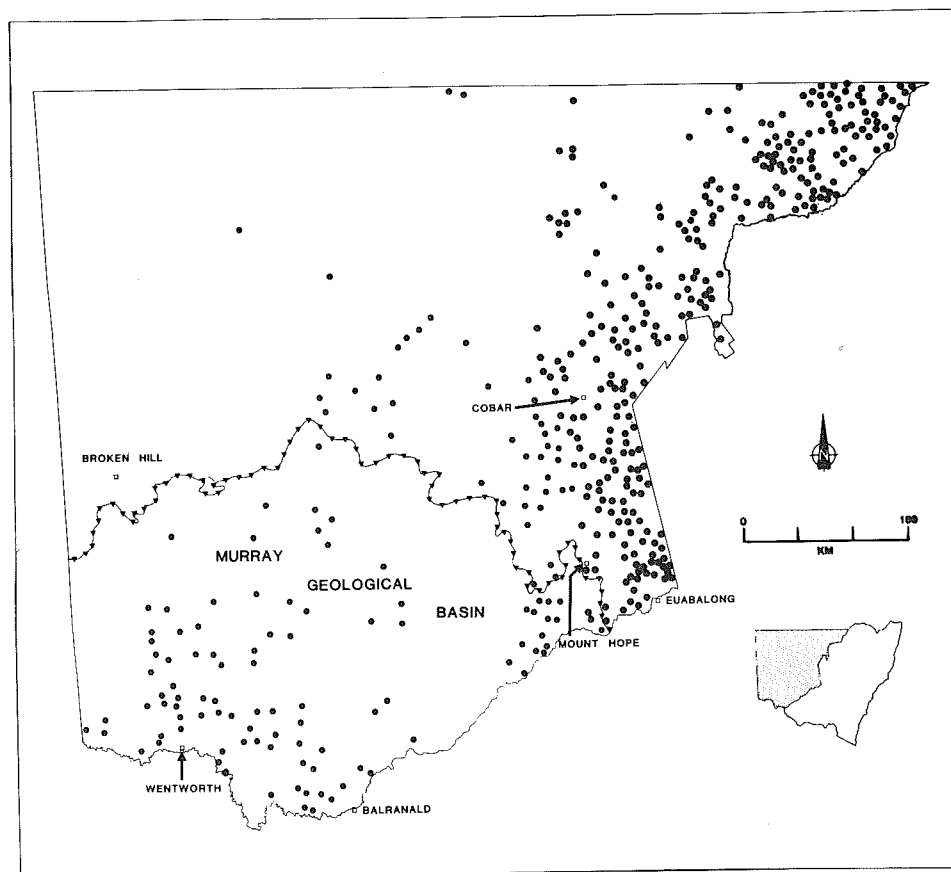


Figure 2. Location of clearing licences granted in the Western division 1984–1989 (from Pressey 1990).

The Central Division (Figure 1) has largely been cleared. This clearing is continuing to encroach into marginal lands to the west (Figure 2). Between February 1984 and November 1989 the Western Lands Commission granted clearing licences for over 560,000 hectares, although this overestimates the amount of land actually cleared (Pressey 1990).

The Western Plains of New South Wales have been grazed extensively since the 1830s, first by cattle then sheep (Heathcote 1965). Denny (1987) compares present-day vegetation with that noted by Sir Thomas Mitchell, Surveyor General of New South Wales, who explored the western river systems in the 1830s. An example is given for a site along the western section of the Murray River:-

Mitchell (1838): '*We crossed grassy plains bounded by sandhills on which grew pines [Calitris], and open forests of goborro (or box tree) prevailed very generally nearer the river..... the remarkable incident of this day's journey, was the discovery of an animal.....'*

The present-day vegetation at this locality has been highly modified. Much of the sand-hill vegetation has been cleared and some of the *Eucalyptus largiflorens* (Box Tree) has been ringbarked (Denny 1987). The animal discovered was the pig-footed Bandicoot (extinct by 1900). Denny records that 80% of the localities checked against Mitchell's notes in this region now have a decreased canopy and middle stratum in their vegetation.

Overgrazing by stock and other introduced animals, particularly the rabbit, combined with severe droughts and a lack of appreciation of the fragility of the environment, particularly the soils, have led to large scale degradation and changes in abundance of native plants and animals. The more palatable plants suffered most. For example, on the Riverina there has been a shift from chenopods to grassland and the reduction of such conspicuous perennials as Old Man Saltbush, *Atriplex nummularia* (Moore 1953). Five of the 11 native species of *Lepidium* (Brassicaceae) and six of the 32 species of *Swainsona* (Fabaceae) (Harden, in press) that have been recorded as occurring in western regions of New South Wales, are now threatened or extinct (Briggs and Leigh 1988).

Since settlement it is estimated that 56% (24 species) of all native mammals that once inhabited these regions are now extinct (National Parks and Wildlife Service 1982). These detrimental impacts on plants and animals in semi-arid regions have come about due to competition with introduced plants and animals, overgrazing and clearing for 'dry-land' cropping in an area with a high frequency of drought. Expanses of scalded country are a conspicuous legacy of past over-exploitation of the outback.

Specific causes of the decline of native vegetation

Grazing

Before European settlement there were no large 'hard-footed' animals or ruminants that could effectively eat dry grass. Domestic and feral animals introduced by European settlers placed increased pressure on native vegetation. Grazing has affected more than 60% of New South Wales and has been the major cause of decline in the vegetation of the State leading to a number of plant extinctions and major reductions in the range and abundance of species and associations (Benson 1989). Clearing has been the cause of decline but other important factors include: alteration of soil structure through compaction and of nutrients through application of fertilizers; erosion, particularly surrounding watering points or on erodible soils or steep slopes; senescence of palatable shrubs and trees with little or no regeneration (Chesterfield & Parsons 1985); changes to fire regimes and introduction of weeds, including the increase of native 'woody weeds' mainly found on the north-western plains. Another indirect

effect of grazing is dieback. This refers to the phenomenon of death or decline in health of eucalypt trees in rural areas. In New South Wales it has been most severe on the tablelands and western slopes particularly on the New England Tableland on the Northern Tablelands (Williams & Nadolny 1980). The causes of dieback are currently being researched. Kile (1980) lists defoliation by insects, drought, tree age, soil salinity, mistletoe infestations and root pathogens such as the fungus *Phytophthora cinnamomi* as factors associated with rural dieback.

Cropping and irrigation

Covering approximately 20% of New South Wales, cropping is most prevalent in the 'wheatbelt' of the Central Division and on coastal valleys and plains. Irrigation is common to many river systems with drastic effects on water supplies along the inland rivers. Because of the intensive nature of cropping there is usually total destruction of the native vegetation and it is difficult for it to re-establish. Intensive cropping has also led to soil structure decline. The nutrient status in soils is altered by ploughing and the application of fertilizers the latter leading to acidification in many places. Pesticides and herbicides affect non-target species in the surrounding natural biota. Introduced weeds, both terrestrial and aquatic, out-compete native species and reduce their abundance.

Salinity is a major problem in areas subject to cropping and grazing, for example, 920,000 hectares (mainly saline scalds) of the Murray-Darling Basin are affected by salination (Murray-Darling Ministerial Council 1989). Dryland salinity caused through the impact of rising water tables is estimated to be affecting 14-20,000 hectares in New South Wales (Keith Emery, Soil Conservation Service pers. comm.). In 1985, 9000 hectares of the Murray, Murrumbidgee and Wakool irrigation areas were visibly affected by salinity through rising water tables and this is projected to increase many times over the next 50 years (Peter Rooke, Water Resources Commission pers. comm.).

Forestry

As of June 1990 3,663,329 hectares (4.6%) of New South Wales was publicly managed for wood production, mainly on the east coast and tablelands but also the *Callitris* woodlands in the central parts of the State. Private lands are also logged. Logging practices range from selective logging to clearfelling for woodchips or pine plantations. These practices result in reduction in native forest areas, younger age classes, soil erosion (Forestry Commission of NSW 1988), changes in the microclimate affecting understorey species, introductions of weeds and pathogens (Ecos 1978) and changes in fire regimes (Fox 1990; Dickinson & Kirkpatrick 1987). Historically, the passing of the Forestry Act in 1916 played a major role in flora conservation by at least protecting areas from total clearing for agriculture. However, the recent trend towards more intensive forestry (Office of State Development 1989), could limit the conservation options for a number of forest associations and their constituent species on the tablelands, eastern escarpment and coast (National Parks & Wildlife Service 1990). By 2005 large areas of *Pinus radiata* plantations will have matured and increasingly they will replace native eucalypt forest in supplying both sawlogs and woodchips (Cameron & Penna 1988; Clark & Blakers 1989). In the interim, the future of the remaining unprotected, unlogged, aesthetically appealing, tall eucalypt forest growing on high- to medium nutrient soils will probably continue to be a topic of public debate.

Urban and industrial expansion

During the 1970s 60,000 hectares of land in New South Wales was developed for housing, industry or roads (Department of Arts, Heritage & the Environment 1986).

The figures for the 1980s are probably higher. Urban expansion is mainly affecting the coast. For example, in Sydney it is endangering a number of plant species, e.g. *Pimelea spicata*, *Grevillea caleyi*, *Eucalyptus camfieldii* and *Acacia pubescens*, and distinctive plant associations such as the Cumberland Plain woodland dominated by *Eucalyptus moluccana* and *E. tereticornis*. Besides direct destruction of the vegetation, weeds and pollution are major consequences of urbanisation. At Wentworth Falls in the Blue Mountains, the largest population of the endemic podocarp *Microstrobos fitzgeraldii* is threatened by excessive algal growth resulting from pollution in the catchment (Smith 1981; Brown 1990).

Mining and quarrying

The effects of extraction industries tend to be localised, but involve total loss of the vegetation. Revegetation depends on the nature of the mining and post-operative rehabilitation works. On the North Coast, beach sand-mining has eliminated some of the largest stands of littoral rainforest e.g. between Harrington and Crowdy Head (Floyd 1979). Underground mining for coal in the Sydney Basin can have detrimental impacts on swamps if hydrology changes as a result of land slumping (Young 1982; Nanson & Young 1983). Pollution and sedimentation downstream from mine sites can severely impede the health of aquatic and riverine vegetation.

Introduced plants

Approximately 20% of vascular plant species in New South Wales are naturalised exotics. Some of these have become major weeds to agricultural and natural environments. Characteristics of weeds include high colonising capacity, efficient dispersal and ability to reproduce rapidly (often asexually) (Groves 1986). Some of the major weed species in New South Wales affecting natural areas are: Lantana (*Lantana camara*), Boneseed and Bitou Bush (*Chrysanthemoides monilifera*), Privet (*Ligustrum* spp.), Camphor Laurel (*Cinnamomum camphora*), Crofton Weed (*Ageratina* spp.), Blackberry (*Rubus* spp.), English Broom (*Cytisus scoparius*) and Groundsel Bush (*Baccharis halimifolia*). Introduced members of the Asteraceae, Brassicaceae and Amaranthaceae are commonly invasive plants. *Salvinia molesta* and *Eichhornia crassipes* are major aquatic weeds. Eradication or control of weeds is expensive. Biological control provides the best option for controlling some weeds and investigations for some species are being carried out. The *Cactoblastis* moth – *Opuntia stricta* (Prickly Pear) case (Dodd 1959), remains the most successful example of biological control to date. Currently there are biological control studies underway for Bitou Bush *Chrysanthemoides monilifera* (John Scott pers. comm.), English Broom *Cytisus scoparius* (Hosking 1990) and *Lantana camara*.

Table 2 outlines the relative importance of various causes on the decline of natural plant associations in New South Wales. Evidence for decline or change in vegetation is outlined in Table 3. Reductions in abundance and distributions of plant associations are the most important aspects of the impact of European settlement.

Threats to plant species

In New South Wales, 14 plant species are reported as extinct; a further 12 plant species are no longer found in the State but exist in other parts of Australia; 213 plant species are threatened, of these 56 are endangered and 157 are vulnerable; 279 are rare and 26 plant species are presumed to be rare though their exact status is unknown (Briggs & Leigh 1988).

Table 2. Causes of decline or change to plant associations in New South Wales. Figures are derived from assessments made in Benson (1989).

Cause	Percentage of plant associations affected
Grazing/clearing	45
Cropping/clearing	18
Forestry	13
Changes in fire regime	6.5
Urban and industrial expansion	6
Drainage and irrigation	5.5
Mining and quarrying	3.5
*Competition with weeds	<2
*Recreational pressures	<2
*Herbicides and pollution	<2

Notes: * These causes of decline are likely to increase in the future.

Table 3. The proportion of plant associations subjected to various changes since European settlement. Figures are derived from assessments made in Benson (1989).

Nature of change	Percentage of plant associations affected
Reductions in range	
Minor reductions in range and/or abundance	36
Major reductions in range and/or abundance	29
Changes in age classes	
Younger age classes over much of an association's distribution (mainly due to forestry practices)	16
Older age classes over much of an association's distribution (mainly due to lack of regeneration due to grazing in pastoral areas. Also including delayed response including 'dieback'.)	10
Major alteration to the understorey	9 *
Increased abundance	1

Notes: *This is a conservative estimate because the understoreys of most plant associations have been altered to some degree. The term 'major' here implies loss of the majority of understorey plant species. Examples would be the box woodland associations on the western slopes.

Table 4. Causes for the extinction and threatened status of species of vascular plants in New South Wales derived by the author based on Leigh, Boden & Briggs (1984), unpublished works, and personal observation.

Cause	X	E	V	Total	%
Agriculture (grazing/cropping)	16	29	67	112	41
Forestry activities	-	2	10	12	4
Urban and industrial	1	5	14	20	7
Mining and quarrying	-	2	10	12	4
Change in fire regime/disturbance	1	5	23	29	11
Competition with introduced plants	-	1	4	5	2
Herbicides/pollution	-	2	1	3	1
*Collection pressures	-	3	6	9	3
**Low numbers	-	18	49	67	24
Recreation, e.g. trampling	-	-	2	2	1
Hydrological changes	-	4	-	4	2
Total	18	71	186	275	

Notes: Risk codes: X = extinct; E = endangered; V = vulnerable as defined by Briggs & Leigh (1988).

'Rare' species are excluded as they are not considered to be threatened.

Many species are affected by more than one cause.

* species threatened by uncontrolled collecting of whole plants or part thereof.

** species threatened because their population(s) are very small (usually less than 300). This may be natural or caused directly or indirectly by other factors.

The main causes for the extinction of or threats to plants in New South Wales (Table 4) are similar to those threatening plant associations — grazing and clearing. *Acacia carnei* is one of the many rare plants suffering from overgrazing. Research into its population dynamics in populations within Kinchega National Park reveal that there is little or no regeneration occurring from rootstock or seedling and there is advanced senescence of mature plants (Auld 1990). The main cause in its decline is rabbits. Where rabbits are less abundant, mature plants are far healthier and there is some recruitment from root-suckers (Auld 1990).

The 'low numbers' category includes species that had 'naturally' small populations (in the order of hundreds of individuals or less) at the time of European settlement and species that may have attained such small populations as a consequent of other causes. When they exist in small populations the long term viability of species is threatened due to genetic drift and consequent loss of fitness to adapt to change (Jarvinen 1982; Brown 1983). This could include possible rapid change in climate due to the Greenhouse Effect.

Some plant species may be endangered because they require particular environmental conditions such as disturbance to complete their life cycle, but now fail to get it due to human interference. Disturbance may take the form of fire, flooding, natural erosion and soil disturbance caused by burrowing animals. Both *Rutidosia heterogama* and *Olearia flocktoniae*, (Asteraceae) (presumed extinct until they were recently rediscovered on the North Coast) were located in disturbed sites; *R. heterogama* along a recently burnt fire trail in Bundjalung National Park, and *O. flocktoniae* on a recently graded roadside batter in a State Forest near Coffs Harbour.

Eriocaulon carsonii (Eriocaulaceae) illustrates a more indirect effect of European settlement. It only grows on a few mound springs in South Australia and one in the far north-western part of New South Wales. Many natural mound springs have been

exploited for artesian water for stock and outback settlements, reducing the supply of water and hydrostatic pressures in the artesian basins. This has led to a decline in the mound springs and the habitat of *E. carsonii* (T. Fatchen pers. comm.). The mound springs have also been physically damaged by the effect of stock trampling.

Uncontrolled collecting of some species is causing their decline. In New South Wales this is particularly so with orchids — *Sarcochilus fitzgeraldii* and *Phaius tancarvilleae* to name two. Australia's rarest eucalypt, *Eucalyptus recurva* (Crisp 1988), which has a population of six growing in two stands near Mongarlowe on the Southern Tablelands (R. Lembit pers. comm.), is threatened by collectors of seed and specimens. Collection pressure is a far greater threat to plant species in Western Australia where there is a substantial export cut flower trade, although this trade is closely monitored by the Western Australian Government.

Introduced naturalised flora

The large-scale invasion of alien plants began with European settlement in 1788. By 1804 the botanist, Robert Brown, had noted 29 introduced plants in Sydney (Groves 1986).

It is not surprising that Europe, Africa and Asia are major sources of alien plants considering the origin of the early settlers and their routes of immigration to Australia. Most of the settlers came from Britain, Ireland or Europe and they would have imported plants either intentionally or accidentally from their homelands. One example is *Lantana camara* (Verbenaceae) which as early as 1846 was present as an ornamental in the garden of Lady Innes at Port Macquarie on the north coast of New South Wales (Boswell 1981). It is now one of the most abundant weeds in coastal parts of the State and in south-east Queensland.

Kloot (1987b) suggests that, over time, plants from climatic regions more comparable with Australia have invaded. This explains the high numbers of naturalised, alien plants from the Mediterranean Region, the Americas and Africa.

Michael (1981) suggests that approximately 10 per cent of Australia's vascular flora are introduced (alien). Of the vascular flora of New South Wales 20 per cent are introduced and naturalised, (Table 1) (the term 'naturalised' is based on the definition of Thellung 1912 cited in Michael 1981). While only about five per cent of introduced plants have become naturalised in Australia and only approximately one per cent have become weeds (Michael 1981), alien plants have continued to have a significant impact on native flora. Asteraceae, Brassicaceae, Poaceae, Boraginaceae and Amaranthaceae are conspicuous in containing large numbers of alien, naturalised plants (Table 5). In western New South Wales approximately one third of all grasses are naturalised aliens (Cunningham et al. 1981).

Indigenous species also have invaded other parts of the continent: *Pittosporum undulatum* (Pittosporaceae), a native of coastal south-eastern Australia, is expanding its range and abundance in southern Victoria and in South Australia (Gleadow & Ashton 1981); *Acacia dealbata* (a native of eastern New South Wales) is spreading rapidly in Western Australia (Groves 1986) and *Acacia saligna* (a native of Western Australia) is expanding in some coastal regions of New South Wales.

Some of the invaders pose major threats to native vegetation. For many weeds, biological control is the only feasible solution but, as Groves (1986) points out, there is a need for more study into the genetics in weed populations to improve the theoretical base for biological control programs.

Fox & Fox (1986) consider that there is no invasion of natural communities unless there has been previous disturbance. One of the weeds threatening native vegetation

Table 5. Plant families with large numbers of alien naturalized species (from Kloot (1987b).

Dicotyledonous families	No of species
Asteraceae	153
Fabaceae (inc. Faboideae, Mimosoideae and Caesalpinioideae)	110
Brassicaceae	49
Caryophyllaceae	34
Solanaceae	38
Rosaceae	45
Lamiaceae	24
Scrophulariaceae	33
Monocotyledonous families	
Poaceae	208
Iridaceae	26
Cyperaceae	21

which comes closest to contradicting this view is *Chrysanthemoides monilifera*, the major weed along beaches in eastern and southern Australia. While this South African colonising species gained a strong foothold in Australia largely on disturbed sites, particularly coastal sand dunes, it is now displacing native species (Weiss 1983, Weiss & Noble 1984). It is detailed in a case study below.

Case studies

The following three case studies illustrate some influences of European settlement on plant communities and plant species, either directly through clearing or modification of the landscape, or indirectly through the introduction of alien plants that have become weeds and out competed native flora.

A threatened plant community: Brigalow

Acacia harpophylla F. Muell. ex. Benth. (Fabaceae) known as Brigalow spans from central northern Queensland to the North-Western Plains of New South Wales (Figure 3) (Sattler & Webster 1984). There are some isolated records further south in central NSW.

In Queensland it once covered about 4.7 million hectares, in New South Wales about 250,000 hectares (Pulsford 1984). In some Brigalow communities it is the only species in the upper stratum, and the understorey features few other plants. In others it is found with other *Acacia* species, *Eucalyptus*, or associated with semi-evergreen vine thickets (Johnson 1964, 1984). In moister regions and on better soils, Brigalow grows up to 20 m high. It mainly occurs on clay soils and in New South Wales these have developed from Quaternary alluvium over sedimentary strata (Isbell 1962, Pulsford 1984).

Unlike many of the other inland plant communities the bulk of the Brigalow country was left uncleared until after World War II. This was partly due to the difficulty of clearing Brigalow as it resprouts readily from rootstock and partly because of the major infestations of a pest, Prickly Pear (*Opuntia stricta*), over much of its range until controlled by the *Cactoblastis* moth. Favourable assessments of the soil under Brigalow for growing crops led to massive clearing operations in the 1950s and 1960s.

Brigalow is now one of the rarest plant communities in New South Wales. In Queensland only 0.5% of the estimated pre-settlement area of Brigalow is reserved and less

than 1% in New South Wales (Sattler & Webster 1984, Pulsford 1984). Clearing still goes on, particularly in the northern parts of its range in Queensland that Lloyd (1984) views as Australia's last agricultural 'frontier'.

In the Narrabri-Bogabilla region of New South Wales only small amounts of Brigalow remain, usually in stands of less than 400 hectares (Pulsford 1984). A large stand of Brigalow survives 100 km north-east of Bourke, west of the Culgoa River. This population is several hundred kilometres west of the main band of Brigalow (Figure 3). Part of this population is under threat from clearing by lessees.

Improving the conservation status of Brigalow is now a priority of both the Queensland and New South Wales National Parks and Wildlife Services. Two small reserves have been established near the town of Narrabri in New South Wales and a number of others are being investigated. Protecting and reserving viable stands of Brigalow north-east of Bourke should be a priority.

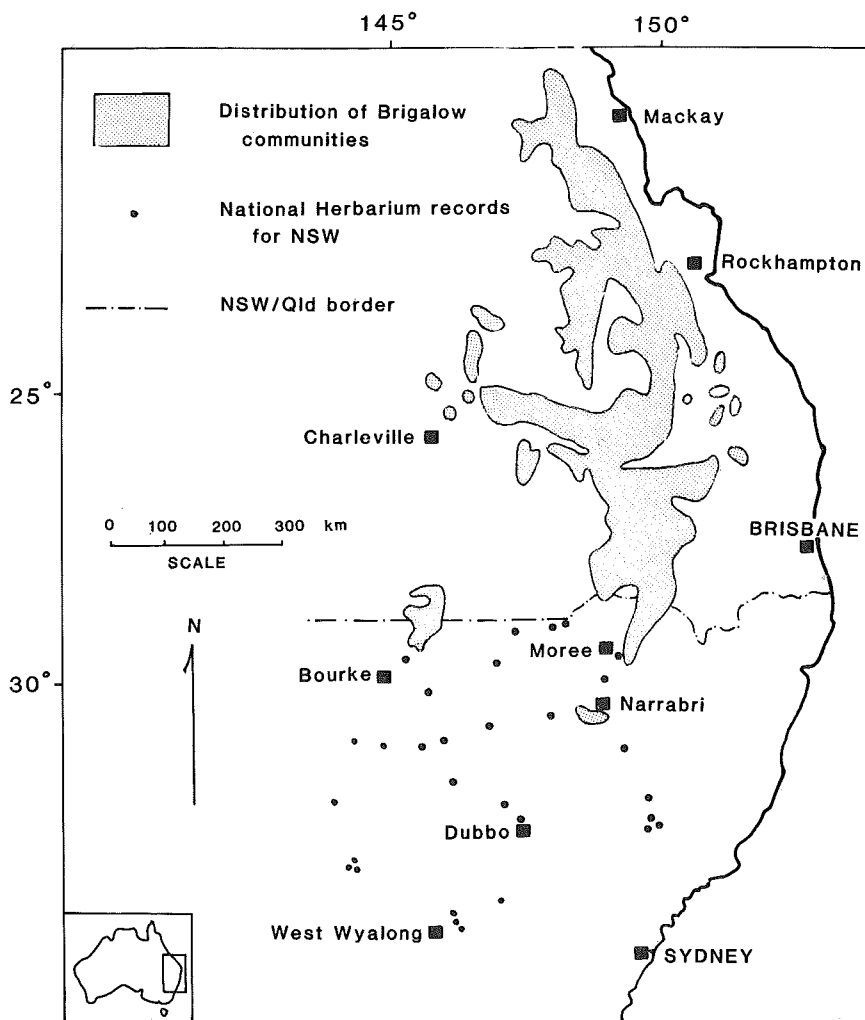


Figure 3. Distribution of Brigalow (*Acacia harpophylla*) in Queensland and New South Wales. Most of the larger stands near Narrabri and Moree in NSW have been cleared: only a few thousand hectares remain in scattered remnants. (Derived from Adamson & Fox 1981 and Pulsford 1984).

An endangered plant: *Rutidosia leptorhynchoides*

There are about 10 species of *Rutidosia* in Australia and four of these are listed as threatened (Briggs & Leigh 1988). *R. leptorhynchoides* F. Muell. (Asteraceae) is a bushy, perennial herb up to 30 cm high, flowering in the warmer months, particularly November and December. It was once more widely distributed in grasslands and woodlands in southern Victoria, centred on the basaltic Keilor Plain north west of Melbourne and in the Canberra–Queanbeyan districts on the Southern Tablelands of New South Wales.

The Victorian populations occur in communities dominated by Kangaroo Grass, *Themeda australis*. Most of the remaining sites near Melbourne are within railway reserves. One population has been observed to decrease from 100 plants to 11 plants over the last 10 years due to unsubstantiated causes (Leigh et al. 1984). In other recorded localities the species has become extinct.

In the Canberra–Queanbeyan area several populations of *R. leptorhynchoides* still occur, although it has suffered a substantial decline in its abundance due to urban expansion. One population on the outskirts of Queanbeyan has been protected in a small 2.2 hectare nature reserve. A few small populations in the Australian Capital Territory are threatened by urban development.

In Victoria, *R. leptorhynchoides* has mainly come under threat from grazing (Scarlett 1979). Fire could also be an important factor in its decline and Scarlett has suggested that summer burning regimes should be maintained or implemented. Further populations need to be protected in reserves and fenced off from grazing animals. Research into its response to grazing and fire is required.

An alien weed: *Chrysanthemoides monilifera*

Chrysanthemoides monilifera Norlindh (Asteraceae) is a 'pioneering' shrub that originates from South Africa where its six subspecies occur in a variety of habitats but commonly along the southern coastal areas of that country (Neser & Morris 1985). Two subspecies are present in Australia: *C. monilifera* subsp. *rotunda*, known as Bitou Bush, is established along the Central and North Coasts of New South Wales and the southern Queensland coast in regions of summer rainfall. *C. monilifera* subsp. *monilifera*, known as Boneseed, is found along the South Coast of New South Wales, in Victoria and in South Australia which receive higher winter rainfall.

Chrysanthemoides was first recorded in Sydney and Melbourne in the 1850s as a garden shrub (Gray 1976, Nicholls 1985). The main impetus for its spread was its use as a sand stabilizer on disturbed coastal sand dunes. This use continued even after it was listed as a noxious weed in other States, but ceased when its invasive properties were publicised and better appreciated. *Chrysanthemoides* now occupies 660 km or 60% of the New South Wales coastline, being dominant along about a third (Love 1985). Although approximately 35% of the coast is protected in conservation reserves, over 50% of the coastline in those reserves is affected by Bitou Bush or Boneseed (Love 1985).

The main native plant communities affected are foredune grasslands, dune scrub, dune forest, headland grassy heath and in particular small patches of littoral rainforest. Some rare plants such as *Cryptocarya foetida* (Lauraceae) are highly susceptible to competition with Bitou Bush (Dodkin & Gilmore 1985). Bitou Bush displaces the native shrub *Acacia longifolia* on coastal dunes on the South Coast of New South Wales because of its competitive advantage in the areas of seed production, rate of juvenile root and vegetative growth and an ability to expand vegetatively (Weiss 1983; Weiss & Noble 1984).

Groves (1985) highlights the need for integrated controls for Bitou Bush and Bone-seed which would include biological control of seed production and growth vigor, selective use of herbicides, use of fire, and the promotion of indigenous plants to replace *Chrysanthemoides* as it is eliminated. A co-operative Commonwealth and States funded project into a biological control program for *Chrysanthemoides* has been underway for several years and several insect predators have been selected for further assessment and trialing (John Scott pers. comm.).

Conservation of the flora of New South Wales

The first legislation that afforded protection to plants in New South Wales was the *Wild Flowers and Native Plants Act* (1927). This only outlawed the picking of 'protected wildflowers' from Crown land or State Forest. It was replaced by the *National Parks and Wildlife Act* (1974) which, as far as the protection of plant species and their habitats is concerned, is not much better than previous laws (Prineas 1987). New South Wales lacks effective legislation that serves to protect threatened species of plants on all land tenures or recognises the importance of habitat conservation (although draft legislation has been prepared). In contrast, Victoria and Western Australia have strong legislation protecting scheduled plant species (Benson 1990).

Given the lack of effective laws directed specifically at protecting plants, the conservation of flora has mainly been achieved as a consequence of the establishment of reserves to protect scenic or recreational features. However, over recent years there has been more emphasis on reserving or managing lands for the plant communities and species that are poorly conserved or under threat.

In August 1990 the National Parks and Wildlife Service managed 3,854,807 hectares or 4.8% of the State for conservation in 308 conservation reserves (broadly shown on Figure 4). The Forestry Commission manages 137 Flora Reserves (located in State Forests across the State) covering 35,000 hectares (Forestry Commission of NSW 1989). Therefore as of August 1990 a total of 4.86% of New South Wales was specifically dedicated to the conservation of the natural environment.

Large tracts of indigenous vegetation remain outside conservation reserves on public lands and private lands. The public lands include State Forests, unalienated Crown land, travelling stock routes, Crown land reserves and some leasehold lands. Unfortunately, from the conservation perspective, there is now much greater competition for the use of these remaining public lands, whether it be using coastal Crown land for tourist or housing developments or harvesting timber from State Forests in a more intensive way than that practised in the past. Most of the Western Division, representing 40% of the State and incorporating half of the Western Plains and all the Far Western Plains botanical divisions, is leasehold land. Theoretically, there is some government control over land-use in the Western Division but as can be gleaned from Figure 2, clearing is still continuing.

Freehold lands, while in the main highly modified, also contain important vegetation. Some of this is poorly represented on public lands, for example coastal freshwater wetlands and some of the White Box (*Eucalyptus albens*) associations on the Western Slopes. There are presently two key State Environmental Planning Policies affording substantial protection to vegetation types. SEPP 14 covers coastal wetlands and SEPP 26 covers littoral rainforest. Additionally, SEPP 19 protects some of the urban bushland remnants of Sydney.

Of the 432 plant associations listed by Benson (1989) as occurring in New South Wales, 179 (42%) are well represented in reserves, 111 (25%) are either vulnerable or

endangered and another 39 (9%) are not at all sampled in the reserve system. Table 6 assesses the conservation and threat status of the 18 major groups of plant associations. Generally, the groups that occur in the Central and Western Divisions are the least well conserved, only approximately 3% of land in these Divisions is protected in conservation reserves (compare Figures 1 and 4). Although there is a far greater proportion of land reserved on the coast and tablelands, i.e. the Eastern Division, it should be emphasised that this Division contains the most diverse, least disturbed and largest natural areas remaining in New South Wales. It is by no means adequately sampled, as those plant associations occurring on richer soils are scarcely represented in reserves, for example the tall eucalypt forests growing on basalt on the Northern Tablelands (Benson & Andrew 1990).

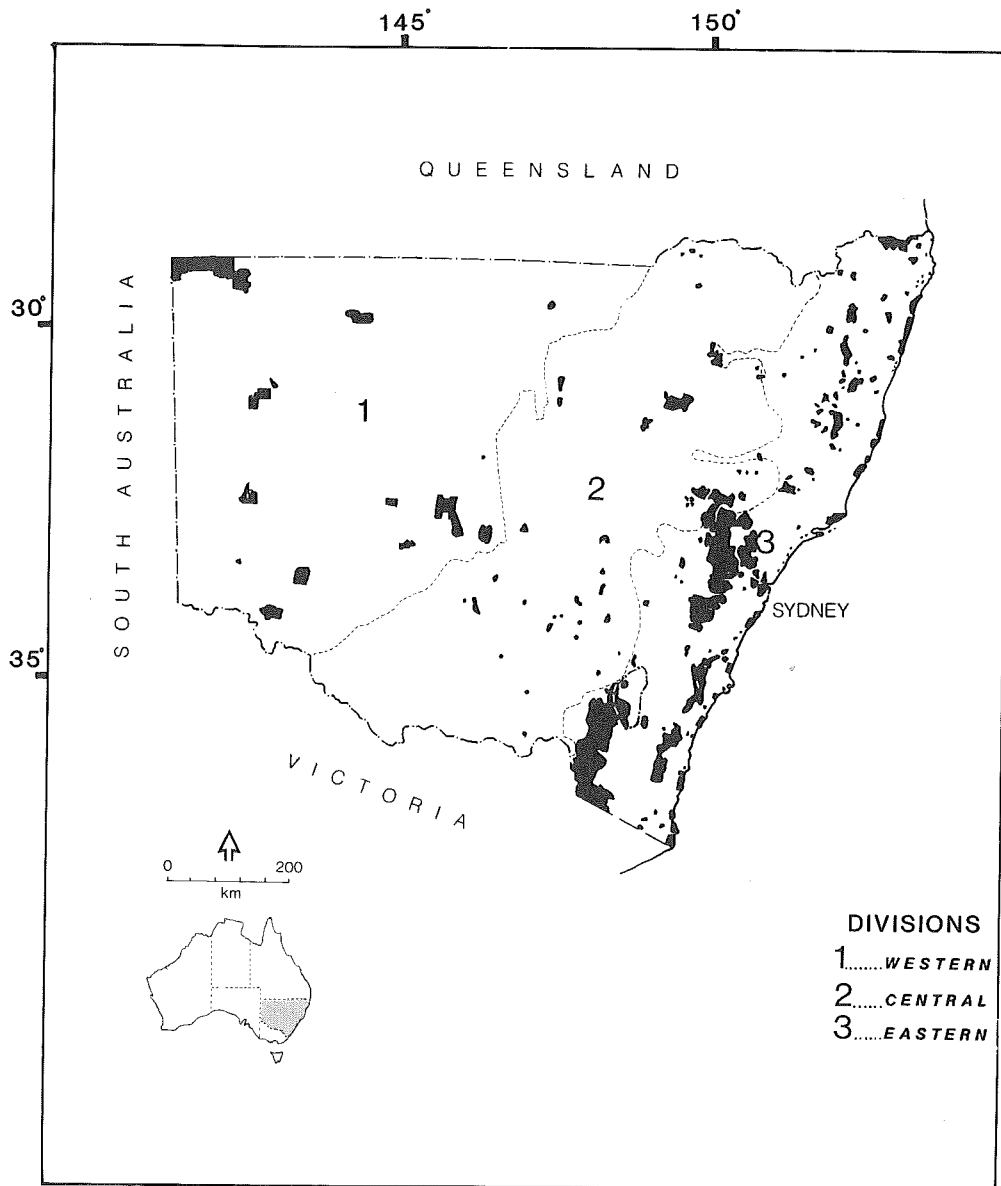


Figure 4. Conservation reserves held by the New South Wales National Parks & Wildlife Service as of 1990.

Table 6. Conservation status of major vegetation groups in New South Wales (from Benson 1989). The figures recorded in the columns refer to the number of plant associations within a vegetation group that are considered to be in a specific risk - conservation code.

No.	Vegetation group	No. of plant associations	Risk - conservation code						General conservation status				
			E1	E2	E3	V1	V2	V3		N1	N2	N3	
1	Rainforest												
1(i)	Subtropical rainforest (incl. littoral)	20	1			3	1		6	9			Good: lowland remnants require special protection and management
1(ii)	Dry rainforest	12	3			1	1		4	3			Fair-good: western slopes associations not conserved
1(iii)	Warm temperate rainforest	14							4	10			Excellent
1(iv)	Cool temperate rainforest	11							2	9			Excellent
	Summary - rainforest	57	3	1		1	4	1	16	31			*Good: except for some lowland subtropical, littoral and western dry rainforest
2	Eucalyptus forests mainly on coastal lowlands, medium to high nutrient soils	38					4		5	14	15		Good-fair: some tall forest associations poorly conserved or vulnerable, particularly in forestry or agricultural regions
3	Eucalyptus forests mainly of the coastal lowlands and central tablelands on low nutrient soils	47				3	1	1	3	7	32		Excellent: except for some associations on aeolian sands

No.	Vegetation group	No. of plant associations	Risk - conservation code						General conservation status		
			E1	E2	E3	V1	V2	V3		N1	N2
4	Eucalyptus forests of cooler highland climates (various soil types)	72	3			5	18	1	21	24	Fair: vulnerable associations occur in agricultural zones, particularly New England, Monaro
5	Ironbark forests and woodlands	16	2			2	3	1	6	2	Poor: mostly cleared for agriculture or logged
6	Box woodlands	25	8			6	5	6			Very poor: most vulnerable or endangered in agricultural lands
7	Inland mallee	10	1			3		2	3	1	Fair: some associations vulnerable to clearing for agriculture
8	Banksia and myrtaceous shrublands coastal lowlands - sands and clays	38				1		5	32		Excellent
9	Acacia and myrtaceous shrublands and related highland communities	22				2	1	1	5	13	Very good: except for some northern tableland associations
10	Alpine shrublands, sedgelands and herbfields (Kosciusko NP)	12				2				10	Excellent: but changing land use could threaten some associations
11	<i>Casuarina cunninghamia</i> forests	3				1			2		Fair: better conserved in east than in west
12	Inland acacia and casuarina shrubland/woodlands	13	2	2		3		5	1		Poor: considering distribution; some associations endangered on north-west plains

No.	Vegetation group	No. of plant associations	Risk - conservation code						General conservation status				
			E1	E2	E3	V1	V2	V3		N1	N2	N3	
13	Inland forests and shrublands dominated by 'rainforest' genera	4	1							3		Poor: one endangered, others widely distributed or poorly conserved	
14	Halophytic shrubland of the southern plains	9	2			1	2			4		Very poor: little conserved some associations endangered or vulnerable	
15	Natural grasslands	26	2			3				3	7	11	Fair: <i>Astrelba</i> and <i>Stipa</i> poorly conserved
16	Plant associations of the inland water-courses, floodplains and discharge areas	11				2	1			3	5		Very poor
17	Coastal freshwater wetlands and sedgelands	17					7				2	8	Excellent: sedgelands Poor: wetlands
18	Estuarine wetlands	12									6	6	Fair: generally not well conserved below high water mark, particularly sea grasses, and saltmarshes
Grand total			432	23	4	0	20	58	6	39	103	179	

KEY

E = endangered V = vulnerable N = not threatened at this stage

1 = not conserved or, if so, to a very minor degree

2 = inadequately conserved (small areas conserved or geographical range poorly conserved)

3 = adequately conserved (large areas conserved over the major part of its range)

* Statements are made in the context of remaining vegetation. Since two-thirds of subtropical rainforest has been cleared it may never be possible to adequately sample many sites.

See Benson (1989) for the floristic classification of the vegetation of New South Wales.

The most poorly conserved vegetation groups in New South Wales are:

Central and Western Divisions

- box woodlands;
- inland semi-arid 'dry rainforest' remnants;
- halophytic shrublands;
- plant associations along inland watercourses and discharge areas;
- inland *Acacia* and *Casuarina* associations;
- natural grasslands.

Eastern Division

- tall *Eucalyptus* forest associations on higher nutrient soils on the coastal plains and escarpment;
- *Eucalyptus* forest associations of the cooler highland climates, particularly those on richer soils;
- most coastal freshwater wetland types and some estuarine wetland types.

Rare or threatened species

It is estimated that half of the 532 plant species registered as being rare or threatened in New South Wales (Briggs & Leigh 1988) are adequately reserved (Benson 1989), that is with over 1000 individuals being present in reserves. However, this does not necessarily imply these are being managed sympathetically for their long-term conservation.

Although rainforest and alpine plant associations combined cover less than 4% of the State, these contain approximately 20% of the rare or threatened plants (Table 7). These two vegetation groups are relatively well conserved.

While most rare or threatened plant species occur in the Eastern Division of the State, 44% of the vulnerable species are in the poorly reserved and heavily grazed or cropped Central and Western Divisions, thus following the trend identified above for plant associations. Because of the magnitude of the task of conserving viable and representative samples of all plant associations and plant species (particularly those that are rare or threatened) not yet adequately protected in New South Wales, priorities need to be set. It is suggested that the most threatened and poorly conserved plant associations be surveyed and viable samples reserved and managed sympathetically. For rare or threatened plant species, those that are most threatened and most distinct in the taxonomic sense should be given special emphasis in protection strategies. Some plant species and plant associations will require more detailed ecological research if they are to survive. Others may only require passive management and monitoring, particularly regarding the effects of different fire regimes and nutrient cycles.

There is still the opportunity to improve the conservation of the flora of New South Wales as, (unlike some other parts of the world), viable natural areas remain. An integrated approach is necessary, involving rational land-use decisions by government, protection of remnant vegetation through planning controls, reservation of important sites, taxonomic research, monitoring and ecological research.

While plant taxonomy has been given impetus by the *Flora of Australia* series, Parsons & Scarlett (1989) demonstrate that some genera are being much more extensively examined than others. The *Flora*, working to tight deadlines, leaves a proportion of taxonomic problems unresolved. That presents a deficiency in information needed for conservation programs.

Table 7. Number of rare or threatened plant species for major biogeographical habitat-provinces in NSW (from Benson 1989).

Habitat - Provinces	Extinct (X)	Risk Codes			Rare (R)	Unknown Status (K)			Risk Code Totals	Total X+E+V +R+K=													
		Endangered (E)	Vulnerable (V)																				
Rainforest (All types)	1	9	7	4	0	1	3	11	1	0	6	18	17	2	0	0	0	12	16	33	18	67	80
Alpine (above treeline - Kosciusko NP)	0	0	0	0	0	0	3	1	0	0	17	13	0	0	1	0	0	0	0	21	14	35	35
Forests, heaths and swamps of high altitudes - tablelands	8	8	3	1	1	19	13	19	4	8	6	65	33	1	0	2	0	36	22	87	38	147	191
Forests, heath and swamps of lowland coastal zones	7	12	4	2	0	14	12	18	5	8	5	44	25	3	1	6	0	35	22	70	30	122	164
Forests, woodlands grasslands of western slopes & eastern plains (Central Division)	6	0	0	2	0	11	1	6	3	0	2	8	2	2	0	1	0	13	3	17	5	25	44
Semi-arid shrublands woodlands, grasslands, swamps of the western plains mainly Western Division	5	1	4	0	0	17	2	0	2	1	0	1	3	4	0	3	0	22	6	4	5	15	43
Total	27	30	18	9	1	62	31	57	16	15	19	153	93	12	1	13	0	119	68	232	92	411	557

For explanation of risk codes see Briggs and Leigh (1988)

CI = inadequately conserved ie. less than 1000 individuals located in conservation reserves

Ca = adequately conserved ie. 1000 or more individuals located in conservation reserves

C- = known to be in reserve(s) but adequacy unknown

N = not known from any conservation reserves

Conservation reserves include all reserves managed by the NSW NPWS & Flora Reserves managed by the NSW Forestry Commission.

Note: These figures were derived by the allocation of species to one or more habitat - provinces depending on their distribution. In most cases species are restricted to only one habitat - province. Nevertheless the fact that some species are located in more than one habitat - province explains the inflated total figure of 557 compared to the figure for the number of rare or threatened plants listed for NSW which is 532. Species extinct in NSW but extant in other states are ignored. For example 10 species which once existed on the western plains now only occur in other states.

Some ecological research is now attempting to investigate some of the processes that can lead to the extinction of species (besides the obvious ones such as direct destruction through clearing the land). One aim is to extrapolate the results of studying functional groups and universal factors such as fire to a range of other species and associations of species. In addition to this type of research there remains the special need to investigate the population dynamics of threatened plant species that have been assessed as having declining populations. Also, research into the genetic variation within and between populations can play a major role in conserving species with small populations (Moran & Hopper 1983; Sampson et al. 1989).

I suggest that additional research into and application of biological control of 'environmental weeds' would, over the long term, be most beneficial (and cost-effective) for many native plant associations and species.

Until we gain more knowledge of our flora conservation decisions will continue to be based on 'qualified' subjectivity, particularly in choosing reserves and managing them. To conserve the flora of New South Wales, we will need more effective controls over excessive clearing of vegetation, river diversion and other developments. This can be achieved through more effective use of soil conservation, planning and wildlife protection legislation, and these need to be improved. The current growth of 'Land Care' in rural regions is encouraging, but the past losses of native vegetation have been so great that this may not be enough. Within the next 10 years most of the State's remaining tall old growth forests may be logged, much of the remnant vegetation on the Western Slopes will be further degraded and extensive clearing of the central and north-eastern sections of the Western Division may continue. Prevention of the continued widespread destruction of vegetation and the consequent loss of species will continue to depend on educating the public and its institutions about ecology and conservation, but it would also benefit by the enactment of improved legislation to protect habitats and the enforcement of all the relevant laws affecting nature conservation.

Acknowledgments

The author is grateful to Robert Dick who prepared Figure 1 from LANDSAT imagery, Ms Ifeanna Tooth for the preparation of other figures and to Dr Marilyn Fox, Doug Benson and Dr Annie Ross for their comments on the text.

References

- Adamson, D.A. & Fox, M.D. (1982) Change in Australasian vegetation since European settlement in J.M.B. Smith (ed.) *A History of Australasian vegetation* (McGraw-Hill: Sydney).
- Auld, T.D. (1990) Regeneration in populations of the arid zone plants *Acacia carnei* and *A. oswaldii*. *Proc. Ecol. Soc. Aust.* 16: 267-272.
- Barlow, B.A. (1981) The Australian flora: its origin and evolution in *Flora of Australia*. 1 Introduction, 25-77. Bureau of Flora & Fauna, Canberra.
- Barrallier, F. (1802) *Journal of the expedition into the interior of New South Wales* (Marsh Walsh Publishing: Melbourne, 1975).
- Beadle, N.C.W. (1981) *The vegetation in Australia* (Cambridge University Press).
- Beadle, N.C.W., Evans, O.D. and Carolin, R.C. (1982) *Flora of the Sydney region*, third edition. (A.H. & A.W. Reed: Sydney).
- Beaton, J.M. (1982) Fire and water aspects of Australian Aboriginal management of cycads. *Archae. Oceania*, 17: 59-67.

- Benson, J.S. (1989) Establishing priorities for the conservation of rare or threatened plants and plant associations in New South Wales. In Hicks, M. & Eiser, P. *The conservation of threatened species and their habitats*. Occasional Paper No 2: 17–82. Australian Committee for IUCN, Canberra.
- Benson, J.S. (1990) Australia's threatened plants. In Kennedy, M. (ed.) *Australia's endangered species* (Simon and Schuster: Sydney).
- Benson, J.S. & Andrew, D. (1990) The flora, fauna and conservation significance of Ben Halls Gap State Forest, Nundle, New South Wales. *Technical Report 90/1*. National Parks & Wildlife Service of N.S.W., Hurstville.
- Boswell, A. *Annabella Boswells' Journal: an account of early Port Macquarie* (Angus & Robertson: Sydney (1981)).
- Bowman, D.M.J.S. & Brown, M.J. (1986) Bushfires in Tasmania: a botanical approach to anthropological questions. *Archae. Oceania*, 21: 166–171.
- Briggs, J.D. & Leigh, J.H. (1988) *Rare or threatened Australian plants*. Special Publication No. 14 Australian National Parks & Wildlife Service, Canberra.
- Brown, A.M. (1983) Conservation genetics in Victoria. *Technical Report Series No. 1*. Dept. of Conservation & Lands, Victoria.
- Brown, I. (1990) Living on the edge. *Aust. Nat. History*, 23(3): 252.
- Cameron, J.I. & Penna, I.W. (1988) The wood and the trees. A preliminary economic analysis of a conservation-orientated forest industry strategy. Australian Conservation Foundation, Melbourne.
- Chesterfield, C.J. & Parsons, R.F. (1985) Regeneration of three tree species in arid south-eastern Australia. *Aust. J. Bot.*, 33: 715–732.
- Clark, R.L. (1983) Pollen and charcoal evidence for the effects of Aboriginal burning on the vegetation of Australia. *Archae. Oceania*, 18: 32–34.
- Clark, J. & Blakers, M. (1989) *Forest conservation and wood supply: no need for conflict*. Faculty of Environmental Design and Construction, Royal Melbourne Institute of Technology, Melbourne.
- Costin, A.B., Gray, M., Totterdell, C.J. & Wimbush, D.J. (1979) *Kosciusko Alpine Flora* (Collins: Sydney).
- Crisp, M.D. (1988) *Eucalyptus recurva* (Myrtaceae), a new species from the Southern Tablelands of New South Wales. *Telopea* 3(2): 223–230.
- Cunningham, G.M., Mulham, W.E., Milthorpe, P.L. & Leigh, J.H., (1981) *Plants of western New South Wales* (New South Wales Government Printer: Sydney).
- Denny, M. (1987) *Historical and ecological study of the effects of European settlement in inland New South Wales*. Report to the NSW Nature Conservation Council & National Estate Committee of the Heritage Council of New South Wales. Nature Conservation Council, Sydney.
- Department of Arts, Heritage & Environment (1986) *State of the environment* (Australian Government Publishing Service: Canberra).
- Department of State Development. (1989) *New South Wales Pulp and Paper Industry Task Force Report*. Department of State Development, Sydney.
- Dickinson, K.J.M. & Kirkpatrick, J.B. (1987) Fuel dynamics, fire risk and economic productivity in Tasmanian dry eucalypt forests on dolerite. *J. Environmental Management* 25: 197–214.
- Dodd, A.P. (1959) The biological control of Prickly Pear in Australia. *Biogeography and Ecology in Australia*. Monographiae. Biologicae, VIII. W. Junk, The Hague, Holland.
- Dodkin, M.J. & Gilmore, A.J. (1985) Species and ecosystems at risk, in A. Love and R. Dyason (eds) *Bitou Bush and Boneseed: Proceedings of a Conference on Chrysanthemoides monilifera*, 1984. National Parks & Wildlife Service and Department of Agriculture, New South Wales.
- Ecos (1978) A destructive forest fungus. *Ecos* 15: 3–14.
- Floyd, A.G. (1979) Littoral rainforest clearing. Report on littoral rainforest: rainforest report: Forster to Crescent Head. National Parks & Wildlife Service of New South Wales, Hurstville.
- Floyd, A.G. (1990) *Australian Rainforests of New South Wales*, Vol 1. (Surrey Beatty and Sons: Sydney).
- Forestry Commission of New South Wales (1988) *Forestry operations in the Eden Management Area: Environmental Impact Statement*, October 1988. Forestry Commission of New South Wales, Sydney.
- Forestry Commission of New South Wales (1989) *Forest preservation in State Forests of New South Wales. Research Note No. 17*, 2nd Edition. Forestry Commission of New South Wales.

- Fox, M.D. & Fox, B.J. (1986) The susceptibility of natural communities to invasion, in R.H. Groves & J.J. Burdon (eds.), *Ecology of biological invasions* (Australian Academy of Science: Canberra).
- Fox, B.J. (1990) Two hundred years of disturbance: how has it aided our understanding of succession in Australia. *Proc. Ecol. Soc. Aust.* 16: 521-529.
- Frith, H.J. (1977) The destruction of the 'Big Scrub', in Goldstein, W. (ed.) *Parks & Wildlife*, 2(1): 7-12.
- Gill, A.M. (1975) Fire and the Australian flora: a review. *Australian Forestry*, 38: 4-25.
- Gleadow, R.M. & Ashton, D.H. (1981) The invasion by *Pittosporum undulatum* of the forests of central Victoria: invasion patterns and plant morphology. *Aust. J. Bot.*, 29: 705-720.
- Gray, M. (1976) Miscellaneous notes on Australian plants, 2: *Chrysanthemoides* (Compositae) *Contributions Herbarium Australiense*, 16: 1-5.
- Groves, R.H. (1981) *Australian vegetation* (Cambridge University Press: Cambridge).
- Groves, R.H. (1985) Ecological consequences of biological control of *Chrysanthemoides monilifera*, in A. Love and R. Dyason (eds) *Bitou Bush and Boneseed: Proceedings of a conference on Chrysanthemoides monilifera*, 1984. NSW National Parks & Wildlife Service and Department of Agriculture, Sydney.
- Groves, R.H. (1986) Plant invasions of Australia: an overview, in R.H. Groves and J.J. Burdon (eds) *Ecology of biological invasions: An Australian perspective*. Australian Academy of Science, Canberra.
- Hager, T. & Benson, J.S. (1990) Review of the conservation status of vegetation associations in New South Wales, Stage 1, Part 1: assessment of the 'Specht' methodology and development of specifications for a database. National Parks & Wildlife Service of New South Wales, Hurstville.
- Hardin, G.J. (ed.) (in press). *Flora of New South Wales*, Vol 2. (University of New South Wales Press: Sydney).
- Heathcote, R.L. (1965) *Back of Bourke: A study of land appraisal and settlement in semi-arid Australia* (Melbourne University Press: Melbourne).
- Horton, D.R. (1982) The burning question: Aborigines, fire and Australian ecosystems. *Mankind*, 13(3): 237-251.
- Hosking, J. (1990) The feasibility of biological control of *Cytisus scoparius* (L.): preliminary report on overseas study tour, June-September 1990. Unpublished report to the NSW Department of Agriculture & Fisheries.
- Hunter, J. (1793) *An historical journal of the transactions at Port Jackson and Norfolk Island* (John Stockton: London).
- Isbell, R.F. (1962) Soils and vegetation of the Brigalow lands, eastern Australia. *Soil and Land Use Series*, No. 43. CSIRO.
- Jacobs, S.W.L. & Pickard, J. (1981) *Plants of New South Wales: A census of the Cycads, Conifers and Angiosperms* (Royal Botanic Gardens: Sydney).
- Javinen, O. (1982) Conservation of endangered plant populations: single large or several small reserves? *OIKOS* 38(3): 301-307.
- Jones, R. (1969) Fire-stick farming. *Australian Natural History*, 16: 224-228.
- Johnson, R.W. (1964) Ecology and control of brigalow in Queensland. Queensland Department of Primary Industries, Brisbane.
- Johnson, R.W. (1984) Flora and vegetation of the brigalow belt, in A. Bailey (ed.). *The Brigalow Belt of Australia*. Royal Society of Queensland, Brisbane.
- Keith, D. & Benson D.H. (1988) The natural vegetation of the Katoomba 1:100 000 map sheet. *Cunninghamia* 2(1): 107-143.
- Kershaw, A.P. (1978) Record of last interglacial-glacial cycle from north-eastern Queensland. *Nature*, 272: 159-161.
- Kile, G.A. (1980) An overview of eucalypt dieback in rural Australia, in K.M. Old, G.A. Kile and C.P. Olmont (eds.) *Eucalypt dieback in forests and woodlands*. CSIRO, Australia.
- Kloot, P.M. (1987a) The naturalised flora of South Australia, 2, its development through time. *J. Adelaide Bot. Gardens*, 10(1): 91-98.
- Kloot, P.M. (1987b) The naturalised flora of South Australia, 3, its origin, introduction, distribution, growth forms and significance. *J. Adelaide Bot. Gardens*, 10(1): 99-111.
- Leigh, J., Boden, R. & Briggs, J. (1984) *Extinct and endangered plants of Australia* (Macmillan: Melbourne).

- Lewis, H.T. (1982) Fire technology and resource management in Aboriginal North America and Australia, in N.M. Williams and E.S. Hunn (eds) *Resource Managers: North American and Australian Hunter Gatherers*. A.A.A.S. Selected Symposium 67: 45–67 (Westview Press Inc.: Colorado).
- Lloyd, P.L. (1984) Agricultural and pastoral land use in the brigalow belt of Queensland, in A. Bailey (ed.) *The Brigalow Belt of Australia*. Royal Soc. Qld.
- Love, A. (1985) Distribution of Bitou Bush along the New South Wales coast, in A. Love and R. Dyason (eds.) *Bitou Bush and Boneseed: Proceedings of a conference on *Chrysanthemoides monilifera* 1984*. National Parks & Wildlife Service and Department of Agriculture, Sydney.
- Michael, P.W. (1981) Alien plants. In R.H. Groves (ed.) *Australian Vegetation*. Cambridge (University Press: Cambridge).
- Mitchell, T.L. (1838) *Three expeditions into the interior of eastern Australia with description of the recently explored region of Australia Felix and of the present colony of New South Wales* (T. & W. Boone: London).
- Mitchell, T.L. (1848) *Journal of an expedition into the interior of tropical Australia* (Longman, Brown, Green & Longmans: London).
- Moran, G.F. & Hopper, S.D. (1983) Genetic diversity and the insular population structure of the rare granite rock species, *Eucalyptus caesia* Benth. *Aust. J. Bot.*, 31: 161–172.
- Moore, C.W.E. (1953) The vegetation of the south-eastern Riverina, New South Wales, 1, the climax communities. *Aust. J. Bot.*, 1: 485–547.
- Moore, R.M. (1966) Man and plant communities. *Proc. Ecol. Soc. Aust.*, 1: 106–110.
- Murray-Darling Basin Ministerial Council. (1989) *Murray-Darling Basin Natural Resources Management Strategy: Background Papers*. Murray-Darling Basin Ministerial Council, Canberra.
- Nanson, G.C. & Young, R.W. (1983) Environmental concerns in a sandstone landscape with particular reference to the Sydney Basin, N.S.W.. In Young, R.W. and Nanson G.C. (eds) *Aspects of Australian Sandstone Landscapes*. Australian and New Zealand Geomorphology Group Special Publication No. 1.
- Nanson, G.C., Young, R.W. & Stockton, E.P. (1987) Chronology and paleoenvironment of the Cranebrook Terrace (near Sydney) containing artefacts more than 40,000 years old. *Archeo. Oceania*, 22(2): 72–78.
- National Parks & Wildlife Service of New South Wales (1982) Submission to Joint Select Committee Enquiry on the Western division of New South Wales. National Parks and Wildlife Service, Sydney.
- National Parks & Wildlife Service of New South Wales (1990) Submission to the New South Wales Pulp and Paper Industry Task Force Report. National Parks & Wildlife Service, Hurstville.
- Neser, S. & Morris, M.J. (1985) Preliminary observations of natural enemies of *Chrysanthemoides monilifera* in South Africa, in A. Love and R. Dyason (eds) *Bitou Bush and Boneseed: Proceedings of a Conference on *Chrysanthemoides monilifera*, 1984*. NSW National parks and Wildlife Service & Department of Agriculture, Sydney.
- Nicholls, W. (1985) Bitou Bush, Boneseed and the Australian heritage, in A. Love and R. Dyason (eds) *Bitou Bush and Boneseed: Proceedings of a Conference on *Chrysanthemoides monilifera*, 1984*, NSW National Parks & Wildlife Service and Department of Agriculture, Sydney.
- Parsons, R.F. & Brown, J.H. (1983) Causes of plant species rarity in semi-arid southern Australia. *Biol. Cons.*, 24: 183–192.
- Parsons, R.F. & Scarlett, N.H. (1989) Lack of taxonomic research as a threat to part of the southern Australian flora, in Hick, M & Eiser, P (eds) *The conservation of threatened species and their habitats*. Occasional Paper No. 2 Australian Committee for IUCN, Canberra.
- Pressey, R. (1990) Clearing and conservation in the Western Division of New South Wales. *National Parks Journal*, 34(6): 16–19 and 22–24.
- Prineas, P. (1987) Effectiveness of current wildlife legislation in Australia and the appropriateness and implementation of endangered species habitat protection legislation. Unpublished report. NSW National Parks & Wildlife Service of New South Wales.
- Pulsford, I.F. (1984) Conservation status of Brigalow *Acacia harpophylla* (Mimosaceae) in New South Wales, in A. Bailey (ed.) *The Brigalow Belt of Australia*. Royal Society of Queensland, Brisbane.
- Reed, P. (1990) An historical perspective on: Conserving what? — the basis for nature conservation in New South Wales 1967–1989. *Australian Zoologist* 26(2): 85–91.

- Robinson, A.G. (1829–1834) *The friendly mission: the Tasmanian journals and papers of George Augustus Robinson, 1829–1834*. Ed. N.J.B. Plomley, Tasmanian Historical Research Association, Hobart.
- Robinson, M. & Benson, J.S. (1990) Review of the conservation status of vegetation associations in New South Wales, Stage 1, Part 2: the conservation of some coastal plant associations in NSW. National Parks & Wildlife Service of New South Wales, Hurstville.
- Ross, A. (1984) If there were water: prehistoric settlement patterns in the Victorian mallee. PhD Thesis, Macquarie University, Sydney.
- Sampson, J.F., Hopper, S.D. & Coates, D.J. (1989) *Eucalyptus rhodantha*: Western Australian Wildlife Management Program No. 3. Dept. Conservation & Land Management, Perth.
- Sattler, P.S. & Webster, R.J. (1984) The conservation status of Brigalow (*Acacia harpophylla*) communities in Queensland, in A. Bailey (ed.) *The Brigalow Belt of Australia*. Royal Society of Queensland, Brisbane.
- Scarlett, N.H. (1979) A register of rare or threatened plants in Victoria. Unpublished report, La Trobe University.
- Singh, G. (1982) Pollen analytical work from Lake Frome, N.E. South Australia, in B.G. Thom and R.J. Wasson (eds) *Holocene Research in Australia 1978–1982*. Occasional Paper 33 Dept. Geography, University of New South Wales, Duntroon.
- Singh, G., Kershaw, A.P. & Clark, R. (1981) Quaternary vegetation and fire history in Australia, in A. Gill (ed.) *Fire and the Australian Biota*. Australian Academy of Science, Canberra.
- Smith, J. (1981) The distribution and conservation status of a rare conifer, *Microstrobus fitzgeraldii* (Podocarpaceae). *Cunninghamia* 1(1): 125–128.
- Smith, J.M.B. (1982) An introduction to the history of Australasian vegetation, in J.M.B. Smith (ed.) *A history of Australasian vegetation*. McGraw-Hill, Sydney.
- Strom, A.A. (1977) On the Illawarra, in W. Goldstein (ed.) *Parks and Wildlife*, 2(1): 13–17.
- Tindale, N.B. (1959) Ecology of primitive Aboriginal Man in Australia. *Biogeography and ecology in Australia*. Monographiae Biologicae, 8: 36–51 (Junk: Dee Haag).
- Webb, L.J. & Tracey, J.G. (1982) Australian rainforests: patterns and change, in A. Keast *Ecological biogeography of Australia* (W. Junk: The Hague).
- Weiss, P.W. (1983) Invasion of coastal *Acacia* communities by *Chrysanthemoides*. PhD Thesis, Australian National University, Canberra.
- Weiss, P.W. and Noble, I.R. (1984) Interactions between seedlings of *Chrysanthemoides monilifera*. *Aust. J. Ecol.*, 9: 93–98.
- Wells, K.F., Wood, N.H. & Laut, P. (1984) Loss of forests and woodlands in Australia: a summary by state, based on rural local government areas. *CSIRO Tech. Mem.* 84(4).
- White, M.E. (1986) *The greening of Gondwana* (Reed Books: Sydney).
- Williams, J.B. & Nadolny, C. (1980) A survey of eucalypt species involved in New England dieback, in K.M. Old, G.A. Kile and C.P. Ohmont (eds) *Eucalypt dieback in forests and Woodlands*. CSIRO.
- Wright, R. (1986) How old is zone F at Lake George? *Archae. Oceania*, 21, 138–139.
- Young, A.R.M. (1982) Upland swamps (dells) on the Woronora plateau, N.S.W.. PhD Thesis University of Wollongong, Wollongong.

Manuscript received 11 February 1988

Revised manuscript received 2 January 1990

Manuscript accepted 7 March 1991