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COVER

Kinchega National Park is a key conservation area for the threatened small tree *Acacia carneorum*. Most stands consist of ageing trees with no young recruits. Recent extreme rabbbit control measures and effects of rabbit calicivirus have allowed the growth of new suckers (foreground) in the last few years (photo: Andrew Denham).

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The vegetation of Kinchega National Park, western New South Wales

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Westbrooke, M.E., Kerr, M.K.C. and Leversha, J. (Centre for Environmental Management, University of Ballarat, PO Box 663 Ballarat, Victoria, Australia 3353) 2001. The vegetation of Kinchega National Park, western New South Wales. Cunninghamia *7(1): 1–25.*

The vegetation of Kinchega National Park (latitude 32°18'–32°40'S and longitude 142°10'–142°25'E) in far western New South Wales was assessed using intensive quadrat sampling and mapped using extensive ground truthing and interpretation of aerial photographs and Landsat Thematic Mapper satellite images. Three hundred and fifty two species of vascular plants were recorded from this survey, which, together with other records indicates the presence of 503 species from 69 families including 100 (20%) exotic species. Fifteen vegetation communities were identified and mapped, the most widespread being *Maireana* species low open-shrubland, *Acacia victoriae* open-shrubland and *Eucalyptus largiflorens* open-woodland. The Park also contains a number of rare or threatened species and vegetation communities. One hundred and fifty years of grazing by introduced herbivores coupled with the impact of a modified hydrological regime has resulted in degradation of many of these communities.

Introduction

Kinchega National Park (latitude 32°18'–32°40'S and longitude 142°10'–142°25'E) is located in far western New South Wales 110 km south-east of Broken Hill (Fig. 1). The Park covers an area of approximately 44 000 ha. It largely encompasses Lakes Menindee and Cawndilla, which form a major part of the Murray Darling Basin Commission's Menindee Lakes Storage Scheme. About half the bed of Lake Menindee and all of the bed of Lake Cawndilla are managed by the NSW National Parks and Wildlife Service as part of the Park. The Department of Land and Water Conservation, which is responsible for the Menindee Lakes Scheme, retains the right to flood and drain Lakes Menindee and Cawndilla as part of its operations (NPWS 1999a).

History of the area

The Paakantji Aboriginal people travelled the length of the Darling River from Wilcannia through Menindee towards Wentworth. The large number of middens and stone relics encountered today is evidence of their strong ties to the river (H. Johnston, NSW Parks and Wildlife Service, Buronga, pers. comm.). With the development of pastoral leases in the 1850s, Aboriginal people were moved from their traditional homes to government missions at Menindee, Ivanhoe and Lake Cargelligo. The first Europeans to visit the area followed the Darling River in search of pasture for sheep. The Burke and Wills and Charles Sturt exploration parties both camped at Kinchega. Kinchega National Park was once part of the Kinchega-Kars pastoral lease held by the

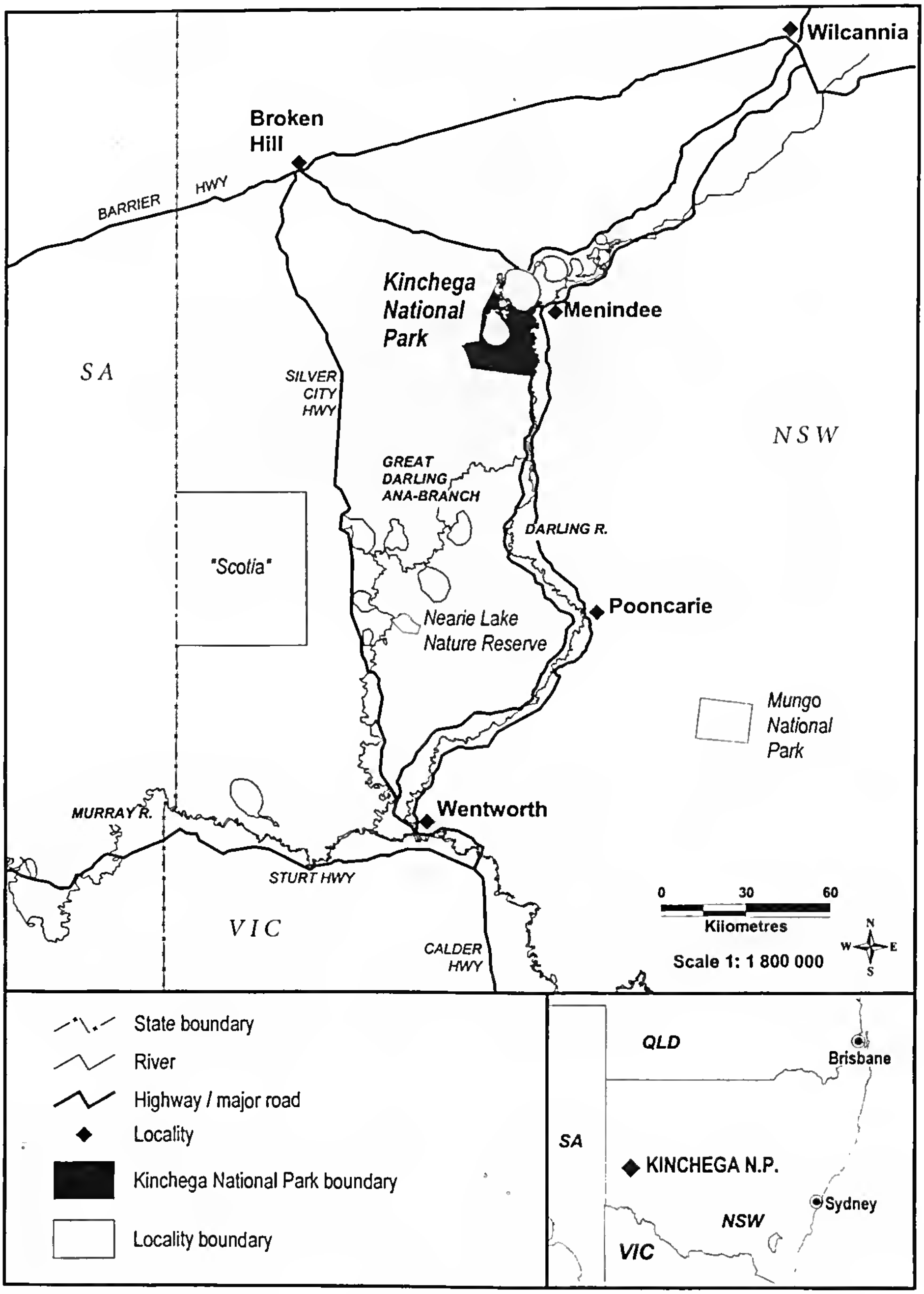

Fig. 1. Location of Kinchega National Park.

Hughes family from early 1870. The property once extended from Menindee to Broken Hill and covered an area of over 800 000 ha. The Park was established in 1967 to protect the cultural and biological features of land systems associated with the overflow lakes of the Darling River.

Climate

The climate is classified as cool semi-arid (Dick 1975), the area being within climatic zone 1B for NSW (Edwards 1979). Temperatures are high in summer and mild in winter with average daily maximum of 34°C in January and 17°C in July and average daily minimum of 19°C in January and 5°C in July. The mean annual rainfall is approximately 244 mm and annual potential evaporation is 2335 mm. The seasonal distribution of rainfall is even but annual variation is high (Clewett et al. 1994).

Geology and geomorphology

The study area lies within the Murray Basin geological province and consists of Quaternary material, with little rock outcropping (Lawrie & Stanley 1980). The lakes and dry lakebeds are underlain by lacustrine deposits of the Coonambidgal Formation and the surrounding areas consist of unconsolidated red-brown siliceous silty sand, calcareous silty clay and sandy clay of the Woorinen Formation. Associated with the floodplain of the Darling River are fluvio-lacustrine deposits of the Shepparton Formation (Brodie 1994). Four broad land systems are present (Walker 1991):

1. The lake system of deep grey cracking clays with partially stabilised sandy lunettes.
2. Alluvial plains of the Darling and Ana-branch with associated dunes and red sandy plains.
3. Partly scalded sandplains of sandy loam to sandy solonised soils.
4. Dunefields of east-west trending dunes and swales of sandy red earths and calcareous red earths.

Previous studies

The most complete study of the vegetation of far western NSW is that by Beadle (1945, 1948) who included the study area as saltbush formation. More recently the National Herbarium of New South Wales, Sydney, has undertaken mapping of the vegetation of areas to the south at 1: 250 000 scale. Reports on Ana Branch-Mildura (Fox 1991), Balranald-Swan Hill (Scott 1992) and Pooncarie map sheets (Porteners 1997) have been published. A study of the vegetation of the Willandra Lakes World Heritage Area was undertaken for the New South Wales Department of Planning and Environment (Rice 1987). Detailed surveys and vegetation maps for Mallee Cliffs National Park (Morcom & Westbrooke 1990), Mungo National Park (Westbrooke & Miller 1996), Nearie Lake Nature Reserve (Westbrooke et al. 1997) and the Scotia Country (Westbrooke et al. 1998) to the south have also been published. Auld (1990, 1993, 1995a, 1995b, 1995c) has studied the ecology of tree and shrub species in the Park and Robertson (1987, 1988) investigated the effect of rainfall on ground vegetation, but no systematic survey of the vegetation of the Park has been undertaken.

Methods

Following preliminary survey, 171 × 0.09 ha (30 m x 30 m) quadrats were sampled. All vascular plant species occurring were recorded, as was a cover abundance value, modified from Braun-Blanquet (1928) for each species. Quadrats were subjectively located following the method of Gullan (1978). This ensured that all communities were sampled and provided data on floristic variability within them. Communities were generally sampled in proportion to the area they covered. However, since many quadrats were located along transects wherever community type was observed to change, those with a discontinuous distribution may have been over-sampled. Sampling was undertaken in December 1996 and December 1997, both surveys following above average spring rains. Data from the quadrats were analysed via a computer-based numerical classification procedure coupled with a hand sorting procedure of the type outlined in Gullan (1978). A species list was compiled incorporating all vascular plant species recorded from sampled quadrats, species recorded following opportunistic collection and other records from the Park (NPWS 1999b, R. Parsons, La Trobe University, pers comm.). Further restricted and/or interesting communities recorded during the field work but not evident from the numeric classification were added to the final classification to provide 15 vegetation communities. For each community, mean species richness, total species richness and number of exotic species as a proportion of the total number of species recorded from quadrats were calculated (Table 1).

During surveys, ground truthing was undertaken by driven and walked transects. Information from these was used in conjunction with study of colour aerial photographs (Central Mapping Authority 1995) and Landsat Thematic Mapper satellite image data (Scene 96–83) to produce a vegetation map at 1: 100 000 scale. The mapped vegetation communities were defined by floristic and structural characteristics (Specht 1970). Nine communities from the vegetation classification could be mapped at this scale. Additional vegetation types of restricted occurrence, e.g. those dominated by *Acacia loderi*, *Acacia ligulata* and *Acacia carneorum* were located as points on the map. The classified image was transferred to the MapInfo Geographic Information System (MapInfo Corporation, Troy, New York) database for final production of the vegetation map.

Results

Vegetation

The vegetation of the study area consists predominantly of riverine woodlands of *Eucalyptus largiflorens* and *Eucalyptus camaldulensis* around the lake system and on the floodplains of the Darling River and Great Ana-branch, with arid woodlands and shrublands on the sandplains and dunefields. Fifteen communities were recognised. While several of these are of limited distribution they add significantly to the conservation values of the Park. The approximate area occupied by each community, the sampling intensity, mean species richness, total species richness and mean % weediness of these communities are given in Table 1.

Table 1. Area, sampling intensity, species richness and weediness of plant communities of Kinchega National Park.

Community	Area (ha)	Mean species richness	Total species richness	Mean % exotic species	No. of quadrats
Eucalyptus camaldulensis open-woodland	815	26	128	27	18
Eucalyptus largiflorens open-woodland	16 765	22	184	23	31
Casuarina pauper/Alectryon oleifolius low open-woodland	2415	16	79	13	16
Acacia aneura tall open-shrubland	< 5	22	22	14	1
Acacia loderi tall open-shrubland	< 5	17	44	9	4
Acacia ligulata open-shrubland	153	11	25	25	6
Acacia carneorum open-shrubland	< 5	13	29	14	4
Acacia victoriae subsp. *victoriae* open-shrubland	1512	19	76	16	7
Senna/Dodonaea/Eremophila open-shrubland	1768	27	77	7	10
Atriplex nummularia open-shrubland	154	13	42	11	5
Maireana pyramidata low open-shrubland	16 462	18	116	14	31
Chenopodium nitrariaceum open-shrubland	667	19	65	14	5
Scleroleana spp./*Atriplex* spp. low open-shrubland	1642	18	109	14	15
Zygochloa paradoxa hummock grassland	72	21	67	17	6
Herbland	417	20	120	26	12

All vegetation communities are described below, grouped according to structural attributes. The distribution of vegetation types is shown on the vegetation map.

1. Woodlands

1a *Eucalyptus camaldulensis* open-woodland

Eucalyptus camaldulensis open-woodland (10 metres tall) occurs on heavy soils along the Darling River and in a generally narrow band around the overflow lakes. *Eucalyptus largiflorens* is frequently associated and the native shrubs *Einadia nutans, Enchylaena tomentosa* and *Muehlenbeckia florulenta* are common components of the understorey. The exotic herbs *Carrichtera annua, Centaurea melitensis* and *Sisymbrium erysimoides* are frequent in the ground layer (Fig. 2).

Fig. 2. *Eucalyptus camaldulensis* open-woodland occurs as a narrow strip along the Darling River.

1b *Eucalyptus largiflorens* open-woodland

This open-woodland (10 m tall) occurs on heavy soils on the floodplains around the Darling River and the overflow lakes. Trees are commonly infested with the mistletoe *Amyema miquelii*. *Atriplex leptocarpa*, *Chenopodium nitrariaceum*, *Einadia nutans* and *Enchylaena tomentosa* are commonly associated understorey species. The exotic species *Centaurea melitensis*, *Centaurium spicatum* and *Cirsium vulgare* are frequent in the ground layer (Fig. 3).

1c *Casuarina pauper*/*Alectryon oleifolius* woodland/open-woodland

Casuarina pauper woodland/open-woodland growing to 10–12 metres tall, occurs in the form of monospecific groves or associated with *Alectryon oleifolius* subsp. *canescens*, which in places itself forms monospecific stands. *Casuarina pauper* may be host to the mistletoe *Amyema linophyllum* whereas *Alectryon oleifolius* subsp. *canescens* is commonly host to *Amyema miraculosum*. Most commonly associated understorey shrubs are *Enchylaena tomentosa* and *Maireana pyramidata*. Common ground layer species include *Enneapogon avenaceus*, *Myriocephalus stuartii*, *Tetragonia moorei*, *Salsola kali* and the exotic *Schismus barbatus* (Fig. 4).

2. Acacia shrublands

2a *Acacia loderi* open-shrubland

Groves of *Acacia loderi* open-shrubland occur to 7 m on the dunefields and sandplains to the west of Lakes Menindee and Cawndilla. Commonly associated shrubs include *Enchylaena tomentosa*, *Maireana pyramidata* and *Sclerolaena obliquicuspis* (Fig. 5).

Fig. 3. *Eucalyptus largiflorens* open-woodland occurs across the floodplain of the Darling River.

Fig. 4. Degraded examples of *Casuarina pauper/Alectryon oleifolius* low open-woodland occur in the south-west of the Park.

Fig. 5. Isolated stands of *Acacia loderi* tall open-shrubland show no recent regeneration.

Fig. 6. Areas of *Acacia victoriae* subsp. *victoriae* open-shrubland occur in association with the Darling River floodplains.

2b *Acacia victoriae* ssp. *victoriae* open-shrubland

Acacia victoriae ssp. *victoriae* open-shrubland to 3 m occurs on sandplains in the south east of the Park. Associated shrub species include *Dodonaea viscosa* subsp. *augustissima, Senna artemisioides* subsp. and *Eremophila sturtii.* The ground layer is dominated by *Dissocarpus paradoxus, Enchylaena tomentosa, Calotis erinacea,* and *Vittadinia cuneata* (Fig. 6).

2c *Acacia ligulata* open-shrubland

Acacia ligulata open-shrubland occurs on low sandy rises on alluvial plains. Associated shrubs include *Enchylaena tomentosa* and the ground layer is dominated by *Enneapogon avenaceus, Myriocephalus stuartii* and the exotics *Schismus barbatus* and *Centaurea melitensis.*

2d *Acacia carneorum* open-shrubland

Small areas of *Acacia carneorum* open-shrubland occur on dunefields in the south west of the Park. *Enchylaena tomentosa* is the only shrub consistently associated and the ground layer consists of *Dissocarpus paradoxus, Myriocephalus stuartii, Nicotiana velutina* and *Tetragonia moorei, Salsola kali* with the exotic *Schismus barbatus* (Fig. 7).

2e *Acacia aneura* tall open-shrubland

Small patches of *Acacia aneura* tall open-shrubland occurs in the south west and northwest of the Park. *Sclerolaena* species and the exotic grass *Schismus barbatus* dominate the ground layer.

3. Low open shrublands

3a *Dodonaea viscosa* subsp. *augustissima/Senna artemisioides* subspecies *Eremophila sturtii* shrubland

Associated with *Casuarina pauper* woodland/open-woodland and *Acacia* shrublands are extensive areas of mixed species shrubland in which *Dodonaea viscosa* subsp. *augustissima, Senna artemisioides* subspecies and *Eremophila sturtii* are prominent. Other associated shrubs include *Acacia victoriae* subsp. *victoriae, Enchylaena tomentosa* and *Maireana pentatropis. Stipa scabra, Vittadinia cuneata, Scleroleana obliquicuspis* and *Calotis erinacea* dominate the ground layer.

3b *Maireana pyramidata/ Maireana sedifolia* low open-shrubland

Low open-shrubland dominated by *Maireana pyramidata* is the most extensive community on more elevated areas of the alluvial plains. In a few sites it is associated with *Maireana sedifolia or Maireana astrotricha.* Herbs in the ground layer include the exotic *Schismus barbatus* and the natives *Chamaesyse drummondii, Enneapogon avenaceus, Lotus cruentus, Rhodanthe corymbifolia, Vittadinia cuneata* and *Stipa scabra* (Fig. 8).

3c *Atriplex nummularia* low open-shrubland

An open-shrub community dominated by *Atriplex nummularia* occurs on grey cracking clays to the west of the Cawndilla channel. Commonly associated shrub species include *Chenopodium nitrariaceum,* and *Scleroleana divaricata.* The herb layer includes *Atriplex lindleyi, Crassula colorata, Sclerochlamys brachyptera* and the exotic *Schismus barbatus* (Fig. 9).

Fig. 7. Small areas of *Acacia carnei* *orum*, an endangered species in NSW, occur to the south of Lake Cawndilla.

Fig. 8. The most extensive community of the park is *Maireana pyramidata/Maireana sedifolia* low open-shrubland.

3d *Chenopodium nitrariaceum* low open-shrubland

Low open shrubland dominated by *Chenopodium nitrariaceum* occurs on the floodplain, in old billabongs of the Darling River and along the Cawndilla Channel. Associated low shrubs include *Scleroleana divaricata* and *Scleroleana muricata* var. *muricata*. There is a diverse ground layer within which the exotics *Carrichtera annua* and *Schismus barbatus* are prominent.

3f *Sclerolaena* species/*Atriplex* species low open-shrubland

A low chenopod community occurs on low-lying areas subject to inundation. Common dominants include *Atriplex angulata, Atriplex eardleyae, Sclerochlamys brachyptera, Scleroleana decurrens, Scleroleana diacantha, Scleroleana divaricata* and *Scleroleana stelligera*. Associated herbs include *Plantago drummondii, Nicotiana velutina, Osteocarpum acropterum, Brachyscome ciliaris* and the exotics *Carrichtera annua, Centaurea melitensis* and *Schismus barbatus* (Fig. 10).

4. Grasslands/Herblands

4a *Zygochloa paradoxa* hummock grassland

Small patches of *Zygochloa paradoxa* hummock grassland occur on the lunette of Lake Cawndilla. Associated shrubs include *Chenopodium nitrariaceum, Dodonaea viscosa* subsp. *angustissima, Enchylaena tomentosa* and *Maireana pyramidata*. The ground layer includes *Brachyscome ciliaris, Myriocephalus stuartii, Nicotiana velutina, Phyllanthus lacunellus, Pimelea trichostachya, Senecio quadridentatus, Vittadinia cuneata* and the exotic *Schismus barbatus* (Fig. 11).

4b Lakebed herbland

On some areas of the lakebeds, an annual herbland has developed. This is dominated by *Epaltes australis, Heliotropium curassavicum, Stemodia florulenta, Teucrium racemosum* and the exotics *Centaurea melitensis, Centaurium spicatum* and *Conyza bonariensis*. This community is the habitat for *Solanum karsense* which is listed as vulnerable in NSW (Schedule 2, *NSW Threatened Species Conservation Act 1995*) (Fig. 12).

The species

A total of 364 vascular plant species were recorded during this study. A further 139 species have been recorded from the Park (NPWS 1999b). Thirty-seven species from the total recorded (see Appendix 1) have not been previously recorded from South Far Western Plains Botanical subdivision (Jacobs & Pickard 1981, Jacobs & Lapinpuro 1986, Harden 1990–93, Morcom & Westbrooke 1990, Westbrooke & Miller 1996, Westbrooke et al. 1997, Westbrooke et al. 1998, Scott 1992). Of these, eleven are exotic.

Significant species

Two species recorded from the Park, *Acacia carneorum* and *Solanum karsense*, are listed vulnerable in NSW under the *NSW Threatened Species Conservation Act 1995* (TSC Act) and vulnerable in Australia under the *Environment Protection and Biodiversity*

Fig. 9. *Atriplex nummularia* open-shrubland occurs adjacent to the Darling River and Cawndilla Channel.

Fig. 10. In the south of the Park periodically flooded lakebeds support *Sclerolaena* spp./*Atriplex* spp. low open-shrubland.

Fig. 11. The small areas of *Zygochloa paradoxa* hummock grassland occur on the Lake Cawndilla lunette.

Fig. 12. Periodically inundated flats adjacent to the main lakes support a herbland community.

Conservation Act 1999 (EPBC Act). *Acacia carneorum* primarily occurs on sand ridges in inland *Acacia* and *Casuarina* shrublands and woodlands (Ayers et al. 1996), but also in alluvium along watercourses in chenopod low shrubland. Within the Park, this species is found in *Casuarina pauper/Alectryon oleifolius* woodland/open-woodland (1c) and in *Maireana pyramidata/Maireana sedifolia* low open-shrubland (3b) near Lake Cawndilla. *Solanum karsense* occurs in occasionally flooded depressions on heavy grey soils and dry lake beds as well as on open treeless plains with solonised brown soils, generally with *Eucalyptus largiflorens* and *Atriplex nummularia* (Ayers et al. 1996). Within the Park, *Solanum karsense* mainly occurs in lake beds and flood run-outs between Lake Cawndilla and the Darling River.

There are also unconfirmed Park records of two other threatened plant species — *Swainsonia pyrophila*, which is listed as vulnerable in NSW and Australia, and *Swainsona adenophylla*, which is endangered in NSW (NPWS 1999b).

Occurrence of exotic species

Of the 503 species recorded from the Park, 100 (20%) are exotics. Mean percentage occurrence of exotic species ranged from 27% in the *Eucalyptus camaldulensis* open-woodland (Fig. 13) to 7% in the mixed shrubland (Table 1). The highest levels of occurrence of exotic species were in communities subject to the greatest influence from water, i.e. the open woodlands and herblands associated with the lakebeds and major channels. This is in accord with Westbrooke (1990) who found a high negative correlation between occurrence of exotic species and distance from water in studies at Mallee Cliffs National Park and Nanya Station. A number of exotics are winter rainfall

Fig. 13. *Eucalyptus camaldulensis* open-woodland communities around lake Menindee have a high level of exotic weeds.

stimulated and thus may not have been recorded during these surveys. Three species were recorded as artificial plantings. Although not naturalised, these are of historic and cultural significance.

Discussion

Distribution of communities

The distribution and species composition of vegetation communities within Kinchega National Park is largely determined by variation in topography, landform position and soil type. *Eucalyptus* species open-woodlands are associated with grey cracking clays of the Darling River floodplains and the overflow lakes. *Maireana* species low open-shrubland occurs on the sand plains whilst *Casuarina/Alectryon* low woodland is associated with east-west dunefields in the south west of the Park. A number of other factors, notably past grazing history, have also played a role in determining the present distribution and floristic composition of the communities present.

The *Dodonaea viscosa* subsp. *angustissima* shrublands (4a) are likely to result from vegetation clearance and subsequent replacement by unpalatable species such as *Dodonaea*. Noble (1984) and Harrington et al. (1984) report an increase of *Dodonaea* species in response to grazing and the genus is also reported as an early coloniser following clearing (Beadle 1948, Onans & Parsons 1980).

The impact of water conservation measures

The most obvious effect of the modification of the water regime through the Menindee Lakes Storage Scheme is the large areas of dead *Eucalyptus largiflorens* in the bed of Lake Menindee and areas of Lake Cawndilla. Since the Scheme was established, overflow of water from the Cawndilla Channel which was then unable to drain away naturally has caused the death of a further 250 ha of *Eucalyptus largiflorens* woodland. On the western shore of Lake Menindee a large area of regeneration of *Eucalyptus largiflorens* and *Eucalyptus camaldulensis* results from a rise in the water level of the lake. The *Eucalyptus largiflorens* woodland around Emu Lake may be at risk due to the lack of regular flushing by floodwater due to a narrow pipe carrying water under the causeway near the ranger station (Mike Erny, Department of Land and Water Conservation, Dareton, pers. comm.) (Figs 14, 15).

Conservation status of plant communities

The New South Wales Scientific Committee has recently listed *Acacia loderi* Shrublands as an Endangered Ecological Community in NSW on Part 3 of Schedule 1 of the *NSW Threatened Species Conservation Act*. The Committee noted that *Acacia loderi* shrublands in NSW are largely confined to the south-west and are generally fragmented. Most remnant stands are located on pastoral leases and subject to threats including clearing and a lack of regeneration of overstorey through grazing pressure, particularly from stock and rabbits. Even within Kinchega National Park, it is recognised that rabbit grazing pressure has severely limited regeneration of *Acacia loderi* and flooding from

Fig. 14. Flooding of the lake system resulted in death of large areas of *Eucalyptus largiflorens* open-woodland.

Fig. 15. Large areas of *Eucalyptus largiflorens* open-woodland have been killed as a result of prolonged flooding from the Cawndilla Channel.

over-filling of the Menindee Lakes has resulted in destruction of several stands of the community (NSW Scientific Committee 2000).

Acacia carneorum open shrubland is severely degraded. Surviving plants of the dominant species are senescent, there is no regeneration and the conservation status of this community should be viewed with considerable concern. Auld (1992) has raised concerns regarding this community and Kinchega National Park is the only conservation reserve in which it is represented. It is important that steps are taken to protect and ensure rehabilitation of this community.

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Appendix: Vascular plant species recorded from Kinchega National Park. Nomenclature according to Harden (1990–1993).

* denotes exotic species ✦ denotes species recorded by NPWS (1999) but not recorded in this study. + denotes new records for South Far Western Plains.

V = vulnerable in Australia (EPBC Act). e = endangered in NSW (TSC Act). v = vulnerable in NSW (TSC Act).

AIZOACEAE
Disphyma crassifolium
Glinus lotoides
**Mesembryanthemum crystallinum*
**Mesembryanthemum nodiflorum*
✦*Mollugo cerviana*
**Psilocaulon tenue*
Tetragonia moorei
Trianthema triquetra
Zaleya galericulata

AMARANTHACEAE
+✦*Alternanthera angustifolia*
Alternanthera denticulata
Alternanthera nodiflora
✦*Amaranthus grandiflorus*
+✦*Amaranthus macrocarpus* var. *pallidus*
✦*Ptilotus atriplicifolius*
✦*Ptilotus nobilis*
Ptilotus obovatus var. *obovatus*

AMARYLLIDACEAE
✦*Calostemma purpureum*
Crinum flaccidum

ANACARDIACEAE
**Schinus areira*
ANTHERICACEAE
✦*Thysanotus baueri*

APIACEAE
Daucus glochidiatus

ASCLEPIADACEAE
Marsdenia australis
Sarcostemma australe

ASPHODELACEAE
**Asphodelus fistulosus*
Bulbine alata
Bulbine bulbosa
Bulbine semibarbata

ASTERACEAE
Actinobole uliginosum
✦**Ambrosia confertiflora*
✦*Angianthus brachypappus*
✦*Angianthus tomentosus*
**Aster subulatus*
Brachycome basaltica var. *gracilis*
✦*Brachycome* species B
Brachycome ciliaris var. *lanuginosa*
+✦*Brachycome ciliocarpa*
Brachycome heterodonta
Brachycome lineariloba
Brachycome melanocarpa
✦**Calendula arvensis*
Calotis ancyrocarpa
Calotis cymbacantha
Calotis erinacea
Calotis hispidula
✦*Calotis plumulifera*
Calotis scabiosifolia var. *scabiosifolia*
✦*Calotis scapigera*
**Carduus tenuiflorus*
**Carthamus lanatus*
**Centaurea melitensis*
Centipeda cunninghamii
Centipeda thespidioides
**Chrysanthemoides monilifera*
✦*Chrysocephalum apicatulum*
Chthonocephalus pseudevax
**Cirsium vulgare*
**Conyza bonariensis*
+**Cotula bipinnata*
✦ *Craspedia haplorrhiza*
**Dittrichia graveolens*
Eclipta platyglossa
Elachanthus pusillus
Epaltes australis
Eriochlamys behrii
Gnaphalium sphaericum
Gnephosis arachnoidea
Gnephosis tenuissima
Hedypnois rhagadioloides subsp. *cretica*
**Helianthus annuus*

✦*Hyalosperma semisterile*
**Hypochoeris glabra*
**Hypochoeris radicata*
Isoetopsis graminifolia
Ixiolaena leptolepis
✦*Ixiolaena tomentosa*
**Lactuca serriola*
✦*Lemoonia burkittii*
Millotia greevesii
Millotia myosotidifolia
Millotia perpusilla
Minuria cunninghamii
Minuria denticulata
Minuria leptophylla
✦*Myriocephalus pluriforus*
Myriocephalus stuartii
Olearia muelleri
Olearia pimeleoides
**Onopordum acaulon*
✦**Picris hieracioides*
Picris squarrosa
Podolepis capillaris
✦**Podolepis jaceoides*
Pseudognaphalium luteoalbum
Pterocaulon sphacelatum
Pycnosorus pleiocephalus
✦*Pycnosorus thompsonianus*
**Reichardia tingitana*
Rhodanthe corymbiflora
Rhodanthe floribunda
✦*Rhodanthe microglossa*
Rhodanthe moschata
✦ *Rhodanthe polygalifolia*
Rhodanthe pygmaea
✦ *Rhodanthe stricta*
Rhodanthe stuartiana
✦*Rhodanthe uniflora*
Senecio cunninghamii var cunninghamii
Senecio cunninghamii var. serratus
Senecio glossanthus
✦*Senecio gregorii*
+*Senecio hispidulus*
Senecio lautus ssp. dissectifolius
✦*Senecio magnificus*
✦*Senecio murrayanus* [*Senecio tuberculatus*]
✦*Senecio platylepis*
Senecio quadridentatus
Senecio runcinifolius
**Sonchus asper* s.l
**Sonchus oleraceus*
+**Urospermum picroides*
Vittadinia cuneata var. morrisii
✦*Vittadinia cervicularis var. cervicularis*
✦*Vittadinia cervicularis var. subcervicularis*
✦*Vittadinia eremaea*
**Xanthium occidentale*
**Xanthium spinosum*

AZOLLACEAE
Azolla filiculoides

BORAGINACEAE
+**Amsinckia intermedia*
**Amsinckia calycina*
+✦ **Anchusa arvensis*
**Echium plantagineum*
Heliotropium curassavicum
**Heliotropium europaeum*
**Heliotropium supinum*
Omphalolappula concava
Plagiobothrys plurisepalus

BRASSICACEAE
**Alyssum linifolium*
✦*Arabidella procumbens*
Arabidella trisecta
✦*Blennodia canescens*
**Brassica tournefortii*
**Carrichtera annua*
Geococcus pusillus
✦*Harmsiodoxa blennodioides*
✦*Harmsiodoxa brevipes*
Lepidium fasciculatum
Lepidium papillosum
✦*Lepidium phlebopetalum*
Lepidium pseudohyssopifolium
+✦*Lepidium sagittulatum*
✦*Phlegmatospermum cochlearinum*
**Raphanus raphanistrum*
✦**Rapistrum rugosum*
**Rorippa palustris*
**Sisymbrium erysimoides*
**Sisymbrium irio*
**Sisymbrium orientale*
Stenopetalum lineare

CACTACEAE
**Opuntia stricta*

CAMPANULACEAE
Wahlenbergia communis s.l.
Wahlenbergia fluminalis

Wahlenbergia gracilenta s.l.
+*Wahlenbergia graniticola*
Wahlenbergia sp.

CARYOPHYLLACEAE
**Silene gallica*
**Spergularia diandra*
**Spergularia rubra*

CASUARINACEAE
Casuarina pauper

CHENOPODIACEAE
Atriplex angulata
Atriplex conduplicata
Atriplex eardleyae
Atriplex holocarpa
Atriplex leptocarpa
Atriplex limbata
Atriplex lindleyi
Atriplex nummularia
Atriplex pseudocampanulata
Atriplex pumilio
Atriplex spongiosa
Atriplex stipitata
Atriplex suberecta
Atriplex velutinella
Chenopodium cristatum
Chenopodium curvispicatum
Chenopodium desertorum
Chenopodium melanocarpum
**Chenopodium murale*
Chenopodium nitrariaceum
Chenopodium pumilio
+✦*Chenopodium truncatum*
Dissocarpus biflorus
Dissocarpus paradoxus
Einadia nutans ssp. nutans
Enchylaena tomentosa
Halosarcia pergranulata
Maireana aphylla
Maireana appressa
✦*Maireana astrotricha*
Maireana brevifolia
Maireana coronata
Maireana decalvans
Maireana georgei
Maireana integra
Maireana pentatropis
Maireana pyramidata
Maireana sedifolia
Maireana sclerolaenoides
Maireana tomentosa
Maireana turbinata
Malacocera tricornis
Neobassia proceriflora
Osteocarpum acropterum var. *acropterum*
Osteocarpum acropterum var. *deminuta*
Pachycornia triandra
Rhagodia spinescens
Salsola kali
Scleroblitum atriplicinum
Sclerochlamys brachyptera
Sclerolaena bicornis var. *bicornis*
Sclerolaena calcarata
Sclerolaena decurrens
Sclerolaena diacantha
Sclerolaena divaricata
Sclerolaena intricata
Sclerolaena lanicuspis
Sclerolaena muricata var. *muricata*
Sclerolaena muricata var. *villosa*
Sclerolaena obliquicuspis
Sclerolaena patenticuspis
Sclerolaena stelligera
Sclerolaena tricuspis
✦*Sclerolaena uniflora*
Sclerolaena ventricosa
Sclerostegia tenuis

CONVOLVULACEAE
Convolvulus erubescens
Cressa cretica
✦**Cuscuta campestris*

CRASSULACEAE
Crassula colorata
✦*Crassula sieberana*

CUCURBITACEAE
**Citrullus lanatus*
**Cucumis myriocarpus*
Zehneria micrantha

CUPRESSACEAE
Callitris glaucophylla

CUSCUTACEAE
**Cuscuta campestris*

CYPERACEAE
✦*Bolboschoenus caldwellii*
Cyperus gymnocaulos

Cyperus pygmaeus
✦*Cyperus squarrosus*
✦*Eleocharis acuta*
✦*Eleocharis pallens*
✦*Fimbristylis dichotoma*

ELATINACEAE
+✦*Bergia ammanioides*
✦*Bergia trimera*

EUPHORBIACEAE
Chamaesyce drummondii
Euphorbia eremophila
+✦*Euphorbia parvicaruncula*
+**Euphorbia peplus*
✦*Euphorbia planiticola*
Euphorbia stevenii
Phyllanthus lacunarius
Phyllanthus lacunellus
**Ricinus communis*
✦ *Sauropus trachyspermus*

FABACEAE
(CAESALPINIOIDEAE)
✦*Lysiphyllum gilvum*
Senna artemisioides nothosubsp. *artemisioides*
Senna artemisioides nothosubsp. *coriacea*
Senna artemisioides nothosubsp. *sturtii*
Senna artemisioides subsp. *filifolia*
Senna artemisioides subsp. *petiolaris*

(FABOIDEAE)
✦*Crotalaria eremaea* subsp. *eremaea*
✦*Glycine canescens*
✦*Glycyrrhiza acanthocarpa*
Lotus cruentus
**Medicago minima*
**Medicago polymorpha*
**Melilotus indicus*
Psoralea australasica
✦*Psoralea cinerea*
Psoralea pallida
Psoralea patens
✦*Sesbania cannabina*
e✦*Swainsona adenophylla*
Swainsona formosa
Swainsona greyana
✦*Swainsona laxa*
Swainsona microphylla
✦ *Swainsona phacoides*
✦*Swainsona procumbens*
Swainsona purpurea
Vv✦*Swainsona pyrophila*
Templetonia egena
+✦*Tephrosia sphaerospora*
✦*Trigonella suavissima*
**Vicia monantha* subsp. *monantha*

(MIMOSACEAE)
Acacia aneura
Acacia brachystachya
Acacia burkittii
Vv *Acacia carneorum* (formerly *carnei)*
Acacia colletioides
Acacia ligulata
Acacia loderi
Acacia oswaldii
✦*Acacia salicina*
Acacia stenophylla
✦*Acacia tetragonophylla*
Acacia victoriae subsp. *victoriae*

FRANKENIACEAE
Frankenia connata

GENTIANACEAE
**Centaurium spicatum*

GERANIACEAE
**Erodium cicutarium*
Erodium crinitum
✦*Erodium cygnorum* subsp. *glandulosum*

GOODENIACEAE
✦*Goodenia cycloptera*
✦*Goodenia fascicularis*
Goodenia glauca
Goodenia heteromera
Goodenia pinnatifida
Goodenia pusilliflora

GYROSTEMONACEAE
✦*Codonocarpus cotinifolius*

HALORAGACEAE
✦*Haloragis aspera*
Haloragis glauca
+✦*Haloragis heterophylla*
Myriophyllum verrucosum

JUNCACEAE
✦*Juncus aridicola*

JUNCAGINACEAE
Triglochin calcitrapum
Triglochin centrocarpum

LAMIACEAE
**Marrubium vulgare*
Mentha australis
+✦*Mentha diemenica*
**Salvia verbenaca*
Teucrium racemosum

LILIACEAE
✦*Dianella longifolia* var. *porracea*

LORANTHACEAE
Amyema linophyllum
Amyema miquelii
Amyema miraculosum
Amyema quandang var. *bancroftii*
Lysiana exocarpi subsp. *exocarpi*

MALVACEAE
+✦*Abutilon malvifolium*
✦*Abutilon otocarpum*
+✦*Abutilon oxycarpum*
✦**Abutilon theophrasti*
✦*Hibiscus brachysiphonius*
✦*Hibiscus krichauffianus*
✦*Lavatera plebeia*
**Malva parviflora*
+✦**Malva verticillata*
✦*Malvastrum americanum*
✦*Sida ammophila*
Sida corrugata
+*Sida cunninghamii*
✦*Sida fibulifera*
Sida intricata
✦*Sida petrophila*
Sida trichopoda

MARSILEACEAE
Marsilea drummondii

MYOPORACEAE
Eremophila bignoniiflora
Eremophila deserti
Eremophila divaricata
Eremophila glabra
Eremophila longifolia
Eremophila maculata
Eremophila polyclada
Eremophila sturtii
Myoporum montanum
Myoporum platycarpum subsp. *platycarpum*

MYRTACEAE
Eucalyptus camaldulensis
Eucalyptus coolabah
Eucalyptus largiflorens
✦*Eucalyptus socialis*

NYCTAGINACEAE
Boerhavia dominii

OLEACEAE
Jasminum lineare

ONAGRACEAE
+*Epilobium hirtigerum*
+*Ludwigia peploides* subsp. *montevidensis*
**Oenothera stricta*

OPHIOGLOSSACEAE
✦*Ophioglossum polyphyllum*

OXALIDACEAE
Oxalis perennans

PAPAVERACEAE
**Argemone ochroleuca* subsp. *ochroleuca*

PITTOSPORACEAE
Pittosporum phylliraeoides

PLANTAGINACEAE
Plantago cunninghamii
Plantago drummondii
Plantago turrifera
Plantago varia

POACEAE
Agrostis avenacea var. *avenacea*
✦**Alopecurus geniculatus*
✦*Aristida holathera* var. *holathera*
✦ *Aristida contorta*
**Arundo donax*
Austrodanthonia caespitosa
Austrodanthonia eriantha
Austrodanthonia setacea
✦*Austrostipa nitida*
✦*Austrostipa nodosa*
Austrostipa scabra subsp. *scabra*
Bromus arenarius
✦**Bromus cartharticus*
**Bromus diandrus*

**Bromus rubens*
Cenchrus longispinus
+**Chloris gayana*
Chloris truncata
+✦*Cymbopogon ambiguus*
Cynodon dactylon
✦*Dactyloctenium radulans*
✦*Dichanthium sericeum*
✦*Digitaria divaricatissima*
✦*Diplachne fusca*
+✦**Echinochloa crus-galli*
✦*Echinochloa lacunaria*
Enneapogon avenaceus
✦*Enneapogon cylindricus*
Eragrostis australasica
✦*Eragrostis cilianensis*
Eragrostis dielsii
Eragrostis falcata
✦*Eragrostis parviflora*
✦*Eragrostis setifolia*
✦*Eriochloa australiensis*
+✦*Eriochloa crebra*
✦*Eriochloa pseudoacrotricha*
**Hordeum leporinum*
✦*Homopholis proluta* [*Panicum prolutum*]
**Lamarckia aurea*
✦*Panicum decompositum*
✦*Paractaenum novae-hollandiae*
**Parapholis incurva*
Paspalidium jubiflorum
**Phalaris paradoxa*
**Phyllostachys nigra*
✦**Poa annua*
✦*Poa fordeana*
+✦**Poa pratensis*
✦**Polypogon monspeliensis*
Pseudoraphis spinescens
✦**Rostraria cristata*
**Rostraria pumila*
**Schismus barbatus*
Sporobolus mitchellii
✦*Tragus australianus*
✦*Triodia scariosa* subsp. *scariosa*
✦*Tripogon loliiformis*
Triraphis mollis
**Vulpia myuros*
Zygochloa paradoxa

POLYGONACEAE
**Acetosa vesicaria*
**Emex australis*
Muehlenbeckia florulenta
Muehlenbeckia horrida
Persicaria lapathifolia
+ ✦*Persicaria prostrata*
Polygonum aviculare
Polygonum plebeium
Rumex brownii
**Rumex crispus*
Rumex crystallinus
Rumex tenax

PORTULACACEAE
Calandrinia eremaea
✦*Calandrinia volubilis*
Portulaca oleracea

PRIMULACEAE
**Anagallis arvensis*

PROTEACEAE
Hakea leucoptera
Hakea tephrosperma

RANUNCULACEAE
Myosurus minimus var. *australis*
Ranunculus pentandrus var. *platycarpus*
✦*Ranunculus pumilo* var. *pumilo*

ROSACEAE
+✦*Potentilla supina*

RUBIACEAE
✦*Synaptantha tillaeacea*

SALICACEAE
+**Salix babylonica*

SANTALACEAE
Exocarpos aphyllus
Santalum acuminatum

SAPINDACEAE
Alectryon oleifolius subsp. *canescens*
Dodonaea viscosa subsp. *angustissima*

SCROPHULARIACEAE
✦*Limosella australis*
✦*Limosella curdieana*
+✦*Mimulus prostratus*
+**Misopates orontium*
Stemodia florulenta
✦**Veronica peregrina*

SOLANACEAE
♦**Datura inoxia*
**Lycium ferocissimum*
**Nicotiana glauca*
Nicotiana velutina
Solanum coactiliferum
Solanum esuriale
Vv *Solanum karsense*
♦*Solanum lacunarium*
**Solanum nigrum*

STERCULIACEAE
‡♦*Gilesia biniflora*

TAMARICACEAE
**Tamarix aphylla*

THYMELAEACEAE
Pimelea microcephala
Pimelea simplex
Pimelea trichostachya

TYPHACEAE
Typha domingensis

URTICACEAE
**Urtica urens*

VERBENACEAE
**Verbena africana*
**Verbena officinalis*
**Verbena supina*

ZYGOPHYLLACEAE
**Tribulus terrestris*
Zygophyllum ammophilum
Zygophyllum aurantiacum
Zygophyllum eremaeum
Zygophyllum iodocarpum
Zygophyllum simile

Flora conservation issues at Kinchega National Park, western NSW

Tony D. Auld and Andrew J. Denham

Auld, Tony D., and Denham, Andrew J. (Biodiversity Research and Management Division, NSW National Parks & Wildlife Service, PO Box 1967 Hurstville NSW 2220 email: tony.auld@npws.nsw.gov.au*) 2001. Flora conservation issues at Kinchega National Park, western NSW.* Cunninghamia *7(1): 27–41.*

Kinchega National Park reserves significant stands of *Eucalyptus largiflorens* open woodland on the Darling River floodplain, low open *Maireana pyramidata* shrubland and *Casuarina pauper/Alectryon oleifolius* open woodland on dune systems. We identify four key issues for the conservation of flora in Kinchega National Park, western NSW. These are:

1) There is an urgent need to initiate regeneration in a number of long-lived perennial trees and shrubs. Failure to do so will lead to local population declines and extinction in a number of species. Reduction in grazing impacts of rabbits and goats is needed. Some degree of rabbit control has been achieved over the last few years through a combination of the effects of the rabbit calicivirus disease (RCD) and an extensive rabbit control program for the reserve.

2) The need to initiate a water plan of management for the reserve to overcome the problem of changes in water flows, flood periodicity and flood magnitude that have occurred in response to water regulation activities on the Darling River.

3) Management of several threatened species and ecological communities on the reserve, in particular the nationally vulnerable species *Acacia carneorum* and *Solanum karsense*. Kinchega NP is the only conservation reserve containing populations of these species and these populations are significant for both species.

4) Management of weeds, in particular those with bird-dispersed fruits as these species have the potential to become severe problems on the park.

Other issues that are likely to be significant in the future are salinity impacts and the interaction between grazing pressure, regeneration and climate change.

Introduction

Management of formal conservation reserves needs to address a range of issues from biodiversity conservation, cultural heritage and recreation. In arid and semi-arid Australia, including far western NSW, the reserve system sits within a landscape that has only been partially cleared of native vegetation. However, much of the landscape has been modified by less dramatic changes, particularly by grazing pressure from stock and introduced feral pests (James et al. 1999). Management of a reserve in this context must consider a range of landscape factors impacting on both the reserve and the surrounding areas.

In arid landscapes throughout the world, grazing management is an important issue for the conservation of flora and fauna habitat (Benson 1991, Fuls 1992, Milton 1994, James et al. 1999). These areas receive little rainfall and plant recruitment is generally triggered by rainfall events (Robertson 1988, Milton 1995). Such recruitment may be tenuous if grazing alters this rainfall driven recruitment process. Changes in such landscapes may be rapid for fauna, for example the decline and extinction of medium size mammals in arid Australia (Morton 1990, Dickman et al. 1993), and for short-lived plants (ephemerals), for example the temporal changes in presence and abundance — (Robertson 1988). However, changes in populations of long-lived taxa such as perennial plants may occur very slowly, and it may be difficult to recognise the existence of a decline without some understanding of the dynamics of species and the processes that control recruitment and growth (Harper 1977, Watson et al. 1997).

With the recent release of the Kinchega National Park Plan of Management (NPWS 1999) and the recent vegetation map of the park (Westbrooke et al. 2001) it is timely to consider the key conservation issues facing the park in the context of its regional landscape. Plant nomenclature follows Harden (1990–1993).

Kinchega National Park

Kinchega National Park, 32°28'S 142°20'E, lies adjacent to the Darling River in western NSW, 113 km south-east of Broken Hill (Fig. 1). The climate at Kinchega NP, is one of low erratic rainfall with no predictable seasonality (average 236 mm per annum) combined with high summer temperatures in excess of 40°C (Robertson et al. 1987). The Park, covering 44 182 ha, was gazetted in 1967 and was the first national park declared in western NSW. The main biological reasons for the reservation of Kinchega NP were to protect samples of the major semi-arid and arid landscapes in western NSW, in particular the Darling River floodplain and large stands of low open shrublands of *Maireana pyramidata* (Black Bluebush). The two major lakes that are largely surrounded by the park (Lakes Menindee and Cawndilla) are not part of the national park.

The vegetation of Kinchega NP has been described in Westbrooke et al. (2001). The most widespread communities are *Eucalyptus largiflorens* open woodland on the floodplain near the Darling River and Tandou Creek; open woodlands of *Casuarina pauper* and *Alectryon oleifolius* on the dune system in the southwest of the park; and low open shrublands of *Maireana pyramidata* on ancient weathered dunes bordering the floodplain. Open shrublands of *Acacia* spp., *Eremophila sturtii, Dodonaea viscosa* subsp. *angustissima* and *Senna artemisioides* also occur in the reserve (Westbrooke et al. 2001).

Kinchega National Park has a rich and diverse ephemeral flora (annuals and short-lived perennials) (Robertson 1987, 1988, Kinchega NP plant list 2000, Westbrooke et al. 2001). This component of the flora is dynamic with the distribution and abundance of species across the landscape varying in response to seasonal rainfall and flooding (Robertson 1987, 1988). The Asteraceae (some 70 native and 20 introduced species), Chenopodiaceae (some 61 species) and Poaceae (some 39 native and 16 introduced species) are the dominant plant families on the reserve. The genera in these families

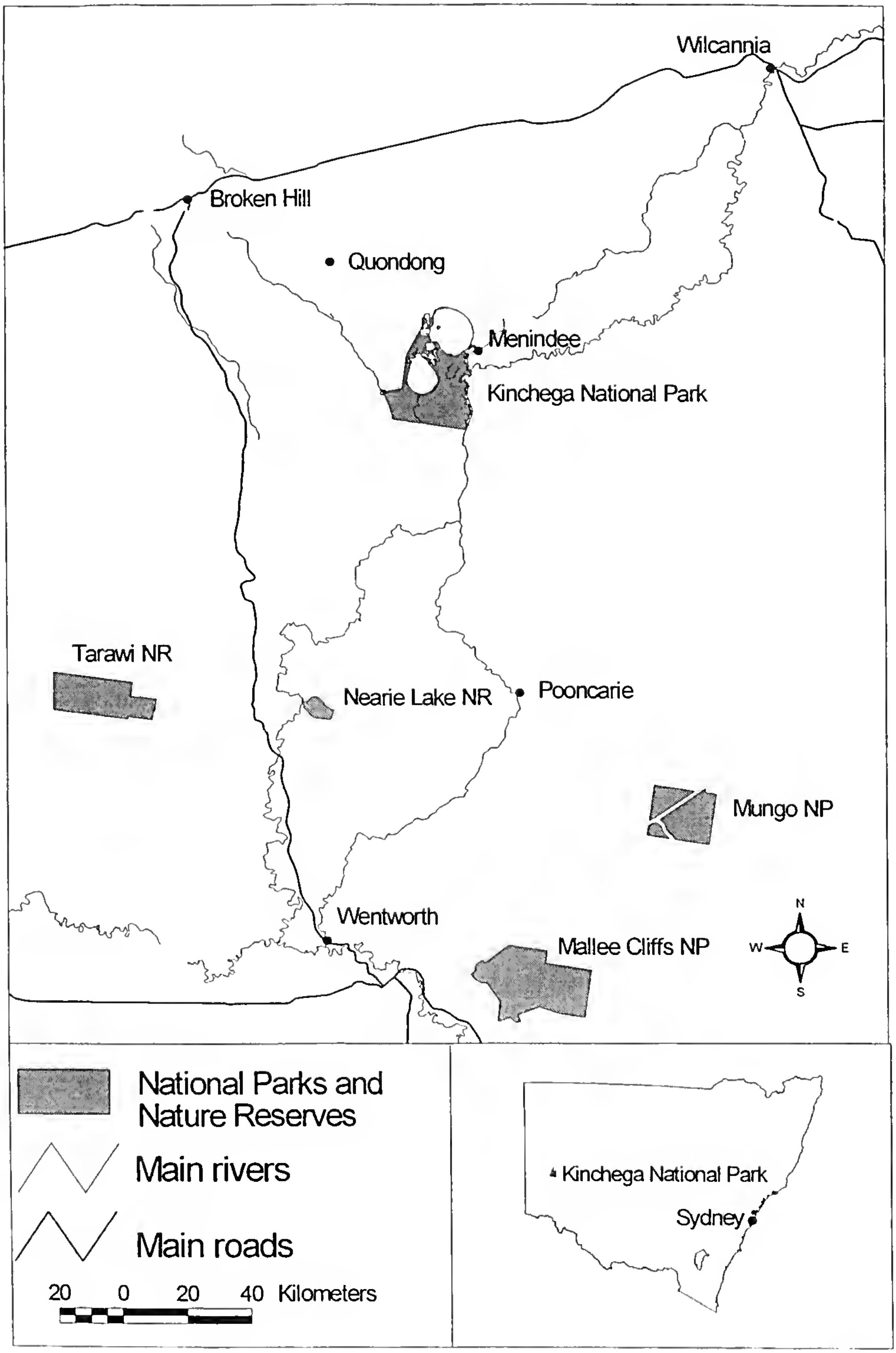

Fig. 1. Location of Kinchega National Park in western NSW.

with the largest number of species on Kinchega NP include *Atriplex* (13 spp.), *Brachycome* (8 spp.), *Calotis* (7 spp.), *Eragrostis* (6 spp.), *Maireana* (15 spp.), *Rhodanthe* (9 spp.), *Sclerolaena* (14 spp.) and *Senecio* (11 spp.). Whilst a few are long-lived perennials, most of these species are a component of the ephemeral flora and the variation in timing of rainfall can transform the landscape from a daisy dominated one to a chenopod dominated one or vice versa. Other genera with a number of species occurring on Kinchega NP include *Acacia* (12 spp.), *Eremophila* (8 spp.) and *Sida* (9 spp.).

Domestic stock grazed the area since the 1860s and the park has been fenced to exclude stock since its inception in 1967. Rabbits, *Oryctolagus cuniculatus*, first reached the area in about 1881 (Caughley 1987) and are now widespread. The major native mammalian grazers on the park are Red, *Macropus rufus*, and Western Grey, *Macropus fuliginosus*, Kangaroos. Euros, *Macropus robustus*, and Eastern Grey Kangaroos, *Macropus giganteus*, occur in small numbers. Goats are uncommon but variable in abundance while pigs are widespread.

Key Issues for Vegetation Conservation

Conservation of long-lived perennial tree species

In arid western NSW, the very high extinction rates for small to medium sized mammals since European settlement are well documented (Morton 1990, Dickman et al. 1993). In contrast, there have only been two extinctions of plant species (Leigh et al. 1984), one small shrub (*Acanthocladium dockeri* — recently rediscovered in South Australia) and a subshrub (*Senecio behrianus*). Grazing by stock and rabbits is thought to have been responsible for the loss of these two species (Leigh et al. 1984).

Many of the plant species and communities currently at risk of extinction or serious decline are large shrubs and small trees that are perennial and long-lived. There is now a large body of evidence from a range of species and locations that suggests that regeneration from seed in many dominant arid plant perennial trees/large shrubs has been eliminated over the last century across a broad area in far western NSW and arid South Australia (Crisp & Lange 1976, Crisp 1978, Chesterfield & Parsons 1985, Lange & Graham, 1983, Auld 1990, 1993, 1995a, 1995b, Woodell 1990, Tiver & Andrew 1997). The cause of this lack of regeneration is grazing by rabbits, goats and domestic stock. Consequently, given the longevity of the parent plants, we predict that we are on the verge of a major episode of decline and local extinction of many plant species and associated communities (including dependent fauna) in these areas. We argue that it is simply the longevity of the plants that were growing at the time of European settlement and the subsequent introduction of pest species, that has masked declines towards extinction in the area.

At Kinchega NP, in the dune country in the southwest of the park, the pattern is one that is typical for the landscape as a whole. There is evidence of a systematic failure of recruitment in the 20th Century in several species (see Table 1) and evidence of the retreat and decline of others that occur in the area. Key examples are *Acacia carneorum* (Purple-wood Wattle, a nationally vulnerable species, Auld 1993), *Acacia loderi* shrublands (an endangered ecological community in NSW, Auld 1995b), *Acacia aneura*

(Mulga), *Callitris gracilis* subsp. *murrayensis* (Murray Pine), *Casuarina pauper* (Belah) and *Alectryon oleifolius* (Western Rosewood). As Westbrooke et al. (2001) have shown, belah/rosewood is a major dominant community in southwestern Kinchega NP. *Acacia aneura* and *Callitris gracilis* subsp. *murrayensis* are highly restricted and scattered on Kinchega NP, but the patterns on the Park are typical of the widespread dying and declining stands of *Aacacia aneura* to the northwest of Kinchega NP and declining stands of *Callitris* to the south and east of Kinchega NP. Both species are retreating to wetter areas where the balance between recruitment success and grazing pressure is more in favour of the plants. Some species such as *Myoporum platycarpum* (Table 1) and *Acacia oswaldii* (Auld 1995a) have some regeneration occurring, but it may be insufficient to maintain populations in the long-term. For *Myoporum platycarpum*, regeneration appears spatially variable at Kinchega NP, with little regeneration on dune systems in the southwest of the Park.

Table 1. Species and Plant communities showing evidence of lack of regeneration on Kinchega National Park.

Species/community	Abundance on park and comments on decline
Acacia aneura	Rare, mostly scattered individuals with canopy dieback. No significant recruitment.
Acacia brachystachya	A few plants only with canopy dieback.
Acacia carneorum	Significant populations, all except one with no evidence of recruitment in past. Some vegetative recruitment recently initiated following rabbit control program.
Acacia ligulata	Several large populations. Several in serious decline, a few with evidence of good recruitment.
Acacia loderi	Several large occurrences. Seedling recruitment absent. General absence of regeneration except at one site where limited vegetative regeneration occurred following rabbit control.
Acacia oswaldii	Widespread as scattered individuals. Recruitment by seed only. Seedlings and some juveniles present but limited by rabbits. Highest recruitment under nurse plants such as *Maireana pyramidata.*
Alectryon oleifolius	Extensive stands. Young saplings from seed extremely rare. Some vegetative recruitment recently initiated following rabbit control program.
Callitris gracilis subsp. *murrayensis*	Rare, mostly scattered individuals with canopy dieback. No recruitment except at two individuals where caging has excluded grazers.
Casuarina pauper	Extensive stands. Seedling recruitment absent. Some recruitment of vegetative suckers to maintain stands. Some areas of extensive dieback.
Exocarpos aphyllus	Uncommon, associated with *Casuarina pauper* or *Eucalyptus largiflorens*. Small individuals absent suggesting a lack of regeneration.
Hakea leucoptera	Scattered stands or individuals. A few stands of mixed size classes, most occurrences with no regeneration and dieback of canopies. No seedling recruitment. Some vegetative recruitment recently initiated following rabbit control program.
Myoporum platycarpum	Common, scattered individuals and some denser stands. Recruitment by seed only. No regeneration in dunes in southwest, but mixed size stands in northwest.
Pittosporum phylliraeoides	Widespread, especially in west. Vegetative suckering widespread. Recruitment levels from seed unknown.
Santalum acuminatum	Rare. Vegetative regeneration prevented by grazing, some regeneration in rabbit proof exclosures.
Templetonia egena	Scattered individuals associated with *Casuarina pauper.* No regeneration.

On Kinchega NP there have been several attempts to control rabbits using biological control (myxomatosis) and local ripping of warrens. Following the accidental introduction of rabbit calicivirus disease into the area in 1996, at Kinchega NP there was an extensive program to rip rabbit warrens and poison rabbits where warrens could not be ripped due to the presence of long-lived perennials. This program was put in place to maximise the extent and scale of reduction in rabbit numbers and to reduce the future rate of population growth in rabbits. If regeneration is to be initiated in many of the perennial plants on the park, both rabbit and goat numbers must be kept low in the long-term. Whilst kangaroos will browse some seedlings and juvenile plants, as well as crushing seedlings sheltering under other shrubs through their habit of utilising hipholes in shady areas, there is no evidence that they eliminate recruitment at Kinchega NP (Auld 1993, 1995a, 1995b). Monitoring of regeneration on park in selective exclusion plots since 1996 has revealed some possible regeneration (Denham & Auld unpubl.), however, the first few years after the dramatic reduction in rabbit numbers from calicivirus and rabbit control, were dry and not conducive to regeneration. The key test for whether or not rabbit numbers are low enough to allow long-term regeneration will be in the next drought, when rabbits have little available food and can ringbark and kill young perennial plants.

Key conservation recommendations are:

a) continue control and monitoring of rabbit numbers;

b) reduce goat impacts through continual goat control;

c) continue monitoring of regeneration in key perennial plant species.

Wetland management and flooding regimes

A large component of the park is essentially an ephemeral wetland (Fig. 2) including:

a) the floodplain of the Darling River and associated Tandou Creek dominated by *Eucalyptus camaldulensis* along the Darling River and large areas of *Eucalyptus largiflorens* (Black Box) woodland, overlying grey cracking clays on the floodplains and along Tandou Creek;

b) the lakes including water storage Lakes Menindee, Cawndilla and Speculation (now more or less permanently filled), and remaining ephemeral lakes (e.g. Emu Lake, with extensive stands of lignum (*Muehlenbeckia florulenta*);

c) the numerous small depressions with *Eucalyptus largiflorens* (Black Box) or *Chenopodium nitrariaceum*. These fill from flooding of the Darling River or Tandou Creek, or in some cases only from heavy local rain.

There have been extensive changes to the historic flooding regime at Kinchega NP. Primarily these have resulted from the development of the Menindee Lakes scheme in 1960s, but they are also the result of water extraction all along the Darling River above the park. Flooding into the park from downstream along Tandou Creek, due to the presence of weirs below the reserve, is also affecting water flows.

The flora and fauna of the Darling River floodplain and associated wetlands and overflow lakes within Kinchega NP are dependent upon periodic flooding and

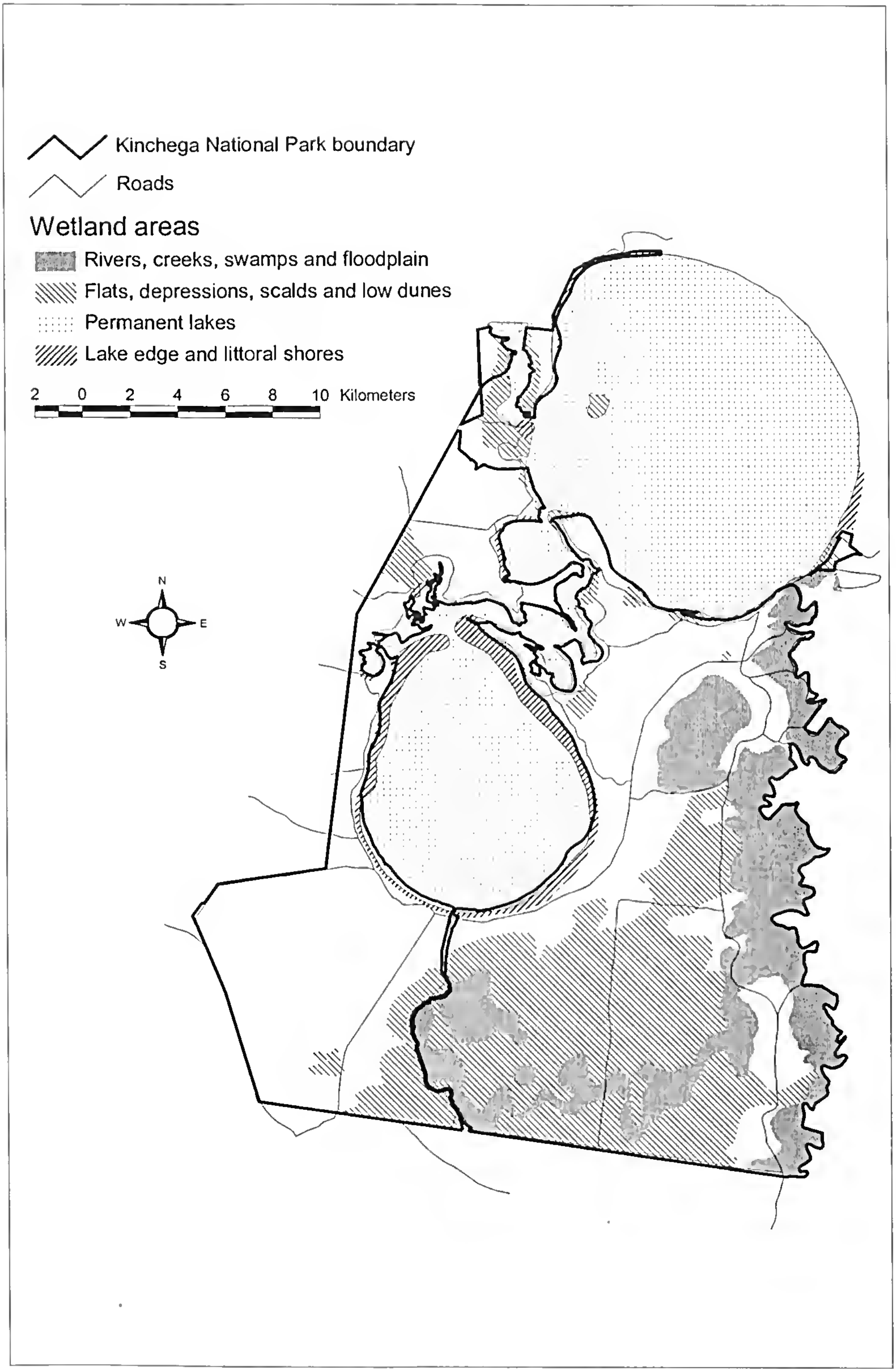

Fig. 2. Distribution of wetland habitat at Kinchega National Park. Some small ephemeral depressions that only fill from heavy local rain are not mapped.

subsequent drying for their continued survival, as are most wetland systems (Kingsford 2000). Key water requirements for flora and fauna concern the periodicity and magnitude of flooding and the length of time an area is flooded or left dry.

Water management issues for biodiversity conservation on Kinchega NP are:

a) Lakes Menindee, Cawndilla and Speculation are now more or less permanently filled and subsequently biologically depauperate in plant and animal species, including the loss of habitat for the vulnerable plant *Solanum karsense* and the loss of extensive stands of Black Box. The numbers of duck species and wading waterbirds, including Paleartic migrants, has also probably decreased (Auld & Kingsford 1992, Kingsford unpubl.).

b) a decline in flood frequency and intensity on major watercourses in NSW, including the Darling River and hence Kinchega NP (Kingsford 2000). This has particular consequences for the large remaining ephemeral lake (Emu Lake) which is habitat for the vulnerable plant *Solanum karsense*, as well as for the persistence of flora and fauna on the extensive floodplain areas;

c) flooding of non wetland habitat by over-filling of Menindee and Cawndilla lakes. This has resulted in loss of several stands of the endangered *Acacia loderi* shrubland community;

d) repeated long duration flooding of several small ephemeral lakes which fill off Lakes Menindee and Cawndilla when high lake levels are maintained. This reduces the productivity of these wetlands, making them less acceptable to diverse types of waterbirds as well as destroying the habitat of the vulnerable plant *Solanum karsense*;

e) serious disruption of the natural drainage patterns of several small ephemeral lakes and Black Box swamps through the construction of the Cawndilla channel which connects Lake Cawndilla to Tandou Creek to the south. These areas previously filled from floodwaters from Tandou Cereek, but now one ephemeral lake fills directly from the Cawndilla channel only, and others fill when water frequently backs up along Tandou creek from the south of the park or when Tandou creek itself floods from the Darling River. This has resulted in the loss of large areas of Black Box trees in two depressions and may impact on the long-term viability of this habitat for a number of wetland plants, including the vulnerable plant *Solanum karsense*, and waterbirds that breed in the trees during floods (cormorants, spoonbills, etc.).

Recommendations for water management

Water management is a key issue for the conservation of plant and animal biodiversity on the park (NPWS 1999). Recommendations for water management are:

a) wetlands require periodic drying to maintain their natural productivity (Briggs 1988, Brock 1999, Casanova 1999);

b) wetlands should not be flooded continuously or tree death and loss of biodiversity is likely to result (Kingsford 2000). Even flooding for two continuous summers has led to the death of extensive stands of *Eucalyptus largiflorens* in depressions near Tandou Creek on Kinchega NP (Auld unpubl.); and

c) when flooded, wetlands should remain inundated continuously for a period of time, eg. four to six months, to ensure appropriate conditions for plant and invertebrate succession (Briggs 1988, Brock 1999, Boulton 1999). Waterbirds require at least this period to acquire necessary body reserves for egg laying, incubation and fledging of young.

d) There needs to be consideration of environmental water flows for maintaining wetland habitat on Kinchega NP.

Threatened species and species of conservation significance

Several plants or ecological communities that are listed as threatened on the *NSW Threatened Species Conservation Act 1995* (TSC Act) occur at or near Kinchega NP as do some rare or poorly known species (Briggs & Leigh 1996). For these species/communities, special management is required to maintain viable populations into the future.

Acacia loderi Shrubland — an endangered ecological community in NSW. This community is threatened by a lack of regeneration of the dominant tree species due to grazing pressure. It is only reserved in Kinchega and Mungo National Parks. In Kinchega NP, successful recruitment from seed has not been observed, and while a cohort of suckers in one area is extensive, overall it appears that the overstorey species is in decline (Auld 1995b). Reduction in rabbit grazing pressure and elimination of goats in Kinchega NP would help promote regeneration of *Acacia loderi*. Also on Kinchega NP, some small stands of the community have been destroyed by flooding as a result of over-filling Lake Menindee. This long-lived tree is killed by flooding and further artificial flooding of its habitat should be prevented.

Acacia carneorum (formerly *Acacia carnei*) — a nationally vulnerable species. This species occurs in arid western NSW and eastern South Australia (Auld 1993). Its only occurrence in a conservation reserve is at Kinchega NP. On Kinchega NP, there are a number of large and small stands and this reserve represents a significant long-term conservation area for *Acacia carneorum*. This species produces vegetative suckers up to twice a year, and is thought to be highly clonal at each known site. Vegetative suckers are readily eliminated by rabbits (Auld 1990, 1993). Rabbits occupy warrens in the sandy dunes where *Acacia carneorum* occurs. In Kinchega NP, in the early 1990s, one patch of *Acacia carneorum* showed signs of successful regeneration from suckers in the recent past, while the remaining locations showed no evidence of regeneration (Auld 1993) .

Estimates of plant age from five samples of wood taken from five different plants for carbon-14 dating indicate that *Acacia carneorum* standing plants may vary from 120 (± 52) to 330 (± 60) years old (ANU 7855–7859, 81 (± 52) BP to 290 (± 60) BP, where BP is before present =1950). This would suggest that it is likely that there has been little or no regeneration in the species since sheep and rabbits arrived in the area. Recent reductions in rabbit numbers across the park have led to some successful recruitment of vegetative suckers, but it is too early to tell if these will persist through the next dry period (Denham and Auld unpubl.). Seed production in *Acacia carneorum* is extremely rare. Two sites that regularly produce seed are known from Middlecamp Station to the southwest of Kinchega NP. On Kinchega NP, there is one patch of *Acacia carneorum* plants that regularly initiates fruits following flowering (other sites flower but do not initiate fruits). However, successful seed production at this site is rare and limited in magnitude. These fruiting sites are very important in the long-term conservation of the species as it is only from dispersal of seeds from these sites (some seeds are dispersed by birds) that new sites can be initiated or old, now extinct sites, can be recolonised. Continued control of rabbits and goats is necessary to maintain *Acacia carneorum* on Kinchega NP and elsewhere.

Solanum karsense — a nationally vulnerable species. This species is endemic to NSW and is essentially confined to the floodplain lakes and depressions of the Darling (below Wilcannia) and Lachlan River systems. It is only known to be reserved in Kinchega NP. The distribution of *Solanum karsense* in Kinchega NP (Fig. 3) is essentially restricted to areas that are periodically flooded (i.e., ephemeral lake beds, Black Box swamps). A few plants have been found on the side of Old Pooncarie Rd but were probably moved there as seeds in soil during road maintenance. When the habitat of *Solanum karsense* is flooded the species survives as seed in the soil of the lake beds (Monaghan & Brownlee 1979). After these areas dry out seeds germinate and young plants emerge from the cracking grey clays. These juvenile plants require 3–6 months to mature, flower and set seed, after which the populations decline and eventually only the soil seedbank is left. The species may be clonal (Purdie et al. 1982) and has spreading lateral roots which can produce new shoots (Monaghan & Brownlee 1979). Germination will once again occur after the next flood cycle or possibly following high local rainfall events. Key water management requirements for *Solanum karsense* are:

i) After a flood recedes, a minimum period of 6 months is required to allow fruiting and replenishment of the soil seedbank. Repeated flooding at short intervals must be avoided; and

ii) long periods of continuous flooding should be avoided. The species has been known to survive for two years under continuous flooding, i.e. beyond the limit for mature Black Box, but it is not known for how much longer seeds can survive. Areas that are effectively permanently flooded are no longer suitable habitat for this species.

Swainsona adenophylla — a species endangered in NSW, not threatened nationally. This species has been recorded from Kinchega NP (Thompson 1993). The species has not been seen on the park since 1974, despite extensive plant collecting on the park. It is likely that this species is locally extinct in Kinchega NP, or if it still occurs on Kinchega NP, is very restricted and ephemeral in nature. Further searching in seasons favourable to the growth of *Swainsona* spp. and in the favoured habitat of the species, sandy flats near lake margins, is needed to try and relocate this species.

Swainsona pyrophila — a nationally vulnerable species, has been recorded for the park in 1973 (Bowen & Pressey 1993) and recently (Westbrooke et al. 2001). We believe that this species is not likely to occur on the park as the species is generally found in mallee

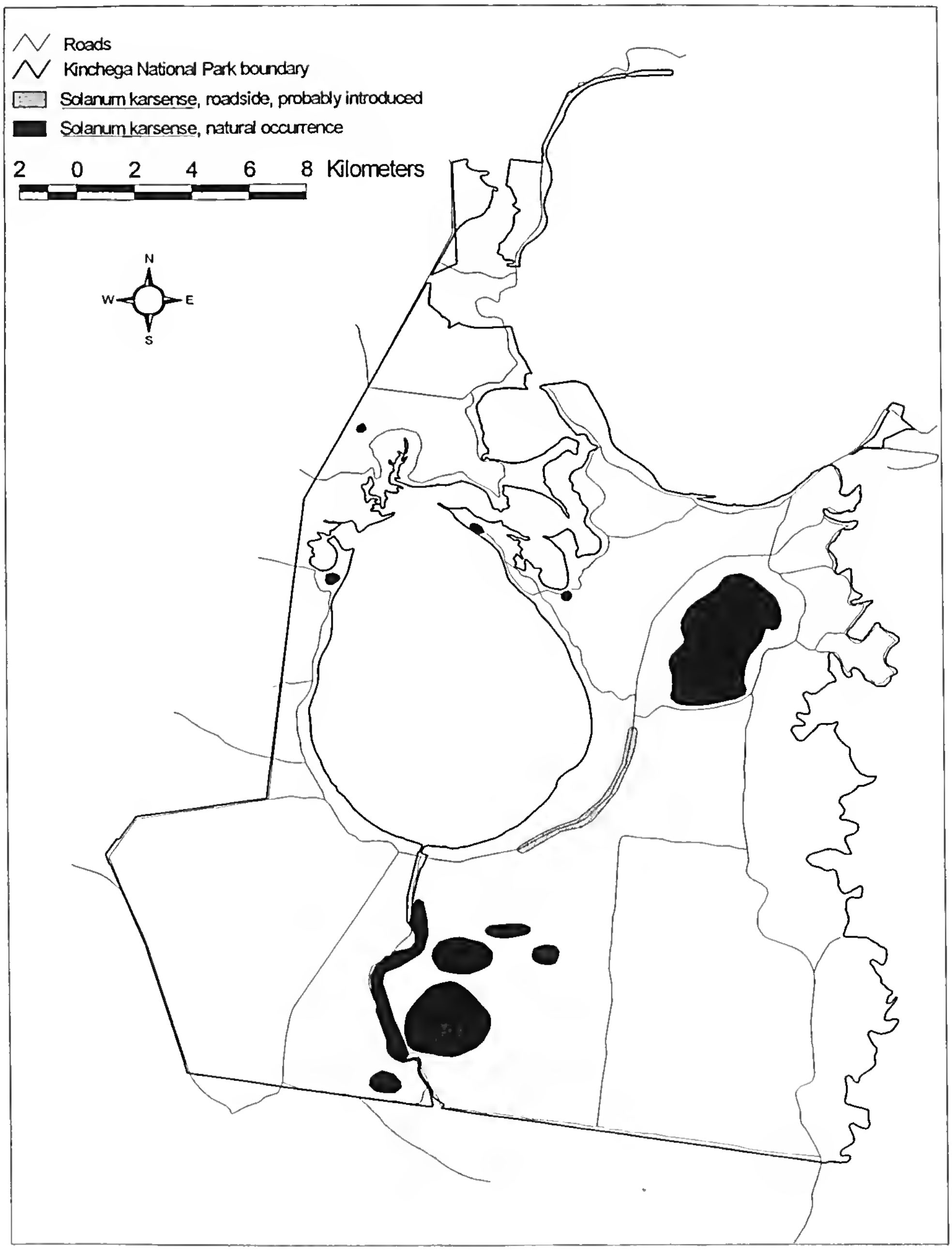

Fig. 3. The distribution of the vulnerable plant *Solanum karsense* on Kinchega National Park.

habitat far to the south and east of Kinchega NP. Records for *Swainsona pyrophila* at Kinchega NP are likely to be misidentifications with *Swainsona laxa*. *Swainsona laxa* was formerly known as *Swainsona rigida*, while *Swainsona pyrophila* was formerly known as *Swainsona laxa* (Thompson 1991, 1993). Taxonomic confirmation of the specimens from Kinchega NP is required.

Haloragis exalata — a nationally vulnerable species, has recently been recorded for Kinchega NP (Westbrooke et al. 2001). This is a major extension of range for this species and is also not in its usual habitat of damp riparian areas (Harden 1990–93, Walsh & Entwisle 1996). Since other *Haloragis* spp. occur in Kinchega NP, taxonomic confirmation of the specimens from Kinchega NP is required.

There are a number of species that are potentially threatened which have been recorded on Kinchega NP. Some of these are locally common, but have been rarely been collected in NSW, for example *Amaranthus grandiflorus*, *Phyllanthus lacunarius* and *Senecio murrayanus*. Given the abundance of these taxa on Kinchega NP, they are likely to be more widespread and are not likely to be threatened. *Echinochloa lacunaria* is a poorly known species (2K, Briggs and Leigh 1996), that is locally rare at Kinchega NP and has a limited distribution outside of Kinchega NP; while *Sida* sp. C (referred to as *Sida spodochroma* in, Walsh and Entwisle 1996) is infrequent where it is known to occur in far western NSW (Harden 1990–93), including at Kinchega NP. Further surveys of *Echinochloa lacunaria* and *Sida* sp. C in suitable habitat in western NSW are needed to determine whether they are threatened.

There are a number of species with distributions that include Kinchega NP as an outlier. Some examples include *Acacia tetragonophylla* (1 plant known), *Acacia colletioides* (2 plants known), *Acacia burkittii* (a few plants in a clump), *Eucalyptus socialis* (3 small clumps known), *Sarcostemma australe* (one diffuse clump on a lunette) and, *Triodia scariosa* (one clump now thought to be locally extinct). These are all very old plants where future local recruitment is unlikely.

Three taxa of conservation significance occur near Kinchega NP. Despite extensive plant collecting in Kinchega NP over 30 years, there have been no recorded sightings of these species on the reserve.

Acanthocladium dockeri was a nationally presumed extinct species from near Kinchega NP (Bowen & Pressey, 1993) that has been rediscovered in South Australia. Searches for this taxon have failed to relocate it near Kinchega NP.

Atriplex infrequens is a nationally vulnerable species where the type specimen (from 1860) is thought to come from Lake Pamamaroo, just to the north of the Park (Wilson 1984). It has not been recorded from the area since.

Atriplex morrisii is a poorly known species (Briggs & Leigh 1996) and is known from some 40 km NNE of Menindee.

Management of weeds

A number of weed species occur on the park, and while many currently occur in low numbers it is likely that without significant management action they will become a conservation problem. The weeds that are of most concern, yet are most likely to respond to changes in management, are shrubs with seeds dispersed by birds and perennial herbs including *Lycium australe* (Australian Boxthorn), (*Chrysanthemoides monilifera* (Boneseed) and *Arundo donax* (Giant Reed). Local infestations of the first two of these weeds respond favourably to simple management strategies such as cutting and painting with herbicide, while the last appears to require more effort to physically extract and remove rhizomes. Monitoring and mapping of these weeds should continue indefinitely to ensure that they do not become more widespread (NPWS 1999). Other, ephemeral, weeds which may have significant impacts include *Asphodelus fistulosus* (onion weed), *Echium plantagineum* (Paterson's Curse), *Carrichtera annua* (Ward's Weed), a range of grasses (*Bromus* spp., *Hordeum leporinum*, *Rostraria pumila*, *Schismus barbatus*, *Vulpia muralis*), *Ricinus communis* (Castor Oil Plant), *Xanthium occidentale* (Noogoora Burr), *Argemone ochroleuca* (Mexican Poppy), *Acetosa vesicaria* (Rosy Dock), *Emex australis* (Three-cornered Jacks), *Centaurea melitensis* (Maltese Cockspur) and *Nicotiana glauca* (Tree Tobacco). For a number of these ephemeral weeds, there can be extensive areas of the park where they dominate or co-occur with native species in some seasons. At other times they may not be obvious in a native dominated flora. Particular problems occur after winter rains and it may be that the weeds have competitively excluded a number of native winter growing forbs and grasses. Solutions to such widespread but temporal weed issues are not currently available and may depend on future biological control actions.

Other Issues

Two areas where biodiversity impacts may occur in the future are the impacts of salinity and climate change. Although there has not been extensive clearing of vegetation in the Kinchega NP area, the maintenance of permanent water in the Menindee Lakes Scheme may cause local uprisings in the water tables in adjacent dryland areas. Recently, within Kinchega NP an area of several hectares has developed extensive death and dieback of *Casuarina pauper*. This may be influenced by rising water tables and salt levels along with the lack of regeneration issue already discussed earlier. Rising salinity levels in the Darling River catchment generally may also influence the long-term survival of wetland/floodplain vegetation.

The impact of future climate change may be important in altering the balance between grazing and recruitment in perennial plants by influencing both the pattern and amount of rainfall and evapotranspiration. Current predictions for the area suggest a slight increase in temperatures (0.5–1.5°C) and a 2–10% decline in daily rainfall by 2030 (Environment Protection Agency 1997). Such predictions would imply a decline in recruiment success in perennial species (given constant grazing pressure) under future climate change.

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Vegetation of Narran Lake Nature Reserve, North Western Plains, New South Wales

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The vegetation of Narran Lake Nature Reserve (4527 ha) in the central north of New South Wales approximately 30 km west of Cumborah (29°43', 147°29') in the Walgett Shire on the North Western Plains and the Darling River Plains Bioregion is described. Seven communities are defined based on flexible UPGMA analysis of cover-abundance scores of all vascular plant taxa. These communities are mapped based on ground truthing, air photo interpretation and geological substrate. All communities are simple in structure being primarily woodlands, shrublands and herbfields. Communities are: 1) Mixed Low Woodlands, 2) Mulga Low Woodlands, 3) Triodia Hummock Grasslands, 4) Chenopod Low Open Shrublands, 5) Ephemeral Herbfields, 6) Riparian Open Forests, and 7) Lignum Shrubby Thickets. A total of 325 taxa were recorded including two species listed under the *NSW Threatened Species Conservation Act (1995), Lepidium monoplocoides* and *Goodenia macbarroni*. An additional 11 species are considered to be at their geographic limit or disjunct in their distribution; 11% are exotic in origin.

Introduction

Narran Lake Nature Reserve is approximately 30 km west of Cumborah (29°43'S, 147°29'E) and lies between Brewarrina, Walgett and Lightning Ridge in the Shire of Walgett on the North Western Plains of NSW (Fig. 1). The reserve was dedicated in 1988 and encompasses an area of 4527 ha. An adjoining property 'Lumeah' has been purchased more recently by the NSW National Parks & Wildlife Service. Other reserves in the general area with vegetative affinities to Narran Lake include Culgoa National Park, gazetted in 1996 (16 616 ha) and Macquarie Marshes Nature Reserve, gazetted in 1971 (18 143 ha).

The Narran River is a tributary of the Bokhara River (part of the Condamine River System) with its headwaters in southeastern Queensland. The Narran River leaves the Balonne near Dirranbandi in Queensland and continues 150 km to Narran Lake. Other rivers flowing from the Condamine River in the general vicinity include the Culgoa and the Balonne Rivers, both of which flow directly into the Darling. The reserve does not include Narran Lake itself. The Narran River delineates the south-western boundary of the reserve.

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This paper gives part of the results of a flora survey conducted on behalf of the Narrabri District of the NSW National Parks & Wildlife Service. The aims were to provide baseline data on the Reserve, to construct a map of vegetation communities to assist in reserve management and to provide information on the distribution of rare or geographically restricted or disjunct taxa. This information will be used to assist the development of appropriate management strategies (Hunter 1999).

Climate

The climate is semi-arid with an average annual rainfall of 358–425 mm. The monthly rainfall is variable with a larger summer (in the long term), but also a winter peak. Years with less than 250 mm often occur in pairs or threes causing drought conditions (Aldis 1987). Despite the severe droughts of the late 1890s, the period prior to 1910 was

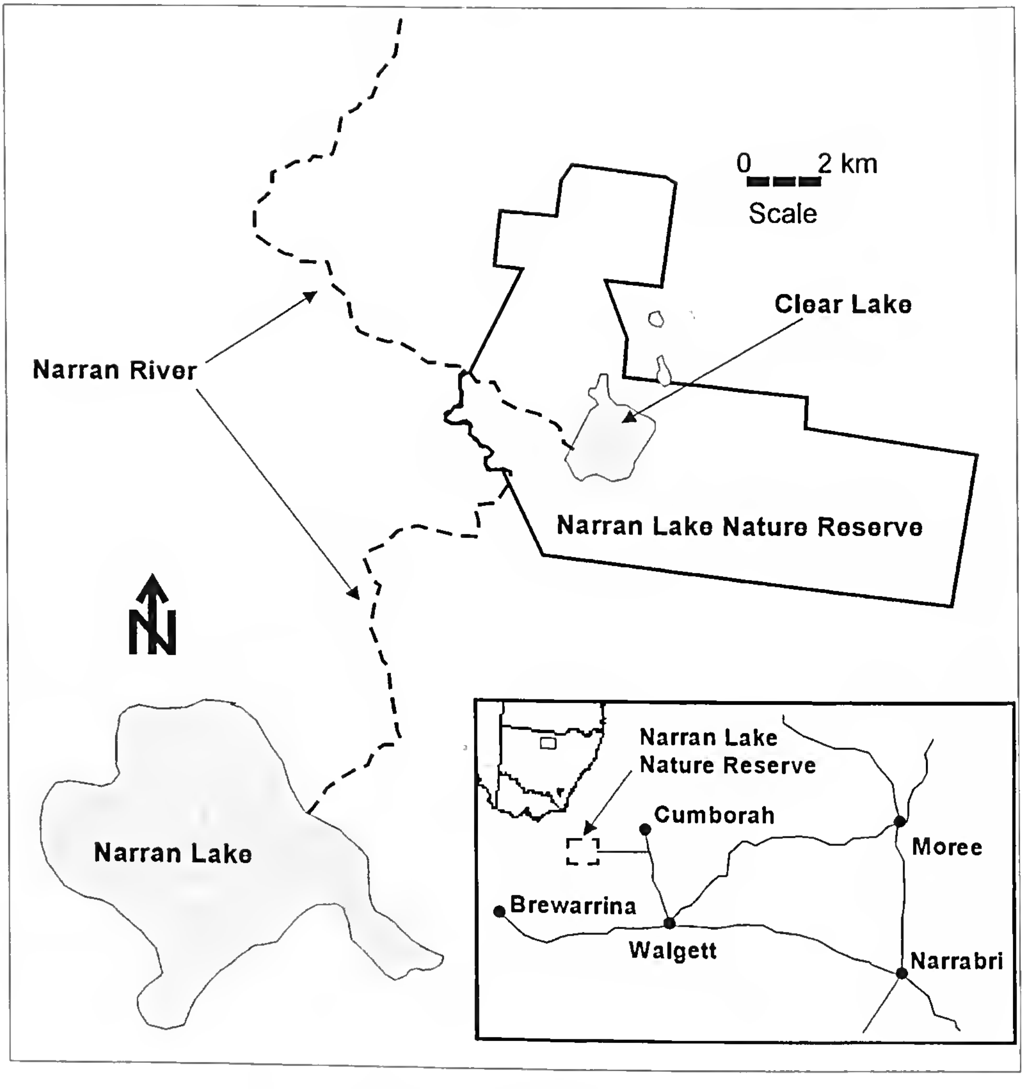

Fig. 1. Map of locality of the Narran Lake Nature Reserve.

wetter than from 1911 to 1947 (Gentilli 1971). Since that time the rainfall has been substantially higher and there has been an increase in summer rainfall (Pickard & Norris 1994). There is a long hot summer and a short cold winter. The diurnal temperature fluctuates greatly. The average maximum and minimum summer temperatures are 36°C and 21°C and winter maximum and minimum are 18°C and 6°C respectively.

Geology and geomorphology

The landforms are gently sloping, undulating plains that fall to the southwest. In terms of fertility, the cracking clay soils are the most important soil group in the area with red earths and sandy red earths being of low fertility (Neldner 1992). The reserve incorporates extensive wetlands, lunettes and sandy and minor rocky ridge country (NSW NP&WS 1996). The region encompassing the Narran is thought to be a plain formed by the coalescence of alluvial fans (Aldis 1987).

Nearly half of the reserve is seasonal wetlands contained within Clear Lake and Back Lake, both subject to flooding by the Narran River. The eastern parts of the reserve are primarily of sandy and rocky ridge country but also include extensive areas of semi-saline playa lakes and drainage depressions (NSW NP&WS 1996). Between the lakes and the ridge country are discontinuous aeolian lunettes and sandy levees.

Coverage of the geology is presented in NSW NP&WS (1996). Cretaceous sandstone and quartzite sediments of the Rolling Downs Group are exposed on the ridge country in the east of the reserve. The ridges are in some places capped by Cenozoic silcrete. Quaternary sediments on the Narran River floodplain overlie the Rolling Downs sediments. These include dark organic muds in the lakes and light grey clays in the nearby playa lakes. The surrounding lunettes are composed of orange sand while the younger dunes closer to the lakes are of yellow-white sands.

The Narran River has a small and shallow channel with a contiguous floodplain. The floodplain of the Narran River is Quaternary alluvium and extends for 120 km and averages about 65 km in width within New South Wales. It is contained by the higher ground around Lightning Ridge in the east and the Myuna and Cartlands Land System in the west (Dick 1993). A number of lakes occur along the main channel and the river terminates at Narran Lake. The river probably originally flowed onto the Barwon River in previous geological times but now only does so infrequently (Aldis 1987).

The Narran wetlands flood more frequently than most other wetlands in western New South Wales (NSW NP&WS 1996). Narran Lake fills approximately every two years (Aldis 1987). Clear Lake, within the reserve, fills first with waters later flowing onto Narran Lake (Aldis 1987). Clear Lake can drop quickly if flows are not sufficient (NSW NPWS 1996). Once flooded, the smaller lakes usually hold water for four to nine months, while Narran Lake can hold water for two years. Flooding in the Narran Lakes is predominately (85%) a summer and autumn event.

History and landuse

Sir Thomas Mitchell and his party were the first recorded Europeans to pass through the Narran Lakes area (Mitchell 1848). Settlement of the district by Europeans began soon after Mitchell's visit. By the 1850s the frontages of the Darling River up to Wilcannia had been occupied with land to the east of the river only being used opportunistically after rain (NPWS 1996). The first squatters brought cattle, later replaced by sheep (Cunningham et al. 1981). The opal mining fields of Glengarry, Cumborah and Lightning Ridge opened up the area near Narran Lake. Currently the main usage in the region is sheep grazing with cattle numbers fluctuating due to market prices; Narran Lake itself is used for dry land cropping (Pickard & Norris 1994).

Previous investigations

During Mitchell's exploration of the Narran River in 1846 a number of new plant species were described (Mitchell 1848) including: *Anthistiria membranacea* Lindley (now *Iseilema membranaceum* (Lindley) Domin.), *Chenopodium auricomum* Lindley, *Haloragis glauca* Lindley, *Kochia lanosa* Lindley (now *Maireana lanosa* (Lindley) Paul G. Wilson), *Kochia villosa* Lindley (now *Maireana villosa* (Lindley) Paul G. Wilson), *Geijera parviflora* Lindley, *Loranthus aurantiacus* A.Cunn. ex Hook. (now included under *Amyema miquelii* (Lehm. ex Miq.) Teighem), *Loranthus linearifolius* Hook. (now *Lysiantha linearifolia* Teighem), and *Pittosporum salicinum* Lindley (now included with *Pittosporum. phylliraeoides* DC.). Later Cambage (1900a, 1900b) published annotated notes on the flora and communities around the Bourke, Cobar, Bogan River and Nyngan areas. Turner (1903, 1905) described the plant species of the Darling and northwestern New South Wales. Haviland (1911, 1913) discussed the flora and vegetation in the Cobar area. The first vegetation map of the western district of New South Wales was prepared by Noel Beadle in 1945 (Beadle 1948). Pickard and Norris (1994) have updated a large area of Beadle's map in their 1: 1 000 000 natural vegetation map of northwestern New South Wales.

Methods

Fifty 20 × 20 m quadrats were surveyed for vascular plants scored using the Braun-Blanquet (1982) cover abundance scale. Quadrats were placed using a stratified random method. As only a relatively low number of sites were used, physiography was used to stratify survey sites. The survey was conducted over five days in November of 1998.

Good quality material of species was retained as vouchers by the Narrabri District NSW NP&WS and duplicates of significant collections submitted to the National Herbarium of NSW. Nomenclature follows that of Harden (1990–1993) except where recent changes have been made.

Analyses and data exploration were performed using options available in the PATN Analysis Package (Belbin 1995a, b). For final presentation of results all species and their relative abundance scores were used and the analysis performed using

Kulczynski association measure which is recommended for ecological applications (Belbin 1995a, b) along with flexible UPGMA and the default PATN settings.

Delineation of community boundaries in Fig. 2 was based on the location of sites and their position within the multivariate analysis, air photograph interpretation and ground truthing. The vegetation map is based on 1: 50 000 topographic map produced by the Western Zone, NSW NP&WS. Structural names follow Specht et al. (1995) and are based on the most consistent uppermost stratum.

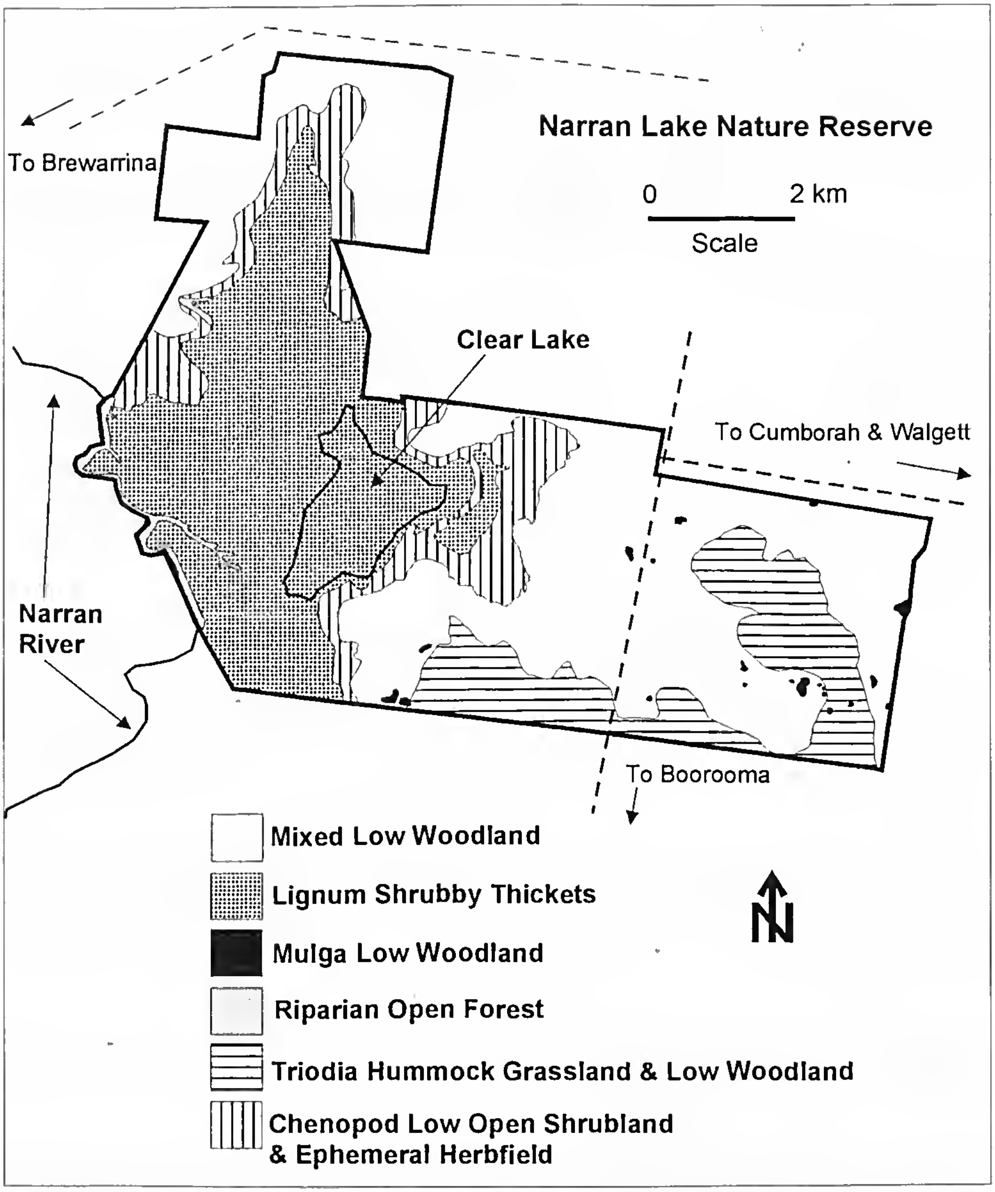

Fig. 2. Map of vegetation communities for Narran Lake Nature Reserve.

Results and Discussion

Seven communities (Table 1) were recognised at the dissimilarity measure of c. 0.8. A summary of the community relationships is given by the dendrogram (Fig. 3). The first major division on the dendrogram is the separation of the wetland areas. The next major division separates the fringing herb and shrublands, which may periodically be inundated, from the woodlands which are rarely inundated. In all 325 vascular plant taxa, from 62 families and 213 genera, were recorded from the collation of existing site data and subsequent sampling. Approximately 11% (37) of all taxa were introduced (Appendix).

Table 1: Selected attributes of the seven defined communities at Narran Lake Nature Reserve.

Note Chenopod Low Open Woodlands could not be mapped effectively at this scale and so the proportion of the reserve and number of hectares are estimates.

Community	Number of Sites	Richness per 400 m² (average)	No. of Species	No. of Introduced Species	Proportion of Reserve	No. of Hectares
Mixed Low Woodlands	18	22–47 (38)	156	9	43.2%	3932
Mulga Low Woodlands	3	19–31 (24)	43	4	0.3%	31
Triodia Hummock Grasslands	6	13–30 (23)	60	3	11.9%	1079
Chenopod Low Open Shrubland	5	8–14 (12)	37	1	?0.2%	?30
Ephemeral Herbfields	4	9–13 (11)	31	3	11%	1000
Riparian Open Forests	4	8–22 (16)	43	4	1%	87
Lignum Shrubby Thickets	10	5–18 (12)	47	2	32.6	2971

Vegetation communities

The communities within Narran Lake Nature Reserve form structurally simple assemblages, low in height and foliage cover (usually < 30%). Although simple, these associations exhibit distinct layering. Figures in brackets represent maximum and minimum values.

Community 1: Mixed Low Woodlands: *Callitris glaucophylla* (White Cypress Pine) - *Geijera parviflora* (Wilga) - *Eucalyptus populnea* subsp. *bimbil* (Poplar Box)

Structure: Upper: (6–) 10–15 (–20) m; 10–20% cover. Middle: 3–6 (–8) m; 10–30 (–60)% cover. Herb: 0.1–0.2 m; (20–) 40–80%.

Trees: *Callitris glaucophylla, Geijera parviflora, Eucalyptus populnea* subsp. *bimbil, Atalaya hemiglauca, Acacia pendula, Eucalyptus melanophloia, Hakea leucoptera, Acacia acuminata, Acacia excelsa, Acacia omalophylla, Alstonia constricta.*

Shrubs: *Chenopodium curvispicatum, Sida cunninghamii, Sclerolaena birchii, Sclerolaena convexula, Abutilon fraseri, Dodonaea viscosa, Eremophila mitchellii, Sida ammophila, Sida* sp. A, *Dissocarpus paradoxus, Teucrium racemosum.*

Climbers & trailers: *Einadia nutans, Glycine canescens, Evolvulus alsinoides, Convolvulus erubescens, Parsonsia eucalyptophylla, Boerhavia dominii, Jasminum linear, Boerhavia repleta, Kennedia procurrens.*

Ground cover: *Pimelea trichostachya, Calotis cuneifolia, Oxalis chnoodes, Ptilotus polystachyus, Calotis lappulacea, Eragrostis lacunaria, Rhodanthe moschata, Angianthus brachypappus, Nicotiana simulans, Austrostipa scabra, Calandrinia eremaea, Chenopodium melanocarpum, Plantago varia, Chamaesyce drummondii, Cheilanthes sieberi* subsp. *sieberi.*

Variability: *Atalaya hemiglauca, Grevillea striata* and *Ventilago viminalis* dominate areas of sandy red earths to the north-west of Narran Lake NR. *Eremophila mitchellii* and

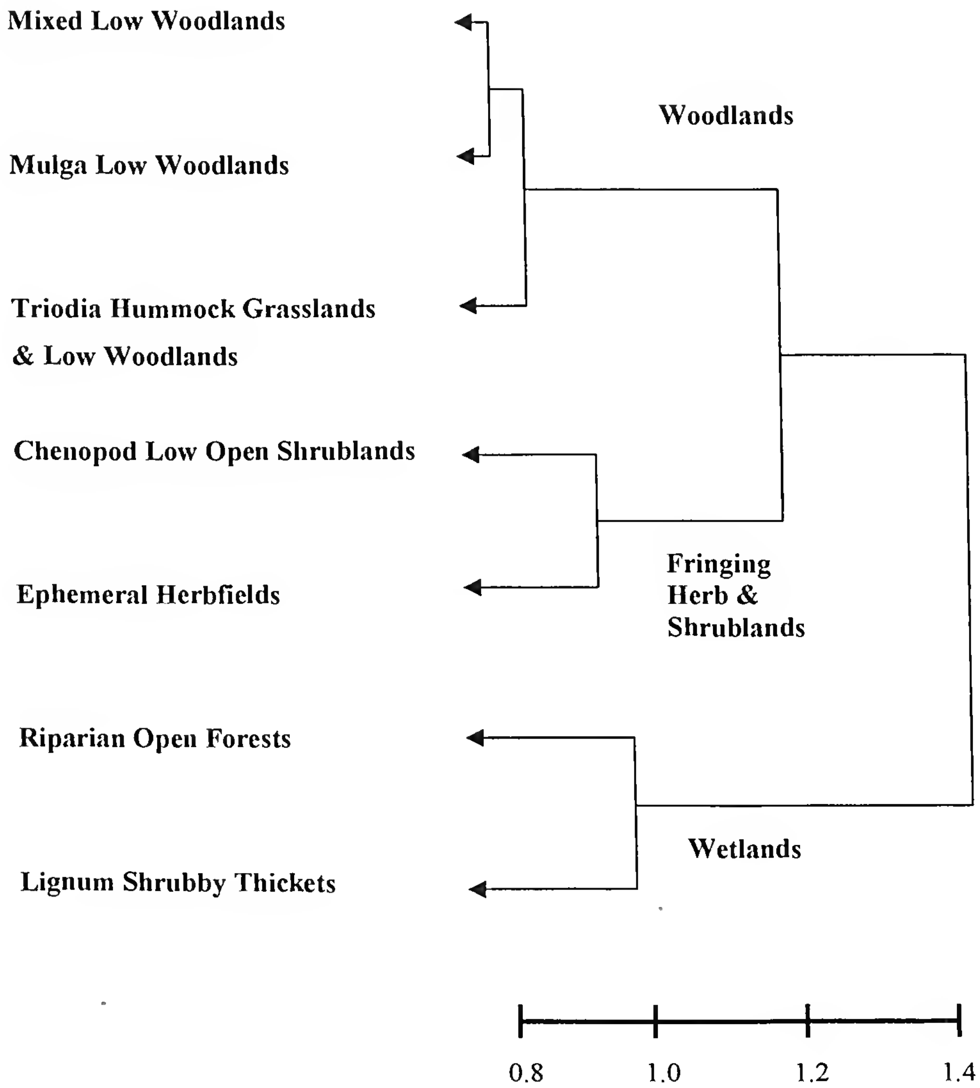

Fig. 3. Summary dendogram of the full floristic dataset of sites using the Kulczynski association and flexible UPGMA fusion strategy and a value of -0.1. Communities have been defined at a dissimilarity level of c. 0.8.

Geijera parviflora are a frequent component of the understorey, a situation found throughout the range of *Eucalyptus populnea* (Neldner 1984). In areas cleared of *Eucalyptus populnea* the woody understorey taxa become prominent and form thickets. In a few places *Acacia cambagei* occurs within the matrix of the Mixed Woodlands. *Acacia excelsa* occurs as mono-specific stands in a few minor areas within *Eucalyptus populnea*. Such mosaics appear to be restricted to north of Bourke and east of Enngonia (Pickard & Norris 1994). In more disturbed sites and particularly over a large area of 'Lumeah', *Callitris glaucophylla* is dominant to the exclusion of most species (Pickard & Norris 1994). In a few minor depressions on the eastern side of Clear Lake, *Eucalyptus populnea* lined swamps are present. Despite the changes in overstorey taxa, all sites were still incorporated within the Mixed Stand Woodlands in analysis, thus suggesting the understorey (primarily ephemeral) species were remarkably similar. Species richness also did not change dramatically between sites within this community.

Conservation and management issues: Mixed Woodlands with *Callitris* extend widely across Australia though associated species differ across this range (Porteners 1993). In many areas of NSW *Callitris glaucophylla* dominant assemblages now occur only as remnants with heavily grazed understoreys. Much of the area in the south-east has been extensively cleared and rabbits have reduced the capacity of the trees to regenerate (Morcom & Westbrooke 1990, Fox 1991, Scott 1992, Porteners 1993). *Atalaya hemiglauca, Grevillea striata* and *Ventilago viminalis* dominate areas of sandy red earths to the north-west of Narran Lake NR. In western Queensland similar associations are widespread and occur on stony rises or limestone outcrops (Boyland 1984, Neldner 1984, Neldner 1991). The lack of *Eucalyptus populnea* and other eucalypt species from the western boundary of Narran Lake NR on the same soil type, and the dominance of tropical taxa such as *Atalaya hemiglauca, Ventilago viminalis, Grevillea striata* and *Hakea leucoptera* may be due to a long absence of fire, differences in soil moisture or the differential effects of drought. Disturbances such as fence construction and some clearing activities in neighbouring properties have stimulated the germination of *Eucalyptus populnea* in these localities. Local farmers state that the last fire in this area was almost 100 years ago. The *Atalaya* dominant sites represent an assemblage that is very restricted within New South Wales (and is only conserved in NSW in Nocholeche Nature Reserve — Specht et al. 1995).

Community 2: Mulga Low Woodlands: *Acacia aneura* (Mulga)

Structure: Upper: 8–12 m; 40–70% cover. Herb: 0.1–0.5 m; 80–100% cover.

Trees: *Acacia aneura.*

Shrubs: *Abutilon leucopetalum, Sida cunninghamii, Hibiscus sturtii.*

Climbers & trailers: *Convolvulus erubescens.*

Ground cover: *Calotis cuneifolia, Stuartina muelleri, Trachymene ochracea, Ptilotus polystachyus, Wahlenbergia stricta, Cheilanthes sieberi, Fimbristylis dichotoma, Goodenia hederacea, Pimelea trichostachya, Bracteantha bracteata, Brunoniella australis, Goodenia macbarroni, Tripogon loliiformis, Velleia arguta, Actinotus paddisonsii, Angianthus brachypappus, Bulbine semibarbata, Calandrinia eremaea, Daucus glochidiatus, Oxalis chnoodes.*

Variability: Although *Acacia aneura* associations have a very wide range they do not form a single assemblage (Boyland 1984). The assemblage present within Narran Lake NR appears to be uniform and occurs in groves that are visually distinct from the surrounding Mixed Woodland matrix. Groving is rare on the eastern margin of the species distribution and is more common in arid areas further west (Boyland 1984, Pickard & Norris 1994).

Conservation and management issues: Large areas of Mulga Low Woodlands have been degraded, they are frequently used for drought fodder (Boyland 1984) and 'woody weeds' invade many. Of particular significance at Narran Lake is that the Mulga Low Woodlands is beyond the predicted eastern limit of its occurrence (Nix & Austin 1973). At present only 0.3% of the Narran Lake reserve is of this community. Mulga Woodlands do not occur in either of the nearby Culgoa NP or Macquarie Marshes NR.

Community 3: Triodia Hummock Grasslands & Low Woodlands: *Callitris glaucophylla* (White Cypress Pine) - *Eucalyptus melanophloia* (Silver-leaved Ironbark) - *Angophora melanoxylon* (Coolabah Apple) and *Triodia mitchellii* (Buck Spinifex)

Structure: Sometimes an Upper: 5–20 m; 10–20% cover. Grass: 1–2 m. 30–80% cover. Herb: 0.1 m; 10–40% (80) cover.

Trees: *Callitris glaucophylla, Eucalyptus melanophloia, Angophora melanoxylon, Acacia murrayana, Eucalyptus populnea* subsp. *bimbil, Geijera parviflora.*

Shrubs: *Dodonaea viscosa, Alstonia constricta.*

Climbers & trailers: *Glycine canescens, Glycine clandestina, Einadia nutans, Kennedia procurrens.*

Ground cover: *Triodia mitchellii, Actinotus paddisonsii, Wahlenbergia stricta, Calandrinia balonensis, Chrysocephalum apiculatum, Poranthera microphylla, Angianthus brachypappus, Calotis cuneifolia, Pimelea trichostachya, Calandrinia eremaea, Chenopodium melanocarpum, Nicotiana simulans, Arthropodium minus, Oxalis chnoodes, Ptilotus polystachyus.*

Variability: Large areas of almost pure *Triodia mitchellii* occur within the reserve. In some areas *Angophora melanoxylon* and *Eucalyptus melanophloia* may occur. Such an association is rare but is also known from small areas in south central Queensland and apparently only occurs in two localised areas north east of Brewarrina in NSW (Beadle 1981, Neldner 1984, Pickard & Norris 1994).

Conservation and management issues: The floristic composition of *Triodia* hummock grasslands is related to fire history and time since last burn. The abundance and diversity of forbs increase initially after fire and then decrease as hummocks mature (Neldner 1984, Neldner 1991). Woody species have been known to increase in *Triodia* communities after fire (Suijdendorp 1981, Maconochie 1982). Maher et al. (1995) state that *Triodia* becomes too thick for other native plant species to survive in any quantity if not regularly burnt. This however, is a proposal from a grazing perspective. Large and old *Triodia* are hollow in the middle and within these hollows a distinct suite of perennial and ephemeral herbs including restricted taxa such as *Actinotus paddisonsii.*

For large hollows to form the hummocks clumps must be of considerable age, as is the case at Narran Lake NR. As such, patchy long inter-fire periods may be beneficial to such communities.

Community 4: Chenopod Low Open Shrublands: *Sclerolaena decurrens* (Green Copperburr) - *Atriplex nummularia* (Old Man Saltbush) - *Halosarcia pergranulata* (Samphire)

Structure: Shrub: 0.1–0.5 m; 20–70% cover.

Trees: None apparent.

Shrubs: *Sclerolaena decurrens, Atriplex nummularia, Halosarcia pergranulata, Chenopodium desertorum, Sclerolaena parallelicuspis, Sclerolaena convexula, Osteocarpum dipterocarpum, Sida* sp. A, *Atriplex holocarpa.*

Climbers & trailers: None apparent.

Ground cover: *Eriochlamys* sp. A, *Bulbine semibarbata, Portulaca oleracea, Chloris truncata, Rhodanthe floribundum, Plantago varia, Wahlenbergia fluminalis, Trianthaema triquetra, Sporobolus actinocladus, Portulaca filifolia, Podolepis jaceoides, Ixiolaena brevicompta, Gypsophila tubulosa, Brachyscome ciliaris, Tripogon loliiformis.*

Variability: The composition of this community is highly variable, as is the ground cover. This variation is probably dependent on rainfall and whether the community is on gilgai.

Conservation and management issues: The Chenopod Low Open Shrublands appear to have very few correlates anywhere. It seems that as circumscribed here, these communities are restricted to the Narran River area and are thus not represented in any other reserves and are unique and of significance.

Community 5: Ephemeral Herbfields: *Eriochlamys* sp. A (Woolly Mantle) - *Tripogon loliiformis* (Five Minute Grass) - *Sclerolaena bicornis* (Goathead Burr)

Structure: Herb: 0.1–0.2 m; 30–80% cover.

Trees: None apparent.

Shrubs: *Sclerolaena bicornis, Sclerolaena parallelicuspis, Maireana appressa, Osteocarpum dipterocarpum, Neobassia proceriflora, Eremophila mitchellii, Atriplex holocarpa, Dodonaea viscosa.*

Climbers & trailers: *Tephrosia sphaerospora, Convolvulus erubescens.*

Ground cover: *Eriochlamys* sp. A, *Tripogon loliiformis, Actinobole uliginosum, Centaurium spicatum, Millotia greevesii, Lepidium monoplocoides, Wahlenbergia fluminalis, Chthonocephalus pseudovax, Podolepis jaceoides, Pimelea trichostachya, Fimbristylis dichotoma, Daucus glochidiatus, Crassula sieberiana, Calandrinia pumila, Brachyscome ciliaris.*

Variability: This community varies from sparse to dense herblands or sometimes-open tussock grasslands. The floristic composition and structure of the vegetation at a site is probably dependent on the flooding frequency and duration, season of flood, soil characteristics and salinity (Aldis 1987, Neldner 1991). Chenopods are common after winter floods on scalded areas (Neldner 1991). Only a few species dominate at any given time.

Conservation and management issues: The Ephemeral Herbfields appear to have very few correlates anywhere. It seems that as circumscribed here, these communities are restricted to the Narran River area and are thus not represented in any other reserves and are unique and of significance. Somewhat similar herbfields are likely to be more widespread but have not been surveyed extensively as they are usually not acknowledged as having any conservation value.

Community 6: Riparian Open Forests: *Eucalyptus camaldulensis* (River Red Gum) - *Eucalyptus coolabah* (Coolibah) - *Eucalyptus largiflorens* (Black Box)

Structure: Upper: 8–20 m; 20–40% cover. Mid: 3–8 m; 10–30% cover. Herb: 1–2 m; 10–70% cover.

Trees: *Eucalyptus camaldulensis, Eucalyptus coolabah, Acacia brachystachya, Eucalyptus largiflorens, Acacia pendula.*

Shrubs: *Eremophila bignoniiflora, Muehlenbeckia florulenta, Sclerolaena divericata, Sclerolaena birchii, Sclerolaena parallelicuspis, Geijera parviflora, Chenopodium curvispicatum.*

Climbers & trailers: *Einadia nutans.*

Ground cover: *Alternanthera denticulata, Crinum flaccidum, Stellaria angustifolia, Ixiolaena brevicompta, Euchiton sphaericus, Eleocharis plana, Marsilea costulifera, Haloragis glauca, Centipeda cunninghamii, Wahlenbergia fluminalis, Pratia concolor, Portulaca oleracea, Pluchea dentex, Plantago varia, Oxalis chnoodes.*

Variability: The ground layers are diverse and contain many ephemeral grasses and forbs that respond quickly to rainfall. Tall shrubs including *Acacia stenophylla* and *Eremophila bignoniiflora* are frequent. Where flooding is less frequent, away from riverbanks and along minor channels; *Eucalyptus coolabah* becomes prevalent as the overstorey species. *Eucalyptus largiflorens* also occurs away from the main channel on slightly higher ground, but is less prevalent along the Narran River than in areas further south.

Conservation and management issues: Although *Eucalyptus camaldulensis* dominated communities are known from many inland rivers they differ along their length in terms of associated species (Scott 1992). Across their range Riparian Open Forests have been modified extensively by grazing and logging (Helman & Estella 1983, Scott 1992). The extent of River Red Gum communities is misleading as, in most situations, they are usually only one to three crown diameters wide. Their high boundary length to area ratio makes them prone to weed infestations and disturbance (Sivertsen & Metcalfe 1995). Changes in flooding regimes due to river regulation has led to a decline in recruitment and the quality of the stands of Riparian Forests in many areas (Porteners 1993). Significant areas of this community are reserved in the nearby Culgoa NP and the Macquarie Marshes NR.

Community 7: Lignum Shrubby Thickets: *Muehlenbeckia florulenta* (Lignum) - *Phragmites australis* (Common Reed) - *Eucalyptus camaldulensis* (River Red Gum)

Structure: Variable. Upper: 6–15 m; 20–40% cover. Mid: 1–4 m; 30–90% cover. Herb: 0.05–0.3 m; (0) 10–80% cover.

Trees: *Eucalyptus camaldulensis, Acacia stenophylla.*

Shrubs: *Muehlenbeckia florulenta, Atriplex vesicaria, Sclerolaena convexula, Abutilon leucopetalum.*

Climbers & trailers: None apparent.

Ground cover: *Azolla filiculoides* var. *rubra, Eleocharis plana, Calotis scapigera, Stellaria angustifolia, Marsilea drummondii, Lemna disperma, Haloragis glauca, Cyperus gymnocaulos, Myriophyllum verrucosum, Phragmites australis, Goodenia glauca, Rorippa eustylis, Cyperus bifax, Cynodon dactylon, Alternanthera angustifolia, Limosella australis.*

Variability: On the margins or in-between major lignum occurrences other associations occur including *Eleocharis plana* and *Cyperus bifax* sedgelands and/or *Marsilea drummondii* herbfields. Such assemblages have been found at 'Kirramingly' near Gurley (Clarke et al. 1998). In less flood prone areas *Acacia stenophylla* occurs with a dense Lignum understorey. *Eucalyptus camaldulensis* will also occur with a dense Lignum understorey. The ground cover is dependent on flooding duration.

Conservation and management issues: Narran Lakes Nature Reserve includes some of the largest expanses of Lignum Shrubby Thickets in NSW (Aldis 1987, NSW NP&WS 1996). Lakebed cropping and subsequent clearing of Lignum have become common practice in many other areas of the state (Aldis 1987, Briggs 1994) and it is estimated that 40% of NSW Lignum areas have been cleared in the last 20 years, with much of the remainder being grazed and disturbed by feral pigs (Scott 1992, Porteners 1993, Porteners et al. 1997). Lignum communities are in both the Culgoa NP and the Macquarie Marshes NR. Within the Lignum Shrubby Thickets are small areas of *Phragmites australis. Phragmites* assemblages are inadequately represented in conservation reserves and many are grazed (NP&WS 1990). The nearby Macquarie Marshes NR contains the largest *Phragmites* area in south-eastern Australia.

General Discussion

Although very little can be grasped from the account of Mitchell (1848) some minor comparisons can be made. Of particular note, are the dense and tall grasslands that Mitchell thought were some of the best he had ever seen in the colony. In particular, *Panicum laevinode* was up to the saddles on the horses. This species was not found during this current survey. A number of the new species whose type specimens were collected along the Narran River by Mitchell were also not located during this survey. Some of this may be explained by the seasonal changes in ephemeral communities, in particular the change from herb dominated to grass dominated after flooding. However, it is likely that significant changes may have occurred over the last 150 years due to grazing and farming practices, which may include changes in fire regimes.

A large number of communities of western NSW are broadly synonymous with those described for Narran Lake NR, but only a few are directly comparable as most previous surveys describe communities with similar dominants but largely different co-dominants and understoreys. The most directly comparable works are those of Beadle (1948, 1981) and Pickard & Norris (1994), descriptive works based on qualitative community definition. Very few communities at Narran Lake NR are synonymous with those in Specht et al. (1995) though the lack of quantitative studies in north western New South Wales probably accounts for lack of direct comparison. There appears to be no 'Lignum' communities in Specht et al. even though they are apparently common throughout the state and have been identified in quantitative analyses many times.

The most directly comparable work is that of Dick (1993). Across the Wombeira Land System, which included the Narran River, Dick placed 65 sites (20 × 40 m and 20 × 20 m). 175 species were found during his survey, with an additional 230 being recorded from collating previous survey records over 19 years (1969–1988). Dick found an average of 20.4 species per site overall, with 25.4 in vegetation away from channelised country and 20 species per site within. Within similar land systems in Narran Lake NR a total of 120 species were found from 22 sites, incorporating 55% of the total number known and 71% of those recorded by Dick. However, the average species richness of sites at Narran Lake Nature Reserve was 12.6, decidedly less than the 20.4 recorded by Dick. This may be explained, but only partly, by the larger size of some of the quadrats used by Dick.

Dick (1993) also qualitatively delineated eleven communities within five structural classes. These 11 communities are circumscribed by two of the communities defined here for Narran Lake Nature Reserve (Community 6: Riparian Open Forests and Community 7: Lignum Shrubby Thickets). Extra sampling may have aided the delineation of more communities within these two though it is unlikely that as many classes of vegetation as described by Dick (1993) actually exist.

Despite such limitations, the general distribution and affinities of all communities described here for Narran Lake NR can be placed into regional and national perspectives as southern outliers of more widely distributed assemblages further north and over the Queensland border.

Conservation Issues

Benson (1989) lists the conservation status of most of the major plant communities in western New South Wales as poor or very poor. Only 2% or the western plains are conserved in national parks or nature reserves (Benson 1991), with only 3% reserved in the north-western sector (Pickard & Norris 1994). Recent analysis by the NP&WS has shown that only 0.83% of the Darling Riverine Plains Bioregion are currently conserved. Of all the vulnerable plants in New South Wales, 44% occur on the western slopes and plains (Benson 1989, Benson 1991). It has been estimated that up to 95% of the original native vegetation has been changed by cropping or pasture improvement in the Murray Darling Basin (Sivertsen & Metcalfe 1995).

Two species currently listed on the *NSW Threatened Species Conservation Act 1995* were found within the reserve and eleven others where thought regionally significant. The herb *Lepidium monoplocoides* (family Brassicaceae) found within Mixed Stand Woodlands is listed as endangered (TSC Act) and ROTAP (3ECi), and is known from semi-arid regions of New South Wales, Victoria and possibly South Australia. The herb *Goodenia macbarronii* (family Goodeniaceae) also found within Mixed Low Woodlands is listed as vulnerable (TSC Act) and ROTAP (3VC-) and found from the Darling Downs in Queensland to northeastern Victoria on the tablelands and slopes. Eleven other significant species are of conservation significance as they are disjunct or thought to be at or near their geographic limit. These species add to the overall importance of Narran Lake NR. These taxa are: *Anacampseros australiana, Glossostigma diandrum, Kennedia procurrens, Myriophyllum striatum, Nymphoides geminata, Pluchea dentex, Rorippa eustylis, Trachymene ochracea, Velleia arguta* and *Zaleya galericulata* subsp. *australis*.

Conclusion

Seven distinct vegetation communities have been identified within Narran Lake Nature Reserve, a number of which are noted for their restricted occurrence and poorly conserved nature. Drainage or time and duration of inundation are the major environmental correlates associated with the delineation of communities. A number of species are significant regionally and two are significant nationally. The park is of regional and national significance but is threatened by impacts of reduced water flows to the wetlands as a result of diversion for irrigation.

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Appendix: Flora of Narran Lake Nature Reserve.

Nomenclature follows that of Harden (1990–1993) except where recent changes have occurred. Taxa found within the survey sites are scored according to their occurrence in each of the 7 communities defined. Some taxa were found in previous surveys or opportunistically and therefore are not assigned to a specific community. 1 = Mixed Low Woodlands, 2 = Mulga Low Woodlands, 3 = Triodia Hummock Grasslands, 4 = Chenopod Low Open Shrublands, 5 = Ephemeral Herbfields, 6 = Riparian Open Forests, 7 = Lignum Shrubby Thickets.

FERNS AND ALLIES

Azollaceae

Azolla filiculoides var. *rubra*

Isoetaceae

Isoetes drummondii

Marsileaceae

Marsilea costulifera 6, 7
Marsilea drummondii 7

Salviniaceae

**Salvinia molesta*

Sinopteridaceae

Cheilanthes distans 1
Cheilanthes sieberi subsp. *sieberi* 1, 2, 3

GYMNOSPERMS

Cupressaceae

Callitris glaucophylla 1, 3

MONOCOTYLEDONS

Alismataceae

Damasonium minus

Amaryllidaceae

Crinum flaccidum 6

Anthericaceae

Anthropodium minus 1, 3
Thysanotus tuberosus subsp. *tuberosus*

Asphodelaceae

Bulbine semibarbata 1, 2, 3, 4, 6, 7

Centrolepidaceae

Centrolepis strigosa

Commelinaceae

Commelina cyanea 1

Cyperaceae

Bulbostylis barbata 1, 3
Cyperus bifax 7
Cyperus difformis 7
**Cyperus eragrostis* 6
Cyperus flaccidus 1, 7
Cyperus gymnocaulos 7
Cyperus squarrosus
Eleocharis pallens
Eleocharis plana 6, 7
Eleocharis pusilla 6, 7
Fimbristylis dichotoma 1, 2, 3, 5
Fimbristylis velata
Isolepis victoriensis
Schoenoplectus dissachanthus

Hydrocharitaceae

Ottelia ovalifolia

Juncaceae

Juncus flavidus 7

Lemnaceae

Lemma disperma 7

Phormiaceae

Dianella longifolia var. *porracea* 1, 6

Poaceae

Agrostis avenacea var. *avenacea* 1, 2, 4, 6, 7
Aira cupaniana 1, 5, 6
Amphibromus neesii
Amphipogon caricinus var. *caricinus* 1
Aristida jerichoensis subsp. *subspinulifera* 1
Astrebla elymoides
Astrebla lappacea
Astrebla pectinata
Astrebla squarrosa
Austrostipa scabra subsp. *scabra* 1, 3
**Bromus cartharticus*
**Cenchrus ciliaris* 1
Chloris truncata 1, 4
Cynodon dactylon 7
Dactyloctenium radulans
Dichanthium sericeum subsp. *sericeum*
Digitaria ammophila 1

Diplachne fusca	
Enteropogon acicularis	1
Eragrostis dielsii	4
Eragrostis eriopoda	
Eragrostis lacunaria	1
Eragrostis laniflora	1, 3
Eragrostis parviflora	5
Eragrostis setifolia	
**Festuca pratensis*	5
Homopholis proluta	
**Hordeum leporinum*	
Monachather paradoxa	1
Neurachne munroi	
Panicum decompositum	
**Panicum miliacem*	
Paspalidium jubiflorum	4, 7
Perotus rara	
Phragmites australis	7
Sporobolus actinocladus	4
Sporobolus caroli	1
Themeda triandra	1
Thyridolepis mitchelliana	1, 2
Thyridolepis xerophila	1
Tragus australianus	1
Triodia mitchellii	1, 3
Tripogon loliiformis	1, 2, 3, 4, 5
Triraphis mollis	2
Urochloa gilesii	

DICOTYLEDONS

Acanthaceae

Brunoniella australis	1, 2
Rostellularia adscendens subsp. *adscendens* var. *pogonanthera*	1

Aizoaceae

Mollugo cerviana	
Tetragonia tetragonoides	
Trianthaema triquetra	
Zaleya galericulata	

Amaranthaceae

Alternanthera angustifolia	7
Alternanthera denticulata	1
**Alternanthera pungens*	
Ptilotus obovatus var. *obovatus*	1, 2
Ptilotus polystachyus var. *polystachyus*	1, 2, 3

Anacardiaceae

**Schinus areira*	

Apiaceae

Actinotus paddisonsii	1, 2, 3
Daucus glochidiatus form C	1, 2, 4, 5
Trachymene ochracea	1, 2

Apocynaceae

Alstonia constricta	1, 3
Parsonsia eucalyptophylla	1
Parsonsia lanceolata	

Asclepiadaceae

Marsdenia australis	

Asteraceae

Actinobole uliginosum	1, 5
Angianthus brachypappus	1, 2, 3
Brachyscome basaltica var. *gracilis*	
Brachyscome ciliaris var. *ciliaris*	4, 5, 6
Brachyscome goniocarpa	3
Brachyscome gracilis	
Brachyscome heterodonta var. *heterodonta*	
Brachyscome sp. A	
Brachyscome sp. B	
Bracteantha bracteata	2
Calocephalus sonderi	1
Calotis cuneifolia	1, 2, 3
Calotis lappulacea	1, 2
Calotis scapigera	6, 7
**Centaurea solstitialis*	1
Centipeda cunninghamii	1, 4, 6, 7
Centipeda minima var. *minima*	1, 4
Centipeda thespidioides	
Chrysocephalum apiculatum	1, 3
Chrysocephalum semipapposum	
Chthonocephalus pseudovax	1, 3, 5
**Conyza albida*	1, 7
**Conyza bonariensis*	
Eclipta platyglossa	
Eriochlamys sp. A	1, 3, 4, 5
Euchiton sphaericus	1, 6
Glossogyne tannensis	1
**Hedypnois rhagadioloides* subsp. *cretica*	
**Hypochaeris glabra*	1, 2, 3, 5
Ixiolaena brevicompta	4, 6, 7
**Lactuca serriola*	2, 7
Lemooria burkittii	
Millotia greevesii subsp. *greevesii* var. *glandulosa*	1, 3, 5
Minuria integerrima	6
Pluchea dentex	4, 5, 6

Podolepis jaceoides	1, 3, 4, 5, 6, 7
Podolepis longipedata	
Psuedognaphalium luteoalbum	1
Pycnosorus chrysanthes	
Rhodanthe floribunda	1, 4
Rhodanthe moschata	1, 2, 3
Senecio quadridentatus	2, 3
Senecio runcinifolius	1, 2, 7
**Sigesbeckia orientalis* subsp. *orientalis*	1
**Soliva anthemifolia*	
**Sonchus oleraceus*	1
Stuartina muelleri	1, 2
**Verbesina encelioides* subsp. *encelioides*	1, 3
Vittadinia cervicularis var. *cervicularis*	3
Vittadinia pustulata	3
Vittadinia sulcata	1, 2
**Xanthium italicum*	
**Xanthium occidentale*	
**Xanthium spinosum*	1, 2

Boraginaceae

Cynoglossum australe var. *australe*	1, 3
**Heliotropium supinum*	

Brassicaceae

Harmsiodoxa brevipes var. *major*	1, 3
**Lepidium bonariense*	1
Lepidium monoplocoides	5
Lepidium pseudohyssopifolium	7
Lepidium sagittulatum	5
Rorippa eustylis	7

Cactaceae

**Opuntia stricta*	1

Campanulaceae

Wahlenbergia fluminalis	1, 4, 5, 6
Wahlenbergia graniticola	1
Wahlenbergia stricta subsp. *alterna*	1, 2, 3

Capparaceae

Apophyllum anomalum	
Capparis lasiantha	
Capparis mitchellii	

Caryophyllaceae

Gypsophila tubulosa	1, 3, 4
Polycarpaea corymbosa var. *minor*	1
**Spergula arvensis*	1, 7
**Spergularia diandra*	
Spergularia rubra	7
Stellaria angustifolia	1, 4, 6, 7

Chenopodiaceae

Atriplex holocarpa	4, 5
Atriplex nummularia	4
Atriplex vesicaria subsp. *macrocystidia*	7
Chenopodium auricomum	
Chenopodium curvispicatum	1, 3, 6
Chenopodium desertorum subsp. *desertorum*	4
Chenopodium melanocarpum	1, 3
Dissocarpus paradoxus	1
Einadia nutans subsp. *eremaea*	1, 3, 6
Einadia nutans subsp. *linifolia*	6
Einadia nutans subsp. *nutans*	6
Enchylaena tomentosa	
Halosarcia pergranulata	4
Maireana appressa	1, 5
Maireana coronata	1
Malacocera albolanata	
Neobassia proceriflora	5
Osteocarpum dipterocarpum	4, 5
Salsola kali var. *kali*	1
Sclerolaena bicornis var. *bicornis*	1, 2, 5
Sclerolaena birchii	1, 3, 6
Sclerolaena convexula	1, 4, 7
Sclerolaena decurrens	4
Sclerolaena diacantha	
Sclerolaena divericata	6
Sclerolaena parallelicuspis	3, 4, 5, 6

Clusiaceae

Hypericum gramineum	1, 4, 6, 7

Convolvulaceae

Convolvulus erubescens	1, 2, 5
**Cuscuta campestris*	
Evolvulus alsinoides var. *decumbens*	1
**Ipomoea hederifolia*	

Crassulaceae

Crassula helmsii	
Crassula sieberiana	1, 3, 4, 5

Cucurbitaceae

**Citrullus lanatus*	

Droseraceae

Drosera peltata	3

Elantinaceae
Elatine gratioloides

Euphorbiaceae
Chamaesyce drummondii 1, 2, 3
Phyllanthus virgatus 1
Poranthera microphylla 3

Fabaceae
Acacia acuminata subsp. *birkittii* 1
Acacia aneura 1, 2
Acacia brachystachya 1, 6
Acacia cambagei
Acacia caroleae
Acacia deanei subsp. *deanei* 1
Acacia excelsa 1
Acacia ligulata
Acacia murrayana 3
Acacia omalophylla 1
Acacia oswaldii 1
Acacia pendula 1, 6
Acacia stenophylla 7
Aeschynomone indica 7
**Astragalus hamosus*
Glycine canescens 1, 3
Glycine clandestina 3
Kennedia procurrens 1, 3
Muelleranthus denticulatus 3
Senna artemisioides nothosubsp. *artemisioides*
Swainsona swainsonioides 1
Tephrosia sphaerospora 1, 3, 5
**Vicia sativa* subsp. *sativa*

Gentianaceae
Centaurium spicatum 1, 4, 5

Geraniaceae
**Erodium cygnorum* subsp. *glandulosum* 1, 2

Goodeniaceae
Brunonia australis 1, 2, 3
Goodenia delicata 6
Goodenia glauca 7
Goodenia gracilis
Goodenia hederacea subsp. *hederacea* 1, 2
Goodenia macbarroni 1, 2
Velleia arguta 1, 2

Haloragaceae
Haloragis aspera 7
Haloragis glauca 6, 7
Myriophyllum striatum
Myriophyllum verrucosum 7

Lamiaceae
Ajuga australis 1
Lycopus australis 7
Teucrium racemosum 1

Lobeliaceae
Pratia concolor 6
Pratia darlingensis

Loranthaceae
Amyema miquelii
Amyema pendula subsp. *longifolium*
Dendrophthoe glabrescens
Lysiana exocarpi

Malvaceae
Abutilon fraseri 1
Abutilon leucopetalum 1, 2, 7
Hibiscus sturtii var. *sturtii* 1, 2
Sida ammophila 1
Sida cunninghamii 1, 2
Sida sp. A 1, 4

Meliaceae
Owenia acidula 1

Menyanthaceae
Nymphoides crenata 7
Nymphoides geminata 7

Myoporaceae
Eremophila bignoniiflora 1, 6
Eremophila longifolia 1
Eremophila maculata
Eremophila mitchellii 1, 5
Myoporum montanum

Myrtaceae
Angophora melanoxylon 3
Eucalyptus camaldulensis 6, 7
Eucalyptus coolabah 6
Eucalyptus largiflorens 6
Eucalyptus melanophloia 1, 3
Eucalyptus populnea subsp. *bimbil* 1, 3

Nyctaginaceae
Boerhavia dominii 1
Boerhavia repleta 1

Oleaceae

Jasminum lineare	1

Onagraceae

Ludwigia peploides subsp. *montevidensis*	7
**Oenothera mollissima*	1, 3, 4

Oxalidaceae

Oxalis chnoodes	1, 2, 3, 6, 7
Oxalis perennans	1

Pittosporaceae

Pittosporum phylliraeoides	1

Plantaginaceae

Plantago varia	1, 2, 4, 6

Polygonaceae

Muehlenbeckia florulenta	1, 6, 7
Persicaria prostrata	7
Rumex stenoglottis	
Rumex tenax	

Portulacaceae

Anacampseros australiana	
Calandrinia balonensis	1, 2, 3
Calandrinia eremaea	1, 2, 3, 4
Calandrinia ptychosperma	
Calandrinia pumila	5
Portulaca filifolia	4
Portulaca oleracea	1, 4, 6, 7

Primulaceae

**Anagallis arvensis*	

Proteaceae

Grevillea striata	1
Hakea leucoptera	1

Rhamnaceae

Ventilago viminalis	1

Rubiaceae

Canthium oleifolium	1
Synaptantha tillaeacea	1

Rutaceae

Eremocitrus glauca	
Flindersia maculosa	1
Geijera parviflora	1, 3, 6

Santalaceae

Exocarpos cupressiformis	1
Santalum lanceolatum	1

Sapindaceae

Alectryon oleifolius	
Atalaya hemiglauca	1
Dodonaea viscosa var. *angustissima*	1, 3, 5

Scrophulariaceae

Gratiola pedunculata	
Glossostigma diandrum	1
Limosella australis	7

Solanaceae

**Lycium ferocissimum*	
Nicotiana simulans	1, 3
Solanum cleistogamum	1
Solanum esuriale	
Solanum ferocissimum	1, 3
Solanum nigrum	
Solanum stuartianum	1

Sterculiaceae

Brachychiton populneus subsp. *trilobus*	
Melhania oblongifolia	1

Thymelaeaceae

Pimelea microcephala subsp. *microcephala*	1
Pimelea trichostachya	1, 2, 3, 5

Verbenaceae

**Phyla nodiflora*	6, 7
**Verbena officinalis*	6

Violaceae

Hybanthus monopetalus	3

An assessment of the conservation status of *Senecio garlandii*, in the Central and South Western Slopes, New South Wales

G.E. Burrows

Burrows, G.E. (Johnstone Centre, Charles Sturt University, PO Box 588, Wagga Wagga 2678, email: gburrows@csu.edu.au*) 2001. An assessment of the conservation status of* Senecio garlandii, *in the Central and South Western Slopes, New South Wales.* Cunninghamia *7(1): 65–76.*

Senecio garlandii F. Muell. ex Belcher (Asteraceae) is a perennial subshrub found mainly on rocky outcrops in the South Western Slopes, New South Wales. It is listed as vulnerable in state, national and international listings. An assessment of its conservation status found i) *Senecio garlandii* has been recorded from about ten localities, ii) it has a relatively large (225 km) north to south distribution from Temora, NSW to Chiltern, Vic., iii) most populations were either within the reserve system (Ulandra, The Rock, Table Top Nature Reserves) or in areas managed for conservation, iv) large populations (> 30 000 individuals) were recorded at The Rock and Table Top Nature Reserves, v) the species appeared capable of regenerating in both the absence and presence of fire, and vi) the populations did not appear to be under direct threat.

However, the known localities were highly disjunct and only three localities had substantiated recordings of large populations, while others had very small populations (e.g. < 200 individuals at Ulandra Nature Reserve). In addition, the species was largely restricted to rocky outcrops and on these it was generally restricted to the upper parts of the east- to south-facing talus slopes, often immediately below cliff lines (a small area of occupancy). Application of the IUCN red list criteria would indicate that *Senecio garlandii* should not be classified as vulnerable. Monitoring is needed to determine whether the populations are in decline or otherwise.

Introduction

Senecio garlandii F. Muell. ex Belcher (Asteraceae, common name Woolly Ragwort) is a perennial subshrub that grows to 1–2 m in height. It is a distinctive plant in the field, even when not flowering, with large (3–9 cm wide × 8–15 cm long) stem-clasping leaves that are dark glossy green on the upper surface, while the lower surface and the stems are densely covered in white, woolly hairs (Belcher 1986, Burrows 2001). Lawrence (1985) and Burrows (1995) provide information relevant to its biology and regeneration, while Ali (1968) and Radford and Cousens (2000) do likewise for *Senecio lautus*, another native, perennial, self-incompatible species of *Senecio* (Lawrence 1985).

A biogeographical analysis of the threatened flora of NSW has recently been published (Mokany & Adam 2000), with the South Western Slopes (SWS) containing significantly fewer threatened species than expected. Twenty-two threatened (endangered or vulnerable), rare or poorly known plant species have been identified in the Rare or Threatened Australian Plant (ROTAP) listings for the SWS of NSW (Briggs & Leigh 1996, Burrows 1998). Of these 22 species, four are considered endangered, ten vulnerable, three rare and five poorly known. Six of the 22 species are considered extinct in the SWS and only *Pterostylis petrosa* (recorded at The Rock Nature Reserve) and *Senecio garlandii* (recorded at The Rock, Table Top and Ulandra Nature Reserves) are conserved in the region (Briggs & Leigh 1996).

Senecio garlandii is listed as vulnerable in the *NSW Threatened Species Conservation Act 1995* (TSCA), the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBCA), the ROTAP listings (Briggs & Leigh 1996) and in the *IUCN red list of threatened plants* (Walter & Gillett 1998). Briggs and Leigh (1996) recorded its risk code as 3VC-, meaning the species has a geographic range of greater than 100 km, is classified as vulnerable, and has at least one population within a conservation reserve but the population size of the reserved population is not known. They record the population at The Rock Nature Reserve as less than 1000 plants, and population sizes at Table Top and Ulandra Nature Reserves as unknown. The aim of this study was to document the distribution, abundance and conservation status of *Senecio garlandii*, probably the most conspicuous and well known threatened plant species in the South Western Slopes.

Table 1. The 10 localities, arranged from north to south, where *Senecio garlandii* has been recorded or observed (NR, Nature Reserve; SF, State Forest; SRA, State Recreation Area).

	Locality	Additional locality information
1	Gidginbung/Trungley Hall	20 km N of Temora
2	Ulandra NR	7 km SE of Bethungra
3	Burrinjuck	in the vicinity of Burrinjuck NR and SRA
4	The Rock NR/Flowerpot Hill	4 km W of The Rock
5	Gregadoo Hills/Big Springs/Livingstone SF	10–30 km S of Wagga Wagga
6	Holbrook	50 km NE of Albury
7	Benambra SF	20 km WSW of Holbrook
8	Table Top NR	7 km ESE of Gerogery
9	Nail Can Range	5 km NW of Albury
10	Chiltern Regional Park	35 km WSW of Albury

Previous records

Senecio garlandii has been recorded from 10 localities in Australia — eight in the South Western Slopes of NSW, one in the Central Western Slopes and one in Victoria (Table 1, Fig. 1). Notes on these records are as follows:

1) The Gidginbung record is based on a herbarium specimen collected in 1975 (NSW 153245, Schlunke 1975, 34°19'S, 147°28'E). *Senecio garlandii* had also been reported as occurring in the Trungley Hall area, 8 km NE of Gidginbung.

2) The Ulandra NR (34°49'S, 147°54'E) record is based on a 1992 collection by Levett (Burrows 1999).

3) The Burrinjuck record is based on a National Herbarium of NSW specimen collected in 1912 (NSW 457440, Cheel 1912, 35°00'S, 148°36'E).

4) While most records are based on a single herbarium collection, The Rock NR (35°16'S, 147°04'E) is represented by 26 herbarium sheets at the National Herbarium of NSW, and the Melbourne and Canberra herbaria. Whiting (1997) includes a map and description of *Senecio garlandii* distribution and abundance at The Rock NR. *Senecio garlandii* has also been recorded from Flowerpot Hill, 4 km SE of The Rock NR (NSW 279856, Burrows 1992, 35°16'S, 147°07'E).

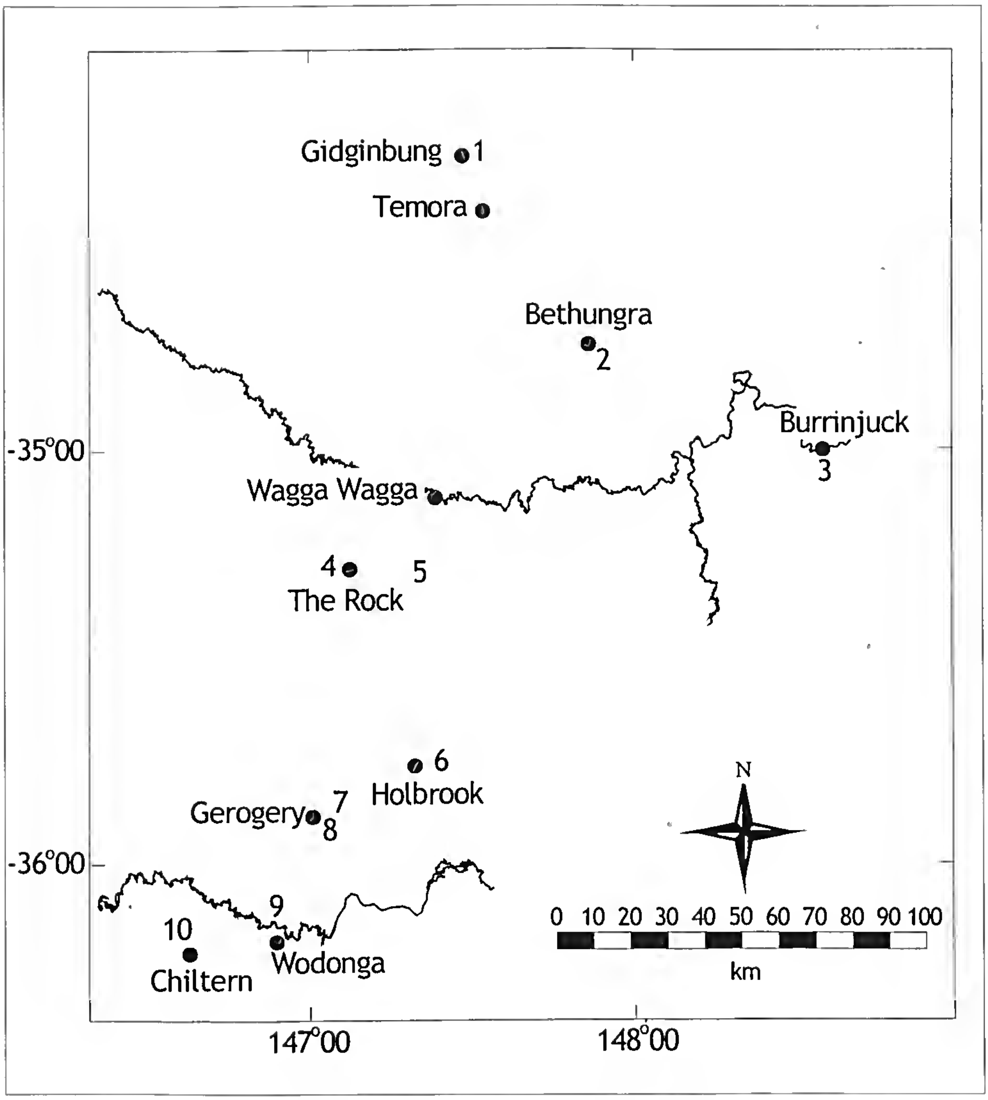

Fig. 1. Map of the 10 recorded localities of *Senecio garlandii*, numbered as in Table 1.

5) The Gregadoo Hills/Big Springs/Livingstone SF records are based on a herbarium record (MEL, Wilson 1971, 35°21'S, 147°21'E) for 'Big Springs', and recently reported recordings on private property on the western side of Livingstone SF and in the Gregadoo Hills.

6) The Holbrook record is based on a herbarium collection (NSW 117786, Skyes 1975, 36°06'S, 146°54'E).

7) Benambra SF (35°48'S, 147°05'E) is based on surveys of Johnston (1978, unpublished species list) and Marshall in 1994 (Burrows 1999).

8) Table Top is based on two Melbourne herbarium collections (Willis 1969, 35°49'S, 147°00'E), and the recordings of Johnston (1978, unpublished species list) and Marshall in 1992 (35°52'S, 147°04'E) (Burrows 1999).

9) Nail Can Range (36°03'S, 146°53'E) is based on recent sightings of a small scattered population (< 1000 individuals) on both private and public lands (Ian Davidson, pers. comm.).

10) Chiltern Regional Park is based on a single plant (Melbourne, Collins 1996, 36°09'S, 146°39'E). This plant has since died (Eileen Collins, pers. comm.).

Survey methods

As noted *Senecio garlandii* is a large subshrub that is conspicuous for most of the year, especially during spring and early summer. Likewise seedlings, even when only 1–2 cm high, are distinctive because of the whitish stems and leaves. Thus, traverses, walked by a pair of people, were used to obtain a rapid and accurate recording of distribution and abundance. The species has an apparent habitat preference for the upper parts of south- to east-facing slopes of rocky outcrops in the SWS (Burrows 1995, 1999) and these were targeted when investigating distribution. A quadrat-based assessment was conducted at The Rock NR (see 4 below) and the results were used to estimate population sizes at all sites. During September to October 1999 survey work was carried out in five of the ten known localities. Botanical names follow Harden (1990–1993).

Survey results

A summary of the survey results is provided in Table 2. Maps of *Senecio garlandii* distribution at Trungley Hall, Ulandra, The Rock and Table Top localities have been prepared and lodged with the NSW NP&WS, Threatened Species Unit, Queanbeyan. Results will also be available through the Atlas of NSW Wildlife database.

Table 2. *Senecio garlandii* population estimates for surveyed sites. NR: Nature Reserve, n.l.: not located.

Locality	Latitude/Longitude	Population estimate
Trungley Hall:		
Government Hill	34°19'S 147°35'E	several hundred
Private property	-	> 10 000
Boginderra NR	34°16'S 147°38'E	n.l.
Ulandra NR:		
SE side of Mt Ulandra	34°49'S 147°54'E	< 200
Merrybundinah Creek	as above	n.l.
The Rock:		
The Rock NR	35°16'S 147°04'E	> 30 000
Little Rock	35°19'S 147°03'E	200
Flowerpot Hill	35°18'S 147°06'E	n.l.
Holbrook:		
Morgan's Ridge	35°43'S 147°24'E	n.l.
Table Top:		
Table Top NR	35°53'S–147°03'E	> 30 000
Pulpit Rock	as above	4000
Bimbadeen Point	as above	1–2000
Table Top Mt.	as above	5000
TOTAL		c. 81 000

1) Gidginbung/Trungley Hall

The herbarium specimen grid reference for Gidginbung places the location at the Gidginbung trig point, a low wooded rise. The lower slopes of this area were being used for the storage of gold mining waste and the area was not surveyed. The herbarium specimen label also mentions 'Big Bush'. The Big Bush NR is about 6 km south of the trig point but was not surveyed. A single plant of *Senecio garlandii* had been recorded on the property 'Carolees' (2 km E of Trungley Hall) and additional survey work was carried out in the Government Hill area. At Boginderra Hill NR in the Nurraburra Hills (6 km E of Trungley Hall), a loop was traversed around the Nurraburra trig point, concentrating on rocky east-facing slopes.

After relocating the single known *Senecio garlandii* on the eastern side of Government Hill, no additional specimens were found on the slopes and rock outcrops to the south. To the north several hundred plants, both adults and seedlings, were found over 100–200 m in amongst the boulders and rocky outcrops on the east-facing slope. Overstorey trees were *Eucalyptus macrorhyncha*, *Acacia doratoxylon* and *Brachychiton populneus*. In a nearby area (the location of which is confidential) *Senecio garlandii* grew as the dominant (more than 10 000 plants present) shrub species in a 500 m long × 50–100 m wide strip along the upper slopes of the western side of a rocky ridge. *Senecio garlandii* was not observed at Boginderra Hill NR, although some steep, rocky, east-facing slopes were traversed.

2) Burrinjuck

Not surveyed.

3) Ulandra Nature Reserve (3934 ha)

The slopes and ridges around Mt Ulandra were surveyed and the previously recorded population was located on the northern side of a gully on the SE side of Mt Ulandra, at approximately 600 m elevation. The population was small (less than 200 plants) with most plants immediately below some of the largest boulders in the area, while the remaining plants were scattered 100 m down from this point on the sides of the gully. The east-facing slope above Merrybundinah Creek, about 1 km west of the above population, was also surveyed but no *Senecio garlandii* plants were found, even though this area had almost identical slope, aspect, soil moisture, overstorey and understorey species and rock formations. During 1992 and 1993 more than 20 extensive flora survey trips were conducted in Ulandra NR (Burrows 1999) and only the population mentioned above was found. It is probable that this is the only population of *Senecio garlandii* in Ulandra NR.

4a) The Rock Nature Reserve (341 ha)

A transect consisting of six 10 × 10 m quadrats, spaced at 30 m intervals, was run down the east-facing slope below the main cliff face. This was replicated three times, with 10 m between each transect, and the number of *Senecio garlandii* plants per quadrat was counted. During October 1999 most of The Rock NR was covered in a number of traverses. Little Rock Hill (35°19'S, 147°03'E), 4.5 km south of The Rock NR, and Flowerpot Hill (35°18'S, 147°06'E) 4 km SE of The Rock NR were also traversed.

The quadrat survey indicated that at high densities of adult plants (greater than 75% foliage projective cover) there were about 3300 *Senecio garlandii* plants/ha and correspondingly fewer in less dense populations. A maximum of 52 adult plants was recorded in two quadrats, which would be equivalent to 5200 plants/ha. The Rock NR is based around a narrow north-south orientated ridge, the highest point of which is 554 m and about 340 m above the surrounding plains (NSW NPWS 2000). The main features of *Senecio garlandii* distribution and abundance were:

i) on the eastern side of the ridge essentially no plants occurred below 300 m and very few (mainly directly below the main cliff face) were present below 370 m, hence *Senecio garlandii* did not occur over a large proportion of the reserve and was mainly restricted to the upper areas.

ii) the main population was present in a narrow (50–100 m wide) band at the base of the east-facing cliffs, which extend for about 1.7 km within the Reserve. More than 30 000 plants were estimated to occur and in the main population areas *Senecio garlandii* was the dominant shrub and the dominant feature of the vegetation.

iii) the western side of The Rock NR is predominantly steeply sloped, with rocky outcrops, and scattered plants were present over much of the northern half of this area. Few plants were observed in the southern extension of the reserve, while some dense populations were present on the slope to the SW of the main peak and in the gully leading NW from the main peak.

iv) small numbers of plants were growing on private property to the east and south of the southern extension, to the west of the main peak and near the NW corner.

In summary, a large number of plants were estimated to be present (more than 30 000) but they occupied a relatively small area (less than 50 ha) of a small (341 ha) reserve.

4b) Little Rock Hill

This area was a miniaturised version of The Rock NR, in terms of topography and *Senecio garlandii* distribution. A small population (less than 200 plants) grew on the SE side, below a cliff face. This area was private property, managed for its conservation values, and the *Senecio garlandii* population, although small and isolated, did not appear to be under direct threat.

4c) Flowerpot Hill

A population of less than 50 plants, growing under an overstorey of *Eucalyptus macrorhyncha* on a gentle slope, with few large rock outcrops, was recorded here in 1992 (Burrows 1999). During the 1999 survey this population was not relocated, nor were any new populations found, though it is considered that the site of the previous recorded population was not relocated, not that it had become extinct.

5) Gregadoo/Big Springs/Livingstone State Forest

No surveys were carried out in this area. The recordings to date are on private property in the vicinity of Livingstone SF, a relatively large and undisturbed area with a high diversity of native plant species (Burrows 1999). Livingstone SF could be expected to be a likely area of occurrence for *Senecio garlandii* but it has not been found in 10 previous survey trips (Burrows 1999).

6) Holbrook

The location of NSW 117786 is given as 'Holbrook, near Albury' but the grid reference (36°06'S, 146°54'E) places the location on the Murray River floodplain, between Albury and Wodonga. Assuming that the grid reference was incorrect the closest suitable *Senecio garlandii* habitat to Holbrook is Morgan's Ridge and the Cromer Hills, 7 km to the east. Several steep east- to south east-facing slopes with large exposed boulders and an overstorey of *Eucalyptus macrorhyncha*, centred on 35°43'S, 147°24'E, were traversed but no *Senecio garlandii* plants were found. No plants were found in a brief inspection of Woomargama SF, 20 km to the south.

7) Benambra State Forest

No surveys additional to Burrows (1999) were conducted. In 1994 and 1995 *Senecio garlandii* was recorded from the area of steep, east-facing slopes in the narrow southern extension (Burrows 1999 and unpublished data). Only 6 km of relatively uncleared land separates Benambra SF from Table Top NR and there may be populations that link the two areas, but few, steeply sloping, south- to east-facing slopes are present in the intervening distance.

8) Table Top Nature Reserve (103 ha) and Table Top Mountain Retreat

Table Top Nature Reserve and the ridgeline that extends south into 'Table Top Mountain Retreat' were surveyed. The topography of this area is unusual for the SWS in that several narrow east-west ridges extend west from the main north-south Table Top Ridge. Cliff lines are present on both the northern and southern sides of these smaller ridges and there are relatively extensive south-facing slopes that are shaded for much of the year. *Senecio garlandii* had an absolute habitat preference for the upper parts of these south-facing talus slopes and the cliffs above them.

Senecio garlandii was the dominant shrub on the main south-facing slope of Table Top NR extending in a band 1.2 km east-west and 100–150 m wide down from the base of the cliff line. While plants on an east-facing slope at The Rock NR were in full flower in mid-October and some individuals were releasing seed, in mid-November these heavily shaded plants at Table Top NR were only in bud. At an estimated average density of 2000 plants/ha, over an area of 12 ha, a population of 24 000 plants was present. In addition, several thousand more plants were present on the cliff face, growing on the many narrow ledges. *Senecio garlandii* was restricted to the cliff face and the upper part of the slopes, at the base of the cliffs. On the small, relatively flat ridge top and the northern and western slopes and cliffs the species was absent.

On the southern side of Pulpit Rock (Table Top Mountain Retreat) several thousand plants were present in a 50 m wide band at the base of the cliff line but no plants were present on the north-facing slope of Pulpit Rock. A further 1–2000 plants were present along the southern side of the ridge leading west from Bimbadeen Point. Some large plants were growing in the drainage line at the base of the slope, but not on the north-facing slope above the drainage line. This distribution pattern was repeated on the southern side of Table Top Mountain (i.e. the 2 km of east-west cliff line to the north of Yambla Basin). Several thousand plants were present, many growing on ledges in the cliff face, but the majority present in a narrow band at the top of the slope, at the base of the cliffs. Near the eastern end of the ridge several large, dense groups of plants were present several hundred metres down a gully. The overstorey was mainly *Eucalyptus macrorhyncha*, *Eucalyptus goniocalyx* and *Acacia implexa*. Few understorey shrubs were present apart from *Bracteantha viscosa*, *Senecio quadridentatus* and *Senecio garlandii* and the groundlayer of this part of the property was dominated by introduced pasture plants and occasionally grazed by cattle. No *Senecio garlandii* plants, including those away from the cliff line, showed any evidence of grazing.

9) Nail Can Range

Not surveyed.

10) Chiltern Regional Park

Not surveyed.

Discussion

The main feature of the distribution and abundance of *Senecio garlandii* was its restricted area of occupancy, coupled with its dominance of the shrub layer in most of those areas where it occurred; i.e. the species was abundant, but only in its small area of occupancy.

Senecio garlandii has been recorded at ten localities, from around Trungley Hall in the north to Chiltern Regional Park in the south, a distance of about 225 km, though its east to west range was much smaller. Belcher (1986) recorded its distribution as 'Very local along the 147°E. meridian …', but it is more of a gentle curve, roughly parallel to the Great Dividing Range. It is very much a species of the western slopes and, more specifically, the mid regions of these slopes.

Senecio garlandii was generally restricted to the upper slopes of the steeper and more rugged ranges and, with some exceptions, it was more abundant on the more mesic east- to south-facing slopes. From the relatively undisturbed populations at The Rock, Table Top and Ulandra Nature Reserves it can be assumed that this is the species' natural habitat, not an artefact of clearing, stock grazing or other human influence. This distribution has been to its conservation advantage in the extensively and intensively disturbed SWS (Burrows 1999).

Senecio garlandii shows little soil specificity and grows on soils that probably have a low nutrient content, especially phosphorus, and minimal organic matter. At Ulandra NR, The Rock NR and in the Table Top region *Senecio garlandii* grows on soils derived from Palaeozoic granites (NSW NPWS 1992), Ordovician metasediments/quartzites (NSW NPWS 2000) and conglomerates (pers. obs.), respectively.

For a species with relatively large and mesophytic leaves (Burrows 1995, 2001) the foliage showed little evidence of damage by herbivores. Most sites had a small number of leaves with minimal insect damage, while at Table Top NR and Table Top Mountain Retreat the leaves were untouched by feral goats and cattle, respectively.

Populations consisted mainly of mature plants, but a small number of seedlings and juvenile plants were present at most sites, though not at the densities recorded at The Rock NR after the 1991 fire (Burrows 1995). It has been suggested that plants could be relatively long-lived, going through repeated cycles of dying back at the end of summer/autumn, then resprouting from the base each winter/spring (Burrows 1995). Monitoring is needed to determine what percentage of the seedlings mature into adults and if populations are stable or otherwise.

This study has provided population estimates for Ulandra and Table Top Nature Reserves, areas for which estimates were not previously available (Briggs & Leigh 1996). The study has also provided a much larger population estimate for The Rock NR than previously recorded (Briggs & Leigh 1996). Whiting (1997) recorded 3–4000 *Senecio garlandii* plants at The Rock NR but conducted the survey during a particularly dry autumn.

Various definitions of 'vulnerable' are employed by different conservation agencies and in various pieces of legislation. The definition given in the NSW TSC Act (which is similar to that in the Commonwealth's EPBC Act), states 'A species is eligible to be listed as a vulnerable species if, in the opinion of the Scientific Committee, the species is likely to become endangered unless the circumstances and factors threatening its survival or evolutionary development cease to operate.' In *Rare or threatened Australian plants* (Briggs & Leigh 1996) the definition of vulnerable emphasises threats, population levels in conservation reserves (usually less than 200 individuals for trees and shrubs) and risk due to specific biological or ecological factors. In the 1997 *IUCN red list list of threatened plants* (Walter & Gillett 1998) five criteria (decision rules) are given regarding a vulnerable listing. These criteria emphasise population reduction or fluctuation, small extent of occurrence or area of occupancy, fragmentation of populations, a small number of locations and small population size as reasons for a vulnerable listing. With regard to these criteria the following positive features are known about *Senecio garlandii*:

i) it has been recorded over a relatively large area,

ii) a relatively large total population has been recorded,

iii) the three largest populations are widely spaced and thus a catastrophic event would be unlikely to affect them all,

iv) previously unrecorded populations have been located in the last ten years and further surveys would probably continue to locate additional populations,

v) a relatively large proportion of the total population is within protected areas. Two large populations (The Rock and Table Top Nature Reserves) and one smaller population (Ulandra NR) are in conservation reserves, several populations are in an area managed for ecotourism (Table Top Mountain Retreat), Benambra SF is soon to be declared a Nature Reserve, while other populations are protected from stock (Little Rock Hill) or were being protected from stock (Trungley Hall),

vi) while further research is needed the species does not appear to need a specific fire regime to survive as there can be a large recruitment after fire (Burrows 1995) and there may be seedling establishment in its absence,

vii) the species does not appear to be favoured by herbivores such as insects, stock or feral animals, and

viii) none of the populations appear to be under direct threat, although the Gregadoo Hills population may eventually be affected by rural subdivision.

However, *Senecio garlandii* is known from only ten localities. The Burrinjuck recording dates from 1912, the Holbrook recording will be difficult to relocate, the Chiltern recording was based on a single plant, while the Ulandra NR and Nail Can Range populations were small. This leaves only three localities with large substantiated populations (Trungley Hall, The Rock NR, Table Top region) and two where further work is needed to record population sizes. Many of the populations are highly disjunct and given the species' relatively specific habitat requirements and the generally flat topography of the CWS and SWS intervening populations are unlikely to be present. As noted for The Rock NR, *Senecio garlandii* occupied a small proportion of a small reserve and the same was true at Table Top NR. In total *Senecio garlandii* probably does not occur on more than 100 ha in NSW. It is this acute restriction in the area of occupancy that, according to Rule D (and also referred to in Rules B and E) of the *IUCN red list of threatened plants* (Walter & Gillett 1998), is the main feature indicating that *Senecio garlandii* should retain a vulnerable listing. However, while the area of occupancy of *Senecio garlandii* is two orders of magnitude less than that suggested in Rule D, this rule is only applicable to species that may become Critically Endangered or Extinct in a very short period. This would not appear to be the case for *Senecio garlandii*. In addition, the average area of occupancy for 112 of the 135 rare or threatened vascular plant species from south-eastern Australia examined by Keith et al. (2000) was about 30 ha (David Keith, pers. comm.). Thus, while the area of occupancy of *Senecio garlandii* was small it was not particularly low for a threatened species.

Application of the IUCN criteria and the ROTAP guidelines would indicate that *Senecio garlandii* should not be classified as vulnerable. This would have little influence on the species' conservation as a large percentage of its total population is within conservation reserves, though the Gidginbung and Trungley Hall populations, as they lie outside the reserve system and are by far the most northerly (Fig. 1), may need special consideration as endangered populations.

One of the main considerations in listing a species as vulnerable is population decline. With no previous measurements of *Senecio garlandii* population size at any of the localities it is impossible to determine if population sizes have declined or otherwise. It is worth noting that *Senecio garlandii* has been recorded as 'very common' to 'abundant' at The Rock NR on various herbarium sheets from 1967 to 1992. Qualitative assessments (Burrows 1995, Whiting 1997) indicate that the *Senecio garlandii* population at The Rock NR increased markedly in number, but not extent, after the 1991 fire.

Conclusions

Senecio garlandii occurs discontinuously over 225 km from north to south. Most populations are either within the reserve system or in areas managed for conservation. Several large populations are known, seedling establishment would appear to occur in both the absence and presence of fire and the populations do not appear to be under immediate threat. However, there are only three known large populations and the populations are highly disjunct. The species has specific habitat preferences, a highly restricted distribution at each locality and a small area of occupancy. Application of the IUCN criteria would indicate that *Senecio garlandii* should not be classified as vulnerable, however monitoring is needed to determine if populations are in decline or otherwise.

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Notes on the distribution and conservation status of some restricted plant species from sandstone environments of the upper Hunter Valley, New South Wales

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As a consequence of vegetation survey carried out in sandstone environments of the upper Hunter Valley over recent years, a number of new populations of significant plant species have been recorded. The opportunity is taken here to document some of these finds, and also to suggest some revisions to the current conservation risk codes. Twenty-three species are discussed; *Acacia bulgaensis, Angophora euryphylla, Callitris rhomboidea, Banksia penicillata, Cynanchum elegans, Eucalyptus aenea, Eucalyptus dealbata, Eucalyptus fergusonii* subsp. *dorsiventralis, Eucalyptus nubila, Eucalyptus prominula, Gonocarpus longifolius, Grevillea johnsonii, Grevillea montana, Melaleuca groveana, Pomaderris bodalla, Pomaderris brunnea, Pomaderris precaria, Pomaderris queenslandica, Pomaderris reperta, Pomaderris sericea, Prostanthera cryptandroides* subsp. *cryptandroides, Prostanthera hindii,* and *Rulingia procumbens.* Voucher specimens have been lodged for new populations of all taxa (except some populations of *Cynanchum elegans*) at State herbaria.

Introduction

Over recent years, vegetation survey in sandstone environments of the upper Hunter Valley in central eastern New South Wales has resulted in several new records of significant taxa. In some cases, these new records allow for the revision of current conservation risk codes, while others extend the known range or reserve representation of certain species. All taxa are considered to be regionally significant in the Hunter Valley. This note briefly details these taxa in terms of the conservation codes applied through the Briggs and Leigh (1996) system. Similar notes have recently been published in regard to plant species in north-eastern New South Wales (Richards & Hunter 1997, Copeland & Hunter 1999). As with the earlier notes, publication of the current status of significant plants from specific regions is considered beneficial when management decisions require the most up-to-date distributional data available.

For all species detailed here (with the exception of some populations of *Cynanchum elegans*), voucher specimens have been lodged at the National Herbarium of NSW, National Herbarium of Victoria, or the Australian National Herbarium. The very small size of some *Cynanchum elegans* populations has deterred collection of herbarium material, but all new locations noted here have been confirmed in the field by recognised experts. Throughout this paper, the upper Hunter Valley refers to the catchment of the Hunter River, as far east as the Singleton area. National Parks have been abbreviated NP, State Recreation Areas SRA, Nature Reserves NR, and State Forests SF. All but four of the species dealt with are currently listed as nationally rare (Briggs & Leigh 1996), or are listed on the *NSW Threatened Species Conservation Act 1995* as Endangered or Vulnerable in New South Wales. The four unlisted species are included as they are considered by the author to be regionally significant in the upper Hunter Valley, primarily due to sizeable range extensions. All four are canopy species; a future note is planned that will summarise regionally significant taxa for the Hunter Region.

Rare or threatened species dealt with in this paper have been discussed in relation to their specific conservation risk codes (Briggs & Leigh 1996). These codes effectively summarise the perceived level of threat for each species. Under this system, the first character is a distributional category, and refers to plant taxa known only from the type location (1), or with a distributional range of less than 100 km (2), or with a range of more than 100 km (3). The second character rates each taxon on conservation status, either as Presumed Extinct (X, not collected or verified in the preceding 50 years), Endangered (E, in serious risk of disappearing from the wild within 10–20 years), Vulnerable (V, taxon not presently Endangered, but at risk over 20–50 years), Rare (R, rare in Australia but without any identifiable threat), or Poorly Known (K, taxon suspected of belonging to one of the preceding categories, but field information is inadequate). The third character (if present) outlines reservation status, generally as Reserved (C, if taxon has at least one population in a national park or other proclaimed conservation reserve). In reference to Reserved populations, these can be Adequate (a, 1000 plants or more known from reserve), Inadequate (i, less than 1000 plants known from reserve), Not Known (-, the reserved population size is unknown), and/ or total known population reserved (t).

1. *Acacia bulgaensis* Tind. & S.J. Davies (Fabaceae: Mimosoideae)

Tindale, Kodela & Davies (1992) described *Acacia bulgaensis* as common in the vicinity of Bulga, Milbrodale and Broke on the edge of the sandstone escarpment south of Singleton. Subsequent to this work, extensive survey of the adjacent Yengo NP has revealed substantial populations of this species (Bell, Vollmer & Gellie 1993, Maryott-Brown & Wilks 1993), which suggests a revision of the ROTAP code of 2RC- applied by Briggs and Leigh (1996) can be made. Indeed, Maryott-Brown and Wilks (1993) state that all sites visited during their survey had large population levels (greater than 1000 plants). Bell (1998) also reports the species for the north-eastern section of Wollemi NP, where it adjoins Yengo NP, while Binns (1996) notes this species as common in a portion of Pokolbin SF excluded from logging.

All populations combined are expected to well exceed 1000 plants, and hence the current ROTAP code of 2RC- should be amended to 2RCa, to reflect the reserved population. The coding for this species in zone 56 should also be amended to 56Ca (Yengo NP).

2. *Angophora euryphylla* (L. Johnson ex G. Leach) L. Johnson & K. Hill (Myrtaceae)

Regarded previously as occurring on sandstone outcrops in a small area between Putty and Wollombi, and south along the Judge Dowling Range (Hill 1991a), *Angophora euryphylla* is now known to occur as far west as the Martindale Range in Wollemi NP (Bell 1997a), with an apparently disjunct occurrence in a coastal location in Brisbane Water National Park near Gosford (Bell & Williams 1996). Sizeable populations also exist within Yengo NP, and Pokolbin and Corrabare SFs (Bell et al. 1993, Binns 1996). The records from Wollemi NP extend the known range into the Central Western Slopes botanical division, while those from Pokolbin SF extend the range into the North Coast botanical division. This species is not currently listed as rare, but is considered of regional significance in the Hunter Region due to its sporadic distribution.

3. *Callitris rhomboidea* R. Br. ex A. Rich. & Rich. (Cupressaceae)

Formerly known only from the Coast and Tablelands in New South Wales (Harden & Thompson 1990), *Callitris rhomboidea* has recently been collected from the middle Lee Creek catchment in north-western Wollemi NP (pers. obs. 1998), and represents the first record for the Central Western Slopes botanical division. In this area, plants were scattered in and near scrubby heath on sandstone pagoda rock formations. This species is not listed as rare, although it is considered regionally significant in the Hunter Region.

4. *Banksia penicillata* (A.S. George) K.R. Thiele (Proteaceae)

Previously reported to occur only in dry sclerophyll woodland on sandstone or around rocky slopes in the Blue Mountains area of the Central Tablelands (Harden 1991), recent collections have extended the range of this species into the Central Western Slopes botanical division. Within Wollemi NP, small populations of this species were recorded as far north as Benjang Gap and the middle Lee Creek catchment south of Bylong in the northwest of the Park (Bell 1998). More recently, additional populations have been recorded in remote parts of the Park immediately west of the Tollagong Range, in close proximity to the Central Coast division (pers. obs. 1998). With other known populations further south in Wollemi (Bell 1998), and possibly also in Blue Mountains and Gardens of Stone NPs, it is likely that there are more than 1000 plants currently in reserve. It is suggested that the current ROTAP code of 3RC- (Briggs & Leigh 1996, as part of *Banksia conferta*) may now be revised to 3RCa to reflect these additional populations. The New South Wales listings should also be amended to include 51C- (Wollemi NP).

5. *Cynanchum elegans* (Benth.) Domin (Asclepiadaceae)

Copeland & Hunter (1999) have recently summarised recent recordings of this species, and suggested that a ROTAP code of 3VCi is more appropriate than the existing one of 3ECi. They base their suggestion on the large number of new populations both in conservation reserves, and in other areas. While this amendment to the conservation risk code appears partly justified, it must be remembered that the majority of known populations generally support less than 30 plants (M. Matthes, NPWS, pers. comm.). Under the definition of an endangered species, Briggs and Leigh (1996) state that this category includes taxa with populations possibly too small (usually less than 100 individuals) to ensure survival, even if present in proclaimed reserves. This reasoning would suggest that the appropriate ROTAP code should remain at 3ECi, despite the additional reserves cited.

A small number of additional conserved populations can also be added to those noted by Copeland and Hunter (1999). These include Flaggy Creek in Glenrock SRA near Newcastle, and Green Point Reserve on Lake Macquarie (M. Matthes, NPWS, pers. comm.). A small population also exists in the Singleton Military Area, which does afford some level of protection for the species (Thomas 1998). Other known locations in the upper Hunter Valley include various sites in Goulburn River NP, Wollemi NP, and Woko NP. There is some doubt over the current status of the record of *Cynanchum elegans* for Mt Dangar in Goulburn River NP (T. Tame, pers. comm; T. Peake, pers. comm.).

6. *Eucalyptus aenea* K.D. Hill (Myrtaceae)

A recently described species previously known only from a few small stands in the eastern sections of Goulburn River National Park (Hill 1997). Recent collections have been made from two populations in Manobalai NR (west of Muswellbrook), both being small stands associated with rocky sandstone outcrops which had not been burnt for (probably) > 30 years. No further stands were located during extensive survey of Goulburn River NP conducted recently (Hill 1999), nor in the adjoining Wollemi NP (Bell 1998). Hill (1997) suggested a ROTAP code of 2RC when describing the species. It is suggested that this code be amended to 2RC- to reflect representation within two conservation reserves. It is possible (but unlikely) that stands in Goulburn River NP may number around 1000 plants, however accurate estimates have not yet been made. Populations within Manobalai NR are certainly well less than this figure.

7. *Eucalyptus dealbata* Cunn. ex Schauer (Myrtaceae)

Eucalyptus dealbata is a widespread species with a scattered distribution in grassy woodland on skeletal soils on basic rocks in the Western Slopes, North Western Plains, and Tablelands of New South Wales, with occurrences also in Victoria and Queensland (Hill 1991b). During survey of Wollemi NP, a small disjunct population was recorded along the Martindale Trail near the northern perimeter of the Park, approximately 45 km south of Denman (Bell 1998). This population grows on skeletal soils of the Triassic Narrabeen sandstone series. No other populations were noted elsewhere in the Park, nor was this species recorded during survey of the nearby Goulburn River NP and Munghorn Gap NR (Hill 1999), Crown land south of Manobalai NR (Bell 1997b), or Manobalai NR itself (Peake & Bell in prep.). This record represents a sizeable extension of range within the Central Western Slopes division. While not considered a rare species, *Eucalyptus dealbata* is generally considered regionally significant within the Hunter Region, where the easterly limit of distribution now occurs.

8. *Eucalyptus fergusonii* subsp. *dorsiventralis* L. Johnson & K. Hill (Myrtaceae)

Previously known only from the Central Coast in dry sclerophyll forest on sandstone ridges from the Wollombi Valley to the Wollemi Wilderness (Hill 1991b), collections of *Eucalyptus fergusonii* subsp. *dorsiventralis* over recent years have substantiated reported populations both within and outside of conservation reserves. This species commonly occurs in the northern parts of Yengo NP (Bell et al. 1993, Maryott-Brown & Wilks 1993), with substantial populations also in Pokolbin and Yango SFs (Binns 1996). Smaller populations occur in the east of Wollemi NP, extending as far south as near the junction of the Colo River with Tootie Creek (Bell 1998), and the Culoul Range above the Colo River (pers. obs 1998). Other populations occur within the Singleton Military Area (Thomas 1998), and it is likely that Corrabare SF also supports it. The species is also present in the north-western parts of Heaton SF (pers. obs. 2000) and in the Quorrobolong Valley (Bell & Murray 2001). Closer to the coast, the subspecies has been reported from Newcastle, although it is likely that these represent *Eucalyptus fergusonii* subsp. *fergusonii*. It does not appear that voucher specimens from this location have been lodged with State herbaria.

Briggs & Leigh (1996) apply a ROTAP code of 2RC- to *Eucalyptus fergusonii* subsp. *dorsiventralis*, although recent finds suggest that this should be amended to 2RCa, or 3RCa if populations around Newcastle are subsequently confirmed. Populations within Yengo and Wollemi NPs alone are thought to exceed 1000 plants. It is possible that exact population counts of this species will never be known, as it commonly occurs with several other ironbark species, and collection of fruits and/or buds from individual trees is often necessary to confirm identity. Hill (1991b) notes that this species occurs only in the Central Coast division. Populations within Pokolbin SF (where it is a community dominant in parts: Binns 1996) and the Singleton Military Area would extend this range into the North Coast, with the latter location probably representing the northern limit of distribution of the species.

9. *Eucalyptus nubila* Maiden & Blakely (Myrtaceae)

Eucalyptus nubila is essentially a species of the western slopes of New South Wales, occurring in sclerophyll woodland on shallow sandy soils north from Dubbo, in the North and Central Western Slopes (Hill 1991b). Sporadic collections have been made in recent years from the northern parts of Wollemi NP (Bell 1998), and at Singleton Military Area between Broke and Cessnock (Thomas 1998). Both of these collections extend the known range into the North Coast division, with the latter probably representing the eastern limit of this species. Elsewhere in the upper Hunter, this species occurs commonly in parts of Goulburn River NP and Towarri NP, in the Central Western Slopes (Hill 1999, pers. obs. 2000). While not listed as a rare species, *Eucalyptus nubila* is generally considered regionally significant in the upper Hunter Valley.

10. *Eucalyptus prominula* L. Johnson & K. Hill (Myrtaceae)

Hill (1991b) indicates that *Eucalyptus prominula* is locally frequent but highly restricted in dry sclerophyll forest on shallow sandy soils in the Bucketty district, and west along the Hunter Range, in the Central Coast division. Binns (1996) has recorded this species as common and widespread on ridges and slopes in the northern half of Pokolbin SF (the best stands of which were proposed as reserve), and more localised in the western part of Olney SF. The Pokolbin SF populations extend the known range of this species into the North Coast division. The species is also locally common in parts of Corrabare

SF (pers. obs. 2000). In reserve, *Eucalyptus prominula* is known from Yengo NP (Bell et al. 1993), and also as far south as the western Culoul Range in Wollemi NP (pers. obs. 1998–9). Populations within Wollemi NP are not extensive (Bell 1998), although it is likely that the species is present in low concentrations along the eastern portions. No counts or estimates of the species have yet occurred in either reserve, but it is possible that more than 1000 plants are represented. *Eucalyptus prominula* is considered by the author to be a rare species with a distributional range of around 80 km, probably with more than 1000 plants in reserve, but further survey is required to confirm this. Briggs and Leigh (1996) have applied a ROTAP code of 2KC- to this species, but it is suggested that this be amended to 2RC- to better reflect current knowledge.

11. *Gonocarpos longifolius* (Schindler) Orch. (Haloragaceae)

Previous records of *Gonocarpus longifolius* exist for the ranges from Armidale to the Blue Mountains, east of Rylstone, on the North and Central Coasts, Central Tablelands, and Central Western Slopes divisions (Wilson 1991a). Recent survey in the ranges around the Goulburn River valley has revealed considerable populations (> 1000 plants) both within and outside of existing conservation reserves (Bell 1998, Hill 1999, Peake & Bell in prep.). The species is particularly common in the northern portions of Wollemi NP (Bell 1998), stretching some 70 km from the California Trail to Coxs Gap. Other populations are also known from the Singleton Military Area (Thomas 1998), which probably represents the eastern most limit of the species. The current ROTAP code for *Gonocarpus longifolius* is listed by Briggs and Leigh (1996) as 3RC-, but a downgrading to 3RCa is now suggested following these recent finds.

12. *Grevillea johnsonii* McGillivray (Proteaceae)

Grevillea johnsonii occurs in rocky situations on sandstone, predominantly in the Goulburn River and Capertee River catchments on the Central Tablelands and Central Western Slopes, and with an unsubstantiated record also from the Brogo River on the South Coast (Makinson 1991). Bell (1998) reports that this species is widespread across the northern portions of Wollemi NP, extending down the western flank of the Park to at least Growee Gulf. The species also occurs in good numbers in Goulburn River NP (Hill 1999) and Manobalai NR (Peake & Bell in prep.). All populations combined would equate to a total population of well over 1000 plants. Collections made within the Goulburn River catchment in recent years suggest the current ROTAP listing of 2RCi be downgraded to 2RCa.

13. *Grevillea montana* R. Br. (Proteaceae)

Restricted to the southern rim of the Hunter Valley, *Grevillea montana* occurs in the area from Sandy Hollow to Kurri Kurri, in the Central Western Slopes and North Coast divisions (Makinson 1991, Olde & Marriott 1994). Sizeable populations (well over 1000 plants) of *Grevillea montana* are known from the northern parts of Wollemi (Bell 1998), Yengo (Bell et al. 1993) and Lower Hunter NPs (pers. obs. 2001), with other semi-conserved populations in the Myambat Logistics Company army base (Fallding, Bell & Murray 1999) and the Singleton Military Area (Thomas 1998). Binns (1996) also records the species in Cessnock and Aberdare SFs, although there is no indication of population sizes at either location. The species is also relatively common in unreserved lands from the Cessnock to Denman area along the sandstone escarpment. *Grevillea montana* is currently listed by Briggs and Leigh (1996) with a ROTAP code of 2KC-, although survey work in recent years has revealed quite substantial populations in reserve, and it is suggested that this code be amended to 2RCa.

14. *Melaleuca groveana* Cheel & C. White (Myrtaceae)

Wilson (1991b) states that *Melaleuca groveana* grows in heath, often in exposed sites, and occurs in higher altitude areas in coastal districts north from Port Stephens, in the North Coast division. Survey in Yengo and Wollemi NPs in recent years has revealed additional populations of this species, where it occurs on Narrabeen sandstone ridges in open eucalypt forest dominated by *Eucalyptus fibrosa, Eucalyptus crebra, Eucalyptus punctata, Eucalyptus sparsifolia, Angophora costata* and *Corymbia gummifera* (Maryott-Brown & Wilks 1993, Bell 1998). In an amendment to Wilson's (1991b) treatment, populations within Yengo NP are reported as being within the Central Coast division (Harden 1993), although the Yengo populations are in fact still within the North Coast. Despite these new populations, no change is considered necessary to the current ROTAP code of 3RC- (Briggs & Leigh 1996), since detailed population counts have still to be made. The current listing of this species as Vulnerable under Schedule 2 of the *NSW Threatened Species Conservation Act 1995* is also considered appropriate until such counts occur.

15. *Pomaderris bodalla* N.G. Walsh & F. Coates (Rhamnaceae)

Pomaderris bodalla is a recently described species previously known only from the South Coast of New South Wales, between Nerrigundah and Brogo (Walsh & Coates 1997, Harden 2000). In the past, *Pomaderris bodalla* has been confused with *Pomaderris brunnea* and *Pomaderris discolor*. During survey of Wollemi NP, new collections of this species were made from the slopes of Woodlands Trig, along the northern escarpment of the Park, approximately 12 km west of Jerrys Plains (Bell 1998). While counts were not made, it is unlikely that more than 1000 plants are present in this location. This new record extends the known range of this species into the Central Western Slopes, and represents a distance of some 450 km from the South Coast locations. Walsh & Coates (1997) attributed a ROTAP code of 2R to this species when describing the species. It is suggested that this should be amended to 3RC- with the new population in Wollemi NP.

16. *Pomaderria brunnea* Wakef. (Rhamnaceae)

Pomaderris brunnea was previously confined to open forest in the lower Colo (Culoul Range) and upper Nepean Rivers to the west of Sydney, in the Central Coast division of New South Wales (Harden 1990a, Harden 2000). A new small population was recently found in western Wollemi NP, in a tributary of Tea Tree Creek, approximately 20 km east of Kandos on the Central Tablelands (Bell 1998). A small number of plants were growing in a riparian forest dominated by *Eucalyptus cypellocarpa*. This species is currently listed as Vulnerable under Schedule 2 of the *NSW Threatened Species Conservation Act 1995*, and has a ROTAP code of 2VC- (Briggs & Leigh 1996). No change is suggested for this code, as the new location lies approximately 80 km northwest of the most distant populations in the upper Nepean River. However, note should be made of the extension of range into the Central Tablelands.

17. *Pomaderris precaria* N.G. Walsh & F. Coates (Rhamnaceae)

The recently described *Pomaderris precaria* (as *Pomaderris* sp. D in Harden 1990a) is noted by Walsh & Coates (1997) to be apparently confined to the Rylstone district, in the Central Tablelands and/or Central Western Slopes of New South Wales. Harden (2000) also adds the Mt Gundangaroo and Hillgrove areas of the Central and North Coasts. Walsh & Coates (1997) attributed a ROTAP code of 2VC-, but were unaware of some recent collections from conservation reserves. Recent survey in parts of north-western Wollemi NP (Oz Mountain: Bell 1998) and Goulburn River NP (Peachtree Flat: Bell 1997c) has established that small populations of this species do occur within reserve, lying well within the Central Western Slopes division. Fallding et al. (1999) also report this species for the Myambat Logistics Company Site, where it occurs as scattered individuals on sheltered sandstone slopes and on alluvial soils. Based on present knowledge, populations within Goulburn River and Wollemi NPs do not appear to exceed 1000 plants, as these are typically composed of less than 100 plants each. Interestingly, Walsh and Coates (1997) indicate that the name *precaria* pertains to the insecure roadside situation of the (then) only known recently collected population of this species, a situation which has now been improved.

Given the small sizes of all documented populations, and the extent of survey that has been undertaken in areas of potential habitat in Wollemi and Goulburn River NPs, and the nearby Munghorn Gap and Manobalai NRs (Bell 1998, Hill 1999, Peake & Bell in prep.), it would be appropriate to revise the current ROTAP code to 2EC-. Consideration could also be given to the listing of this species as Vulnerable under Schedule 2 of the *NSW Threatened Species Conservation Act 1995*.

18. *Pomaderris queenslandica* C. White (Rhamnaceae)

Harden (1990a) has reported that no specimens of *Pomaderris queenslandica* have been collected in New South Wales since 1904, and that this species is consequently very rare in this State. Previously known localities noted include Mt Dangar and near Gloucester, but the species is more widespread in Queensland. Harden (2000) also adds the Slopes north from the Peak Hill district. While *Pomaderris queenslandica* is listed as Endangered under Schedule 1 of the *NSW Threatened Species Conservation Act 1995*, there is no ROTAP code listed in Briggs & Leigh (1996), presumably reflecting this lack of recent material or the prevalence of the species in Queensland. Recent collections of *Pomaderris queenslandica* have occurred in the upper Hunter Valley which confirm its presence in this part of the Central Western Slopes, and probably also represent the southern limit of distribution. Fallding et al. (1999) report on collections from two sites at the Myambat Logistics Company Site near Denman, both consisting of only single individuals. More recently, several plants have been located along a creekline on the Diamond Ridge Trail in Manobalai NR north of Denman (pers. obs. 1999), and also in new additions to Towarri NP near Scone (pers. obs. 2000). All sites assist in the conservation of the species in the region, although populations do appear small (well less than 1000 plants).

As Briggs and Leigh (1996) do not list this species with a ROTAP code, the opportunity is taken here to suggest that a code of 3VCi may be appropriate, at least for the New South Wales populations. For the Central Western Slopes (= zone 51), a code of 51Ci (Manobalai NR, Towarri NP) is suggested.

19. *Pomaderris reperta* N.G. Walsh & F. Coates (Rhamnaceae)

Narrowly endemic to the Denman area, *Pomaderris reperta* was previously known only from the type locality, where shrubs are scattered over an area of approximately 1ha (Walsh & Coates 1997; Harden 2000). Description of the type material by Walsh and Coates (1997) indicated a location east of Denman, when this should in fact have been west of Denman (P. Jobson, pers. comm.). Intensive survey at the Myambat Logistics Company Site west of Denman has recently uncovered additional populations of this species (but numbering only 20–40 plants), located approximately 4 km north of the type locality, but along the same sandstone ridgeline (Fallding et al. 1999). When describing the species, Walsh and Coates (1997) suggested a ROTAP code of 2V. Although no indication is given by these authors of the size of populations present at the type locality, it is possible that, together with the new populations, a total of less than 100 plants exists. Following the system of Briggs & Leigh (1996), the species should be re-coded to 2E, to reflect the small overall population size, and the lack of representation in conservation reserves. Indeed, extensive vegetation survey in the nearby Goulburn River NP (Hill 1999), Wollemi NP (Bell 1998), and Manobalai NR and Crown land (Peake & Bell in prep., Bell 1997b) did not locate any additional populations of this species. It is also suggested that this species should be considered for listing on the *NSW Threatened Species Conservation Act 1995*, as Vulnerable (Schedule 2).

20. *Pomaderris sericea* Wakef. (Rhamnaceae)

Very few records of *Pomaderris sericea* exist for New South Wales, with Harden (1990a, 2000) stating that the species has been collected only from Berrima on the Central Tablelands at the turn of the century. Other populations exist in Victoria, where it is held (inadequately) in reserve (Briggs & Leigh 1996). In New South Wales, this species has been considered extinct in the Central Tablelands division (zone 54), and has been given an overall ROTAP code of 3VCi by Briggs and Leigh (1996). *Pomaderris sericea* is also listed as Endangered under Schedule 1 of the *NSW Threatened Species Conservation Act 1995*.

During survey of Wollemi NP, a small number of plants were located along a narrow creekline in the Benjang Gap area in the north-western section of the Park, within the Central Western Slopes division (Bell 1998). This find extends the known range of this species well north of Berrima, and confirms its existence within New South Wales. No change is considered necessary to the existing ROTAP code, although the coding for New South Wales should be amended with the addition of 51Ci (Wollemi NP).

21. Prostanthera cryptandroides Cunn. ex Benth. subsp. *cryptandroides* (Lamiaceae)

A recent revision of *Prostanthera cryptandroides*, *Prostanthera euphrasioides*, and *Prostanthera odoratissima* by Conn (1999) has re-evaluated the relationship within this complex, and has concluded that a single species with two subspecies is involved (*Prostanthera cryptandroides* subsp. *cryptandroides* and subsp. *euphrasioides*). The former subspecies is restricted to the Central Tablelands and Central Western Slopes between Lithgow and Sandy Hollow, and both occur on dry rocky sandstone ridges (Conn 1999). Briggs and Leigh (1996) have applied a ROTAP code of 2RC-t for *Prostanthera cryptandroides*, indicating that the total known population is contained within conservation reserves. The species is also currently listed as Vulnerable under Schedule 2 of the *NSW Threatened Species Conservation Act 1995*, which undoubtedly refers to subsp. *cryptandroides*. Conn (1999) has suggested that neither subspecies is common and that subsp. *cryptandroides* has a very restricted distribution.

Briggs & Leigh (1996) have indicated that *Prostanthera cryptandroides* (= subsp. *cryptandroides*) is conserved within Blue Mountains and Wollemi NP's on the Central Tablelands, but is listed as Presumed Extinct in the Central Western Slopes (zone 51). A recent collection from this division at the Myambat Logistics Company Site near Denman (Fallding et al. 1999), confirms that the subspecies is still present within this area. Targeted surveys for the subspecies in late 1999 also revealed additional populations from this location (R.Miller, pers. comm.). Consequently, it is suggested that the 2RC-t ROTAP code be revised to 2VC- to indicate that the species is in fact present outside of conservation reserves, and to reflect the listing of this species in NSW on the TSC Act. The Presumed Extinct notation should also be removed from zone 51.

22. *Prostanthera hindii* B.J. Conn (Lamiaceae)

Formerly known as *Prostanthera* sp. D, this species has only recently been described, with reported locations including various sites in the upper Cudgegong Valley in the Rylstone district, parts of the northern Newnes Plateau, and near Glen Davis (Conn 1997). All collections appear to be in or near Wollemi NP, with the former two lying within the Central Tablelands and the latter just inside the Central Coast. Preferred habitat is on sandstone pagoda formations, the distribution of which extends (sporadically) from the Newnes Plateau area to north-western Wollemi NP, a distance of around 65 km. Recent collections of this species from remote parts of the middle Lee Creek catchment in north-western Wollemi NP (pers. obs. 1998) extend the known range into the Central Western Slopes, representing a distance of some 25 km north of populations in the upper Cudgegong Valley. Conn (1997) initially suggested a ROTAP code of 2RCi. This code should now be downgraded to 2RCa in light of the additional populations, and the extent of pagoda rock formations occurring along the western side of Wollemi NP (much of it remote) which probably support the species. Populations are quite sizable in the Dunns Swamp area of Wollemi, and together with those occurring to the north and south of this location, probably constitute over 1000 plants.

23. *Rulingia procumbens* Maiden & Betche (Sterculiaceae)

Rulingia procumbens was previously thought to be confined mainly to the Dubbo-Mendooran-Gilgandra region, with other occurrences in the Pilliga and Nymagee areas (Harden 1990b). Briggs and Leigh (1996) list this species with a ROTAP code of

3V, and it is also listed as Vulnerable under Schedule 2 of the *NSW Threatened Species Conservation Act 1995*. A substantial population (> 100 plants) has recently been recorded on a westerly-facing spur near Sandy Hollow, a distance of approximately 150 km from other known locations to the west (Bell 1997b). A second population on a nearby ridge was also located during this survey, although only a few plants were noted. Both populations were recorded approximately 6–8 months after an aerially ignited fuel reduction burn in Autumn 1996, and were flowering and fruiting profusely. Subsequent visits to one of the sites over the following two years failed to find the species, suggesting that it may in fact be a fire ephemeral. A further population has more recently (1999) been uncovered on the slopes of nearby Mt Dangar within Goulburn River NP, also in a burnt area (R. Miller, pers. comm.). Briggs and Leigh (1996) note that no populations are known from within conservation reserve: at least one population currently lies within Goulburn River NP, and hence it is suggested that the current ROTAP coding of 3V be amended to 3VCi to reflect this fact. The recent finds on Crown reserve offer additional opportunities for the conservation of this species, lying as they do between Goulburn River NP and Manobalai NR.

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Dioecy, self-compatibility and vegetative reproduction in Australian subtropical rainforest trees and shrubs

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Australian subtropical rainforests and plant populations have become increasingly fragmented since European settlement. Managing relict populations and remnants within the landscape matrix is dependent upon our understanding of plant reproductive biology. The incidence of autogamous self-compatibility and dioecy was investigated in subtropical rainforests, near Taree, in the Manning Valley (northern New South Wales). The proportion of dioecious species in rainforests of the region is high (~17%), but varies among sites. The potential for hermaphroditic species to self-pollinate was examined by bagging inflorescences in the field. Of the > 30 species (in 14 families) studied, nine species exhibited high levels of self-compatibility. These were predominantly pioneer and edge species, but other pioneer species were self-incompatible. Different behaviour occurred within families. Twenty species (in 13 families) regenerated from basal coppice or root suckers following bushfire. The significance of knowledge of reproductive biology for management is discussed.

Introduction

Many tropical and subtropical trees and shrubs are characterised by wide geographical distributions, but at individual sites species often have low population densities. During the Tertiary subtropical rainforest was very extensive in Australia (Adam 1992). In recent geological time its distribution has become limited and fragmented, as much of Australia became arid, with fluctuations in extent driven by climatic change during glacial-interglacial cycles. In the last 200 years, since European settlement, distributions have become further fragmented because of clearance, and stand integrity impaired by weed invasion. Local populations of many species are now very small, in some cases reduced to single individuals per stand.

A knowledge of the reproductive biology of species is an important prerequisite to understanding their resilience to environmental change. Whether or not a species has the ability to self-fertilise, and whether there is plasticity in requirements for pollinators, have particular importance to the ability of species to successfully colonise new sites, and are highly relevant to the management and preservation of remnant rainforest stands.

An ability to self-fertilise reduces vulnerability to extinction (Bond 1994) but, historically, the level of self-incompatibility and requirement for out-crossing in tropical rainforest trees has been a contentious topic (Adam 1992). Federov (1966), discussing the structure of tropical rainforest and speciation in the humid tropics, suggested that out-crossing was rare (due to the spatial isolation of species in complex tropical rainforests) and that self-compatibility was general among rainforest trees. Corner (1954) had earlier argued that 'selfing' is the tendency of all trees even though this will tend to reduce heterozygosity in populations. Ashton (1969) partly summarised Federov's case, taking into account the low densities of rainforest species, as 'given the lack of marked seasonality which leads to irregularity and lack of coincidence in flowering', and assuming that pollen dispersal in temperate and tropical regions was equally efficient, 'then the effective populations in tropical tree species must contain on average fewer individuals than their temperate counterparts, and indeed, self-fertilisation must be the rule.' Ashton (1969) argued that, if Federov and Corner were correct, then dioecism and other breeding systems promoting outcrossing would be eliminated but showed that a significant proportion (26%) of tree species in a Sarawak mixed dipterocarp forest were dioecious, and thus obligate out-crossers. Ashton argued on the basis of plant sexual systems, as indicated by floral morphology, but he had no data on the potential for self-compatibility in non-dioecious species.

Here we present data on the incidence of self-compatibility in more than 30 species of Australian subtropical rainforest trees and large shrubs and give an indication of the proportion of dioecious, and occasionally dioecious, woody rainforest plants. While viable seed production is essential for long distance dispersal, and colonisation of new sites, survival of established populations in the face of disturbance may be enhanced by ability to reproduce vegetatively. An important disturbance factor at the edge of rainforest stands and in rainforest/wet sclerophyll forest ecotones is fire. Observations are reported on the recovery of rainforest edge species following a 1994 bushfire in the Manning Valley.

Methods

The study was largely undertaken during 1991–1993 in lowland rainforest remnants near Taree, in the Manning Valley on the north coast of New South Wales, as part of a larger investigation of the pollination ecology of lowland subtropical rainforest communities (Williams 1995). The majority of tree and shrub species studied displayed the general entomophilous flower syndrome, possessing numerous small actinomorphic flowers. An exception was *Hibiscus splendens* which possessed large (> 7 cm diameter) flowers.

Information on plant sexuality was obtained from Floyd (1989), Beadle, Evans and Carolin (1972), Harden (1990–93), and supplemented by direct observation (Williams 1995).

Potential self-compatibility and the influence of pollination vectors on reproductive success/fruit set were investigated by a series of bagging and open pollination comparisons. The majority of the bagging experiments was undertaken in subtropical rainforest and wet sclerophyll forest at Lorien Wildlife Refuge (31°45'00"S, 152°32'30"E), and a smaller set of observations was carried out in littoral rainforest at Harrington (31°52'30"S, 152°41'00"E), floodplain rainforest at Lansdowne Reserve (31°32'30"S, 152°32'30"E), and mixed rainforest-wet sclerophyll forest at Kenwood Wildlife Refuge (31°44'45"S, 152°31'30"E).

Unopened flower buds were counted and inflorescences, or groups of flowers, assigned individually numbered tags. Flower buds were counted by marking them with a coloured marker pen. This minimised recounting or the overlooking of buds. On very large inflorescences, individual sections were designated with coloured thread and these bud sub-sets were then counted and marked as above.

Fine nylon bags with a mesh diameter of < 0.1 mm. were placed over inflorescences and individual or small clusters of flowers and secured with woollen yarn to obstruct insect entry into the bag. Bagged inflorescences were located on at least two plants of each species in most cases. Occasionally large orthopterans chewed through the cloth and thrips gained entry. Data from these were discarded and new inflorescences were bagged. Several bagged inflorescences were snapped in strong wind and had to be duplicated. The bags were very conspicuous and the choice of sites, and to a degree, the choice of plants, was dictated by the availability of locations where disturbance was likely to be minimal. All bags were removed upon the conclusion of flowering.

Artificial manipulation of pollen receipt may reveal self-compatibility in species that cannot automatically self (see Gross 1993). However, no attempt was made to undertake hand pollinations because the large numbers of small sized flowers in inflorescences of mass-flowering tree species (e.g., *Euroschinus falcata, Alphitonia excelsa*) do not open all at once (i.e. staggered receptivity) and would have required a very long time to pollinate by hand. The time consuming nature of the manipulations would have required repeated and relatively long periods of bag removal with subsequent vulnerability of stigmas to uncontrolled extraneous pollen deposition. In addition, in small, generally entomophilous flowers the stigma may be enclosed and difficult of access, making hand pollination impractical.

Bagging of flowers, in itself, does not provide a rigorous assessment of the degree of self-compatibility likely to occur in the field but it does give an indication of automatic self-pollination (autogamy) and the potential to 'self'.

Massed inflorescences presented problems of counting due to the large number of buds, difficulty in counting very small buds, the inability to adequately assess and identify abortion of buds, and the difficulty in differentiating male and female flowers in some monoecious taxa (particularly Sapindaceae). Plants in this later group were bagged without counting individual buds and scored as self-compatible if development of ovaries occurred.

Fieldwork was undertaken during years in which moderate to severe drought conditions were experienced and this potentially influenced results.

Observations on species capable of regrowing by vegetative coppicing were made after a bushfire on 7 January 1994 in Lansdowne State Forest, adjacent to the Lorien Wildlife Refuge (Williams 1995). This fire occurred towards the end of a prolonged drought (1992–late 1994), and air temperatures during the fire exceeded 35°C.

Plant nomenclature follows Harden (1990–93).

Table 1. Dioecious and occasionally dioecious species occurring at study sites.

1 = Floyd 1989, 2 = Beadle et al. 1972, 3 = Harden 1990, 4 = Harden 1991, 5= Williams 1995.

Ebenaceae		
Diospyros australis	dioecious	3
D. pentamera	dioecious	3
Euphorbiaceae		
Claoxylon australe	usually dioecious	3
Drypetes australasica	dioecious	3
Mallotus philippensis	usually dioecious	3
Icacinaceae		
Citronella moorei	dioecious	1
Lauraceae		
Litsea australis	dioecious	3
L. reticulata	dioecious	3
Neolitsea australiensis	dioecious	3
N. dealbata	dioecious	3
Meliaceae		
Dysoxylum fraserianum	bisexual or dioecious	4
D. rufum	bisexual or dioecious	4
Monimiaceae		
Wilkiea huegeliana	dioecious, monoecious	1, 2, 3, 5
Moraceae		
Ficus coronata	dioecious or monoecious	3
F. fraseri	dioecious or monoecious	3
F. macrophylla	dioecious or monoecious	3
F. obliqua	dioecious or monoecious	3
F. rubiginosa	dioecious or monoecious	3
F. superba var. *henneana*	dioecious or monoecious	3
F. watkinsiana	dioecious or monoecious	3
Streblus brunonianus	dioecious	3
Sapindaceae		
Cupaniopsis anacardioides	monoecious or dioecious	4
C. parvifolia	monoecious or dioecious	4
Urticaceae		
Dendrocnide excelsa	dioecious	3
D. photinophylla	dioecious	3
Winteraceae		
Tasmannia insipida	usually dioecious	3

Results

A total of 152 species of dicotyledonous trees and shrubs was recorded from the study sites including 92 species believed to be bisexual, or facultatively bisexual species, and 26 dioecious, or occasionally dioecious, species (~17 %) (Floyd 1989, Beadle et al. 1972, Harden 1990–93) (Table 1). The incidence of dioecy is probably an underestimate because several species are described in floras as being either dioecious or monoecious. Dioecious species are obligate out-breeders; constraints on the breeding systems of the remaining species are largely unknown.

Most sites possessed fragmented or highly clustered populations or isolated flowering plants of species with low abundances. While this spatial disjunction or isolation may assist the identification of self-compatibility (i.e. where the absence of flowering conspecifics negates the possibility of pollen entry onto bagged flowers), for open-pollinated flowers, the proportion of successfully developing fruit may not represent 'normal' fecundity levels. However, inadequate receipt of pollen and commensurate limitation of female success may be common (Burd 1994).

Fruit set in bagged and open flowers is listed in Table 2. In the open pollinated flowers the percentage of flowers with developing fruit was highly variable, but in many cases was low. Whether these low rates are 'normal' for the species concerned is not known.

The results from the bagged flowers indicate that 16 of the studied species (in 14 families) have the ability to automatically self. This number may be fewer if those species with very low percentages, which may represent contamination, are discounted. Nine species demonstrated relatively high levels of selfing: *Abrophyllum ornans, Acradenia euodiiformis, Cupaniopsis anacardioides, Cryptocarya glaucescens, Elaeocarpus reticulatus, Eupomatia laurina, Hibiscus splendens, Scolopia braunii* and *Tasmannia insipida.* These are predominantly pioneer or edge species. Reproductively, *Eupomatia laurina* and *Hibiscus splendens* are specialist species, pollinated by one or a small number of pollinators (Armstrong & Irvine 1990, Williams 1993, 1995). Their ability to self may have important consequences for the maintenance of populations in the absence of pollinators.

The species with no apparent capacity for automatic selfing also include pioneers (e.g. *Alphitonia excelsa, Rhodomyrtus psidioides*). In *Alphitonia excelsa* self-incompatibility may be a consequence of protandry, as the stamens, encapsulated by the petals, are carried away from the latter developing gynoecium as the petals recurve (Williams 1995).

Within a family, species exhibit different behaviour (Table 2 — compare *Cryptocarya glaucescens* and *Cryptocarya rigida; Acradenia euodiiformis* and *Acronychia imperforata, Geijera salicifolia*). The two members of the Escalloniaceae studied (*Abrophyllum ornans, Cuttsia viburnea*) showed very high fecundity in open pollinated flowers, but gave contrasting results in the bagging experiment. *Cuttsia viburnea* is apparently an obligate out-breeder, being self-incompatible, while *Abrophyllum ornans* exhibits high levels of self-compatibility.

Table 2. Autogamy (automatic self-pollination) and open pollination results in lowland rainforest species.

Species	Bagged flower buds			Open pollinated flowers		
	flower buds	developing fruit at conclusion of flowering		flower buds	developing fruit at conclusion of flowering	
	#	#	%	#	#	%
Anacardiaceae						
Euroschinus falcata [1]	508	3	0.6	414	83	20.1
Celastraceae						
Denhamia celastroides [1]	1281	0	0	569	41	7.2
Ebenaceae						
Diospyros australis [1]	147	3	2	179	44	24.6
Elaeocarpaceae						
Elaeocarpus reticulatus [1]	223	86	36.9	304	49	16.1
Epacridaceae						
Trochocarpa laurina [1]	433	0	0	605	55	9.1
Escalloniaceae						
Abrophyllum ornans [1]						
- bagging in 1991-92	404	65	16.1	327	307	93.9
- bagging in 1992-93*	201	59	29.4	-	-	-
Cuttsia viburnea [1]	449	0	0	629	521	82.9
Eupomatiaceae						
Eupomatia laurina [1]	31	3	9.7	66	39	59.1
Flacourtiaceae						
Scolopia braunii [1]	415	74	17.8	297	83	28.0
Lauraceae						
Cryptocarya glaucescens [1]	647	117	18.1	766	189	24.7
Cryptocarya rigida [1]	261	0	0	236	9	3.8
Malvaceae						
Hibiscus splendens [1]	22	2	9.1	38	11	29.0
Monimiaceae						
Daphnandra micrantha [1]	533	11	2.1	538	38	7.1
Myrsinaceae						
Rapanea howittiana [1]	127	0	0	179	0	0[7]
Myrtaceae						
Acmena smithii [1]	360	13	3.6	276	11	4.0
Archirhodomyrtus beckleri [1]	263	0	0	307	96	31.3
Rhodomyrtus psidioides [1]	182	0	0	413	9	2.2
Tristaniopsis laurina [1]	189	0	0	210	40	19.1
Waterhousea floribunda [1]	634	5	0.8	673	135	20.1
Pittosporaceae						
Hymenosporum flavum [1]	45	0	0	95	2	2.1
Rhamnacea						
Alphitonia excelsa [2]	1778	0	0	1826	99	5.4

	#	#	%	#	#	%
Rutaceae						
Acradenia euodiiformis [1]	583	60	10.3	906	36	4.0
Acronychia imperforata [2]	317	0	0	652	0	0[5,7]
Geijera salicifolia [3]	783	0	0	1040	131	8.9
Sapindaceae						
Alectryon coriaceus [2]						
- bagging in 1991–92	228	0	0	80	0	0[6,7]
- bagging in 1992–93**	-	-	-	619	48	7.8[6]
Cupaniopsis anacardioides [2]	185	17	9.2	590	117	19.8
Guioa semiglauca [2]***	-	-	-	474	42	8.9[6]
Guioa semiglauca [1]	536	4	0.8	-	-	-
Mischocarpus pyriformis [4]	1112	0	0	1280	124	9.7[6]
Verbenaceae						
Clerodendrum tomentosum [2]	561	3	0.5	331	4	1.2
Winteraceae						
Tasmannia insipida [1]	46	27	58.7	44	43	97.7

1 location = Lorien Wildlife Refuge, **2** Harrington, **3** Kenwood Wildlife Refuge, **4** Lansdowne Reserve; **5** < 0.001 % of population flowered (buds opened); **6** monoecious sp., bud count includes male and female flowers, therefore 'selfing' is only the proportion of unknown number of female flowers that were present in the bagged inflorescences; **7** did not develop fruit; '*' bagging repeated in second season to confirm high 1991–92 'selfing' level; '**' repeated in 1992–93 due to zero selfing levels in 1991–92 open pollinated flowers; '***' bags damaged, repeated at Lorien site in same year.

There may be variation in the reproductive success of species both within and between years. For example, bagging was carried out in 1992 on a single isolated tree of *Rapanea howittiana* at Lorien Wildlife Refuge. This plant set no seed, though a cluster of trees > 100 m distant, and a second population at the Lansdowne Reserve site did. A single small *Rapanea variabilis* flowered (but was not bagged) at Lorien in 1994 and set numerous seed. The tree had not been previously observed to flower over nine years of observations and thrips (*Thrips setipennis*) were the only flower visitors. No other flowering *Rapanea variabilis* were located in the neighbourhood, suggesting self-compatibility or fertilisation via agamospermy.

Failure to set seed in some years has been observed in *Acronychia imperforata, Alectryon coriaceus* and *Rhodomyrtus psidioides,* although *Abrophyllum ornans, Acmena smithii, Alphitonia excelsa, Cuttsia viburnea, Tasmannia insipida* and *Waterhousea floribunda* populations at Lorien Wildlife Refuge have set large numbers of seed every year, over 14 years of observations, regardless of variation in climatic conditions.

Opportunistic observation allows additions to be made to the list of self-compatible species in Table 2. *Endiandra discolor* (Lauraceae) is regionally rare (Williams 1993) and occurs at the Lansdowne Reserve site as a single mature tree. This tree set seed during April–May 1994, and a germination trial of collected seed demonstrated viability. A single planted tree of *Hicksbeachia pinnatifolia* (Proteaceae), which is not native to the region, set viable seed at Lorien during each year of the study, although no other local ornamental plantings are known.

In *Elaeocarpus reticulatus*, more bagged flowers developed fruit than did open pollinated ones. There are no obvious explanations of this and further observations are required to determine whether this is atypical.

Twenty species of rainforest trees and shrubs, in 13 families, were observed to regenerate from basal coppice following the January 1994 bushfire (Table 3). *Melia azedarach* also regenerated from root suckers. No woody 'rainforest' species present at the site failed to coppice. Two of the species, *Diospyros australis* and *Mallotus philippensis*, are dioecious or usually dioecious (Table 1). The range of species regenerating vegetatively is similar to that recorded by Chesterfield et al. (1990) from burnt rainforest in Victoria.

Table 3. Rainforest trees and shrubs regenerating by coppice growth following bushfire in Lansdowne State Forest, 7 January 1994.

Family	Species
Cunoniaceae	*Schizomeria ovata*
Ebenaceae	*Diospyros australis*
Euphorbiaceae	*Croton verreauxii*
	Glochidion ferdinandi
	Mallotus philippensis
Eupomatiaceae	*Eupomatia laurina*
Lauraceae	*Cryptocarya microneura*
	Cryptocarya rigida
Meliaceae	*Melia azedarach* var. *australasica*
	Synoum glandulosum
Myrsinaceae	*Rapanea variabilis*
Myrtaceae	*Acmena smithii*
	Lophostemon confertus
	Rhodamnia rubescens
Oleaceae	*Notelaea longifolia*
Pittosporaceae	*Hymenosporum flavum*
Rutaceae	*Acronychia oblongifolia*
	Melicope micrococca
Sapindaceae	*Guioa semiglauca*
Solanaceae	*Duboisia myoporoides*

Discussion

Plant reproductive strategies strongly influence the ability of species to colonise and survive in rainforest stands.

Rainforest plants that cannot reproduce vegetatively, and obligate out-crossers that are incapable of producing seed by selfing, are unable to establish colonies from single recruits. Populations reduced to single individuals, and isolated from external pollen sources, are functionally extinct within individual remnants.

Dioecious species would appear to be at a particular disadvantage because reproductive success is linked to the receipt of pollen from male plants. Dioecy is uncommon amongst flowering plants, being found in between 4 and 6% of species (Barrett 1998, Renner & Ricklefs 1995, Richards 1997). The condition is found in many different families, and appears to have evolved independently on a number of occasions (Richards 1997). Some angiosperms may be functionally dioecious, for example where androdioecious plants (with males and hermaphrodites) possess hermaphrodites with nonfunctional pollen (Kearns & Inouye 1993). Muenchow (1987) has suggested that, in general, dioecious species have flowers characteristic of the general entomophilous syndrome. This is the case in our study.

Although dioecy is generally uncommon the incidence is higher amongst trees than herbs (Arroyo & Uslar 1993, Richards 1997, Schatz 1990, Waller 1988) and also in certain habitats — notably rainforest and on oceanic islands (Richards 1997).

The high incidence of dioecy in rainforest has been documented by a number of authors (see Bawa 1980, 1990, Richards 1997). In Sarawak mixed dipterocarp forest Ashton (1969) recorded 26% of trees with girth exceeding 1 foot (~30.5 cm) as dioecious. Russell-Smith and Lee (1992) recorded 16 dioecious species out of a total of 84 (19%) in isolated monsoonal rainforest patches in the Northern Territory. Twenty-one percent of Jamaican montane species, 23% of Costa Rican tropical lowland rainforest species and 31% of Venezuelan montane forest species are documented as dioecious by Bawa (1990).

In our study region the overall incidence of dioecy in rainforest is 17%, but the proportion varies among sites (Table 4).

Table 4. Number of dioecious rainforest tree and shrub species at sites in the Manning Valley.

Site	No. of dioecious spp.	% of total flora
littoral rainforests		
Crowdy Head	9	21
Harrington	16	27
Manning Point	11	36
Saltwater Reserve	9	23
Red Head	13	24
Black Head	14	19
floodplain rainforests		
Wingham Brush Nature Reserve	17	22
Coocumbac Is. Nature Reserve	11	28
Lansdowne Reserve	13	24
montane rainforest		
Dingo Tops (Tapin Tops National Park)	10	12

The evolutionary explanation for the high incidence of dioecy in rainforest is unclear, and various hypotheses are discussed in Richards (1997). Bawa (1980) has argued that female flowers, with no investment in male function may be able to make a high investment in female function, and that in the rainforest environment there is an advantage to producing large seeds. Richards (1997) suggested that within rainforest, individuals of a species may occur at low density with large distances between them. In consequence self-compatible hermaphrodites may be largely self-pollinated, with a loss of vigour and viability. If dioecious variants arise in such species rare long distance cross pollination may result in higher quality offspring, and hence a long term evolutionary advantage despite lower fecundity than in self-compatible hermaphrodites.

Regardless of the original advantages of dioecy the consequence when rainforest stands are very highly fragmented is a high risk of local extinction for dioecious taxa (Bond 1994) and little capacity for successful colonisation of new sites.

While continued selfing by self-compatible hermaphrodites may result in a decline in offspring 'quality' (Richards 1997), selfing may permit the local survival of species in fragmented stands where individual populations are severely reduced (we did not attempt to test the viability of seeds from self-pollinated flowers - but such a study would provide important information about the long term viability of isolated populations).

Studies in various overseas rainforests have indicated that, generally, outcrossing predominates (e.g., Bawa et al. 1985, Murawski et al. 1994, Murawski & Hamrick, 1991, O'Malley & Bawa 1987, Proenca & Gibbs 1994), although the spatial isolation of trees may influence the degree of outbreeding and fecundity (House 1985, 1992, 1993, Appanah & Chan 1981, Murawski et al. 1990). Our results are comparable with those from elsewhere, but many hermaphroditic species retain some capacity for self-pollination. This ability may be important for survival of biodiversity in the face of continuing disturbance to rainforest, and may also explain survival during periods of natural rapid change.

Once established, the ability to survive disturbance will be aided by an ability for vegetative regrowth. A considerable number of rainforest species in New South Wales and in monsoon forest (Floyd 1990, Bowman 1991) have this facility, and our observations of regeneration from the 1994 fire demonstrate that rainforest recovery from a single intense fire is possible, although the effects of repeated burning may be more serious.

Our observations suggest that in developing management and rehabilitation plans for fragmented rainforest stands particular attention should be given to dioecious species, which may form a large proportion of the flora at some sites.

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Clearing of native woody vegetation in the New South Wales northern wheatbelt: extent, rate of loss and implications for biodiversity conservation

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Clearing of native woody vegetation in the New South Wales northern wheatbelt was mapped for the period 1985–2000. The study area comprises the Moree 1: 250 000 scale map sheet and portions of adjacent map sheets. Unpublished draft mapping of native woody vegetation types, based on 1985 aerial photography and a large set of floristic data from field surveys, was used as a baseline for this study. Mapping of clearing was carried out by intensive visual interpretation of Landsat TM satellite imagery. Systematic validation, which compared the satellite interpretation to low-level aerial photography at randomly allocated point locations, showed that the method was highly accurate in detecting vegetation clearing including in the open woodlands and shrublands that characterise much of the study area. Comparisons with previously published mapping of statewide clearing patterns, based on an automated classification of Landsat TM imagery, showed that our intensive visual interpretation detected substantially more clearing. Average annual clearing rates were 8 times higher that those derived from the previous mapping.

Results of the study show that substantial clearing of native woody vegetation is continuing in the northern wheatbelt. Over 110 000 ha of native woody vegetation were cleared between 1985 and 2000. Clearing rates were highest in the four year monitoring period that preceded the introduction of the Native Vegetation Conservation Act. *The subsequent two year monitoring period saw substantially lower clearing rates, though further monitoring is needed to determine if this trend will continue. An analysis of spatial patterns highlighted continued high rates of loss in the most depleted parts of the study area. Results for individual vegetation types indicate that regrowth open shrublands and woodlands and Coolabah (*Eucalyptus coolabah*) dominated woodlands were the most heavily cleared.*

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Introduction

Temperate eucalypt woodlands are among the most poorly conserved and threatened ecosystems in Australia (Yates & Hobbs 2000). In the wheatbelt of Central New South Wales most of the original temperate woodlands have been cleared for agriculture over the last two hundred years (Benson 1999). What remains is mostly present as fragmented remnants which are subject to further threats such as weed invasion, altered fire regimes and overgrazing by domestic stock and feral animals (Fig. 1). The responses of biodiversity to the loss and fragmentation of native vegetation are complex and often difficult to predict in detail (e.g. Cunningham 2000) but the overall consequences of such drastic change are clear and include population and species extinctions and genetic loss (Saunders 1994, Ford et al. 1995, EPA 1997, Sivertsen & Clarke 2000). Population declines and extinctions would be expected to continue long after clearing had occurred, possibly for several centuries (Saunders et al. 1991, Tilman et al. 1994).

Extensive clearing in Central New South Wales has continued over the last three decades, in part driven by high returns available from wheat and cotton cultivation compared to grazing (Benson 1999, Beare et al. 1999). The area sown to cotton in New South Wales increased by approximately 80% between 1989 and 1997 (Bray 1999) while that for wheat increased by approximately 50% between 1992 and 1998 (Australian Bureau of Statistics, http://www.abs.gov.au). Sivertsen and Clarke (2000) present a summary of the area of woody vegetation in the New South Wales northern wheatbelt showing dramatic declines between the 1970s and 1980s with lower, though still substantial, declines between the 1980s and 1990s.

The recognition that native vegetation clearance is the single greatest threat to terrestrial biodiversity in New South Wales (EPA 2000) has prompted a number of legislative and policy responses. In 1995 State Environmental Planning Policy No. 46 on the protection and management of native vegetation was introduced as an attempt to prevent inappropriate land clearing. This was replaced by the *Native Vegetation Conservation (NVC) Act* which began operation in 1998 and sets out a system of regional vegetation management planning by local committees. In 2001 a preliminary determination was made to list clearing and fragmentation of native vegetation as a

Fig. 1. A typical pattern of remaining native woody vegetation in the wheatbelt near Moree.

Key Threatening Process under the *New South Wales Threatened Species Conservation Act*. The determination lists impacts of clearing including the loss of habitat and species populations, expansion of dryland salinity, increased habitat for exotic species and increased greenhouse gas emissions.

Considering all of the above, it is alarming that there is little reliable, fine-scale information available on the distribution and extent of clearing in Central New South Wales. Some recent data are available on the total area of clearing applications that landholders submitted to the Department of Land and Water Conservation but interpretation of these data is difficult. Not all clearing requires approval under the *NVC Act* and clearing may not occur for up to 4 years after approval is granted. Some applications cover areas that have already been partially cleared and illegal clearing is obviously not included in the application data.

Precise and accurate remote sensing methods are required to monitor vegetation loss over an area as large as the wheatbelt. Large scale aerial photography is suitable but acquisition and interpretation is prohibitively expensive, especially for regular monitoring. Several studies have used satellite imagery to map the distribution of clearing. The New South Wales component of a national study by Barson et al. (2000) attempted to determine clearing rates from Landsat Thematic Mapper (TM) satellite data for the period 1991–95 using automated classification methods. This study only considered vegetation with an average tree canopy cover of at least 20% which excludes large areas of woodlands and shrublands with sparse cover (Benson 1999). Another study of Landsat TM data for the period 1995–97 (ERIC 1998) used an automated classification to identify areas of possible clearing followed by visual inspection of these areas. This study claimed to detect vegetation with a minimum tree canopy of 12–15% and found significantly higher rates of clearing than Barson et al. (2000). Although an improvement, the ERIC study still excluded many areas of sparse vegetation which will have high conservation significance. Sivertsen and Metcalfe (1995) mapped native woody vegetation in the southern wheatbelt with tree canopy cover down to 5%. The same threshold is being used for further mapping in the northern and central wheatbelt. Ideally, measurements of clearing would also consider vegetation down to this level of canopy cover.

Direct visual interpretation of satellite imagery is an alternative to automated classification methods and is supported by results from a number of local and overseas studies. Complex patterns involving irregular and diffuse boundaries are more reliably identified using visual interpretation and the human ability to assimilate shape, texture and spatial context is not yet matched by automated methods which only consider spectral information (Chuveico & Martinez Vega 1990, Kushwaha et al. 1994, Janssen & van der Wel 1994, Graetz et al. 1995). Hill and Kelly (1987) found Landsat TM satellite imagery more suitable for visual interpretation than other forms of analysis when considering semi-arid woodlands in southern Queensland. Milne and O'Neill (1989) commented that visual interpretation relies heavily on the skills of the observer and can be prone to inconsistency but they supported its use for identifying abrupt landcover changes such as vegetation clearing.

In this paper we present the first results of a study using visual interpretation of satellite imagery in comparison with available vegetation mapping and aerial photography. Our aims were:

- To measure the remaining extent and rate of loss of native woody vegetation with canopy cover down to 5% over a series of time intervals.
- To use available vegetation mapping to measure the area and rate of loss of vegetation types for each time interval.
- To measure the degree of fragmentation of native woody vegetation for each time interval.
- To identify trends in clearing, overall and for individual vegetation types, and speculate on driving factors and possible future trends.
- To compare the results of visual interpretation of satellite imagery to previous results from automated methods.
- To comment on implications for biodiversity conservation and identify needs for further monitoring and research.

Study Area

Location

The study area is the northern section of the NSW National Parks and Wildlife Service's wheatbelt vegetation mapping area (Fig. 2). It occupies approximately 2.4 million hectares and is bounded by the NSW state border to the north, the Western Division, the 30th parallel of latitude and by a line approximating the 300 metre contour interval to the east. It takes in the Moree 1: 250 000 scale map sheet and parts of the St. George, Goondiwindi, Angledool and Inverell map sheets. It includes the towns of Moree, Goondiwindi, Collarenebri, Rowena and Croppa Creek and the following Local Government Areas: Moree Plains (94% within the study area), Walgett (30%), Narrabri (15%), Yallaroi (13%) and Inverell (7%).

The study area encompasses portions of two important inland river systems, the Macintyre/Barwon and the Gwydir which form part of the Murray/Darling Drainage Basin. The Gingham Watercourse and Lower Gwydir Watercourse are identified as wetlands of international importance (ANCA 1996).

Topography, geology and soils

The predominant topographic feature of the study area is the low, flat to very gently undulating floodplains which are intermittently inundated by floodwaters. In the eastern section of the survey area isolated, low basalt hills and the sandstone footslopes of the Mastermans Range occur.

Much of the floodplains are Quaternary alluvium overlying sandstone, siltstone and claystone of the Rolling Downs Group from the Cretaceous Period (Chesnut 1968, Mond et al. 1968, Offenberg 1973). In the eastern section of the study area, the footslopes of the Mastermans Range are composed of Warialda sandstone formations from the Jurassic Period which form the basis of the shallow, sandy, low fertility soils (Chesnut 1968). Small isolated hills scattered in the east are intrusions of Tertiary basalt (Mond et al. 1968).

The major soil types can best be described as cracking clays of moderate fertility (Laut et al. 1980). Deep grey self-mulching clays dominate most of the study area as well as coarsely structured sandy clays. These soils have a moderate salt content 20–35 cm from the surface and are susceptible to water logging so that a small rise in the water table can cause salinity problems (Northcote 1979). Relic streamlines of residual Quaternary colluvial deposits provide a distinctive sandy red-brown duplex soil that supports quite different vegetation to the surrounding plains. Heavy textured brown and grey soils and black earths commonly display surface micro relief termed gilgai. Soil fertility is higher in the east than the west due to the rich basalt caps of the great dividing range (Morgan & Terrey 1992).

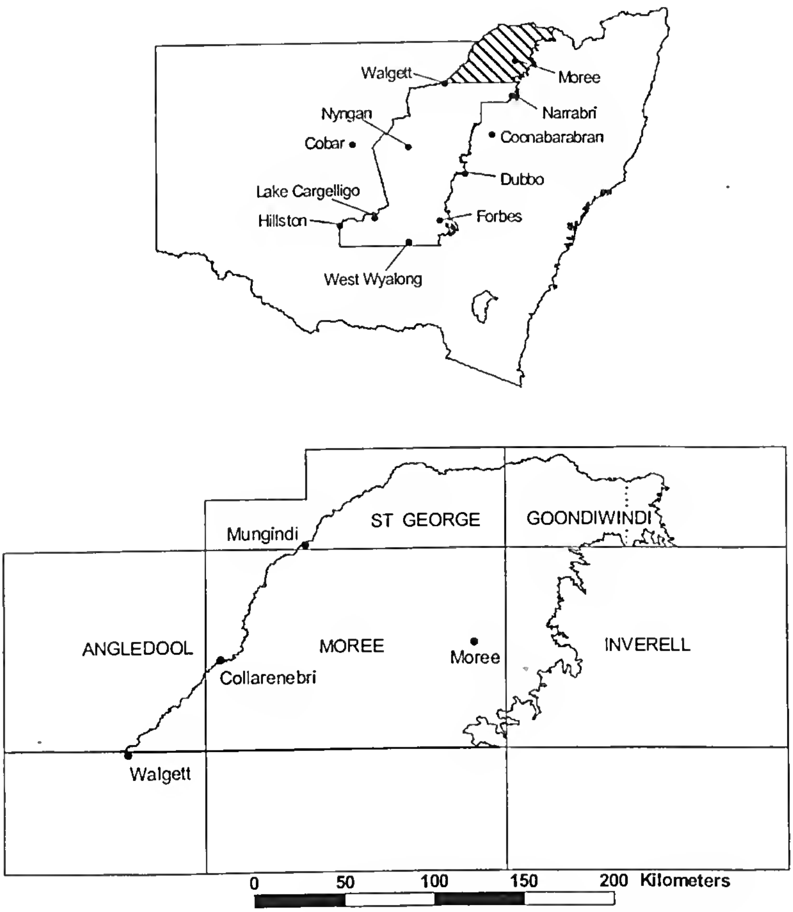

Fig. 2. The NSW National Parks and Wildlife Service wheatbelt vegetation mapping area (top) with the study area for this paper shown crosshatched. The 1: 250 000 scale map sheets covering the study area (bottom).

Morgan and Terrey (1992) identified three bioregional provinces within the study area (Fig. 3): Castlereagh-Barwon Province with extensive alluvial plains; Northern Outwash Province with low rises and alluvial fans; and Northern Basalts Province with gentle undulations and basalt capped hills. Two further provinces, Peel with fine grained hilly sediments and Northern Complex with sedimentary hills and ranges, occupy small areas on the eastern margin of the study area.

Climate

Average annual rainfall varies across the study area from 496 mm at Collarenebri in the west to 638 mm at Croppa Creek in the east (Bureau of Meteorology 1992). Rainfall occurs throughout the year with peaks in summer and autumn. The highest average rainfall is in the north-east of the study area while it becomes increasingly sporadic with lower average falls in the west. Evaporation rates are, on average, considerably higher than precipitation rates. Average temperatures range from 35°C in summer to 5°C in winter (Bureau of Meteorology 1992). Humidity is generally low and when combined with high temperatures the evaporation potential is greatly increased, resulting in a seasonal moisture deficit.

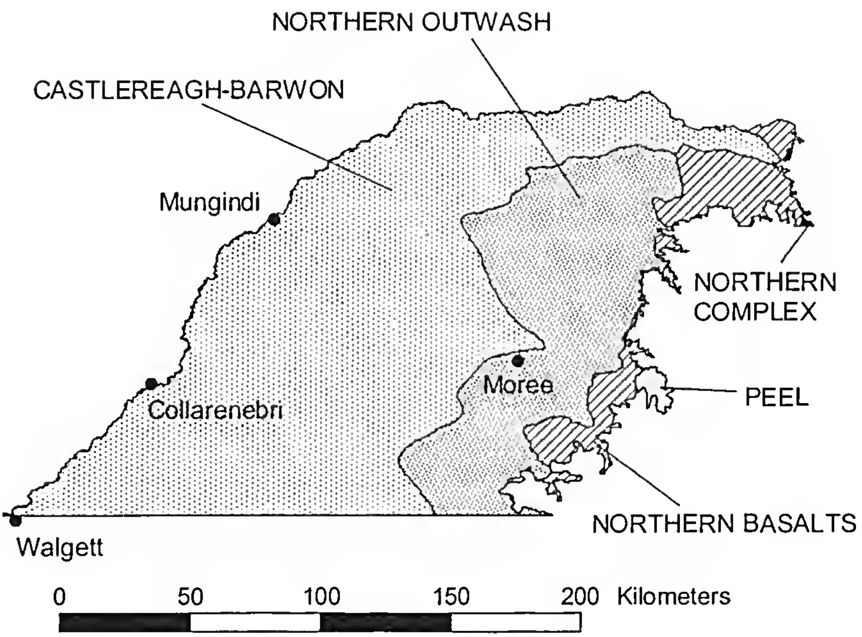

Fig. 3. Bioregional provinces of Morgan and Terrey (1992).

Vegetation

The study area was once a part of the continuous belt of temperate woodlands that ran from Queensland to Victoria (Beadle 1981, Sivertsen & Clarke 2000). Woodland types include savanna woodlands of River Red Gum (*Eucalyptus camaldulensis)*, Coolabah (*Eucalyptus coolabah*), Black Box (*Eucalyptus largiflorens*) and Brigalow (*Acacia harpophylla*); shrub woodlands of Poplar Box (*Eucalyptus populnea* subsp. *bimbil)* and White Cypress Pine *(Callitris glaucophylla)*, Belah (*Casuarina cristata*) and Myall (*Acacia pendula*); Carbeen woodlands (*Corymbia tessellaris*) and box-ironbark woodlands of Poplar Box (*Eucalyptus populnea* subsp. *bimbil)* and Silver Ironbark (*Eucalyptus melanophloia*) (Beadle 1981, Sivertsen & Metcalfe unpublished). Lignum shrublands, wetlands and treeless grasslands are also found in the study area.

The native woody vegetation of the NSW wheatbelt has crown covers ranging from 5% to almost 100% (treating crowns as solid for the purpose of description) but is generally sparse over much of its extent (Sivertsen & Metcalfe 1995). Over half of the native woody vegetation mapped by Sivertsen & Metcalfe (unpublished) in the present study area ranges from scattered trees to open woodlands.

Landuse and Tenure

The flat plains and moderately fertile soils make the area very attractive for agricultural development (Laut et al. 1980). Over the past 50 years the main landuse for the Moree area had been pastoralism, with sheep dominating in the east and cattle in the west. Currently, the major landuses are grazing and cereal farming although the area of both irrigated and dryland cotton cultivation is increasing. The Moree area is the major region in NSW for crops and cattle and had the greatest wheat yield in tonnes per hectare from 768 000 ha sewn in 1997 (Bray 1999).

Most of the study area is in private ownership. Crown Land constitutes approximately 5% of the area. The only areas solely dedicated to conservation are five nature reserves: Boomi (156 ha), Boomi West (149 ha), Careunga (469 ha), Midkin (374 ha) and Boronga (195 ha). Together they occupy 0.05% of the study area. There are no State Forests in the study area.

Methods

Draft vegetation mapping for the northern wheatbelt (Sivertsen & Metcalfe unpublished) provided baseline data for this study. This mapping was derived from interpretation of 1985 aerial photography combined with multivariate analysis of field survey data following similar methods to Sivertsen and Metcalfe (1995). It defines 17 types of native woody vegetation (shrublands, woodlands and forests). Treeless native grasslands, highly modified native vegetation and areas with isolated scattered trees were not mapped. Some sedge dominated wetlands were mapped but these are omitted from the present analysis. Our baseline data are thus a subset of the native vegetation within the study area and hence our analysis of vegetation loss will be conservative.

The extent of clearing of native woody vegetation in 1994, 1998 and 2000 was derived from visual interpretation of Landsat TM satellite imagery (Table 1). We defined clearing as a change in canopy cover from greater than 5% to less than 5%. In addition, clearing was characterised on the images by the lack of near infra-red reflectance typical of vegetation, regular boundaries and more uniform texture and colour compared to adjacent areas of woody vegetation. Some sites with sparse tree cover, where the understorey is completely removed and replaced by cropping or fertilised pasture, will display a marked change in reflectance even though the canopy cover does not change. We treat such instances as clearing of native vegetation. We restricted our analysis to vegetation remnants with an area of at least 10 ha consistent with the limits of resolution of the satellite imagery and our methods.

For 1994 and 1998 we used hardcopy photographic images with 30 m × 30 m pixel size and bands 2 (visible), 4 (near infra-red) and 5 (mid infra-red). Clearing boundaries were drawn on a transparent overlay printed with the baseline vegetation mapping and fixed over each satellite image. The boundaries were then digitised. For the 2000 analysis we used Landsat digital data displayed with ERDAS Imagine 8.4 software on a UNIX workstation. The displayed images were visually interpreted and clearing boundaries were digitised directly on-screen. Inspection of aerial photographs for 1984/85 was used to assist with the interpretation of satellite images. Where an area had very sparse vegetation on the aerial photograph and it was difficult to determine whether it had been cleared from the satellite image the area was marked as uncertain.

There are a number of factors that contribute to uncertainty in interpretation. *Eucalyptus* and *Acacia* species and chenopods, common in most of the study area, have low reflectance at the near infra-red wavelengths used to distinguish vegetation and show little variation with substrate or seasonal change (Milne & O'Niell 1989). When vegetation is sparse, soil and bedrock are a dominant component of the spectral

Table 1. Landsat TM images used for the study.

Path	Row	Date	Map Sheets
90	80	2 Oct. 1998 14 Nov. 1999	Western Goondiwindi
91	80	17 Dec. 1994 20 Oct. 2000	St George, Goondiwindi, Northern Moree & Inverell
91	80	10 Apr. 1996	Northern Moree
91	80	10 Jan. 1998	St George, East Goondiwindi, Northern Moree and Inverell
91	81	17 Dec. 1994 20 Oct. 2000	Southern Moree & Southern Inverell
91	81	9 Mar. 1996	Southern Moree
91	81	12 Dec. 1998	Southern Moree & Southern Inverell
92	80	14 Mar. 1995 22 Mar. 1998 14 Dec. 2000	Angledool & South West Moree
92	80	22 Mar. 1998	Angledool & South West Moree

information. Soils with either very high or very low reflectance will narrow the range of spectral information. These factors make it more difficult to distinguish between the presence and absence of sparse woody vegetation.

We assessed the accuracy of the visual interpretation procedure using additional 1996 Landsat imagery and 1: 50 000 scale aerial photography, both of which were available for the Moree 1: 250 000 scale map sheet. The satellite images were interpreted using the methods described above. Next, random point locations were selected within the area covered by five runs of the aerial photographs such that there were 60 points in the newly cleared category and 100 points in the no change category. Each point in the cleared category was then accurately plotted onto the corresponding 1996 aerial photograph to check for errors in identifying clearing. The points in the no change category were plotted onto both the 1996 and 1985 photographs to check for errors in identifying no change. For the 1998 analysis, an accuracy assessment was carried out using the same method with specially flown 1: 16 000 scale aerial photography.

We assessed the allocation of the uncertain category in our satellite image interpretation with a similar procedure. 60 random point locations were selected from uncertain areas on the 1996 Landsat imagery and checked on the corresponding aerial photographs. For the 1994 interpretation we carried out aerial inspections of all uncertain areas and allocated them to either cleared or no change. This was not possible for 1998 or 2000 and we have excluded the uncertain category from the measurement of vegetation clearing presented here. As such our results are conservative.

We compared the results of our visual interpretation method with previously published data derived from an automated classification of Landsat imagery. These data accompanied a report on vegetation clearing in New South Wales, for the period 1995 to 1997, commissioned by the NSW Department of Land and Water Conservation (ERIC 1998). We compared the extent and location of clearing identified in the ERIC study for 1995 to 1997 to our results for the period 1994 to 1998.

Analyses of the mapped data were carried out using ArcView software. For the baseline 1985 mapping and each of the 1994, 1998 and 2000 coverages we measured the total area of native woody vegetation and the area of each of the vegetation types of Sivertsen and Metcalfe (unpublished). For 1994, 1998 and 2000 we calculated the following statistics for total native woody vegetation and each vegetation type:

- area cleared since the last measurement date;
- area remaining as a percentage of the 1985 extent;
- average annual clearing rate (hectares per year);
- average annual clearing rate as a percentage of the 1985 area;
- average annual clearing rate as a percentage of the area at the last measurement date.

The study area straddles Australian Map Grid Zones 55 and 56. The total area measurements for native woody vegetation were carried out for each map zone independently and the results combined to avoid distortions from reprojecting the data which would be in the order of about 1% overestimation. For measurements of individual remnant areas (see below) and the area of individual vegetation types we reprojected the smaller zone 56 portion of the study area into zone 55 to produce a combined coverage.

For a preliminary assessment of fragmentation of remaining native woody vegetation we calculated the following statistics for total native woody vegetation and each vegetation type.

Number of patches

For overall vegetation this is the number of distinct remnants in the study area. Clearing can lead to both a decrease in this number, through the loss of remnants, and an increase, through the splitting of previously intact patches into new separate patches (Fig. 4). For this reason the number of patches must be interpreted in conjunction with changes in total area. For vegetation types the number of patches means the number of spatially distinct stands of a given type. This is not the same as the number of remnants since stands can be surrounded by other types of native woody vegetation and more than one stand of a type can occur within a single vegetation remnant. But following the number of patches of a vegetation type over time in conjunction with the total area of that type gives an indication of the degree to which its distribution is becoming fragmented.

Minimum, median and maximum patch area

For overall vegetation these statistics relate to the area of spatially distinct remnants. Clearing can lead to both an increase in minimum patch area, through the loss of the previously smallest remnants, or a decrease, through the subdivision of existing remnants (Fig. 4). As mentioned previously, the lower limit for patch area in this study was 10 ha. We have reported on median rather than average areas because of the often highly skewed distribution of area values. For vegetation types the patch area statistics refer to spatially distinct stands of a given type. The minimum patch area for types can vary in either direction as for overall vegetation. Note that the minimum patch area for a vegetation type may be less than 10 ha where the patch is part of a larger vegetation remnant.

Median perimeter to area ratio for patches

Perimeter to area ratio gives some indication of the vulnerability of a patch of vegetation to edge effects and relates to both the size and shape of a patch (Fig. 5). For overall vegetation we calculated the ratio of the total perimeter length of a vegetation remnant to its area. For vegetation types we only consider that part of the perimeter that is adjacent to cleared land (Fig. 6). Accordingly we report on the number of patches that are immediately adjacent to cleared land and it is only these patches that are included in the calculations. To account for the boundary of the study area we masked out those sections of patch perimeters that lay on the boundary.

Size distribution of patches

To further illustrate trends in the sizes of vegetation remnants and patches of individual vegetation types we present histograms showing the percentage of remnants or patches in different size classes. Note that our present analysis of fragmentation is preliminary. A comprehensive assessment would also consider the spatial arrangement of vegetation, condition and disturbance attributes, the requirements and distribution of particular plant and animal taxa, and the interaction between these various elements.

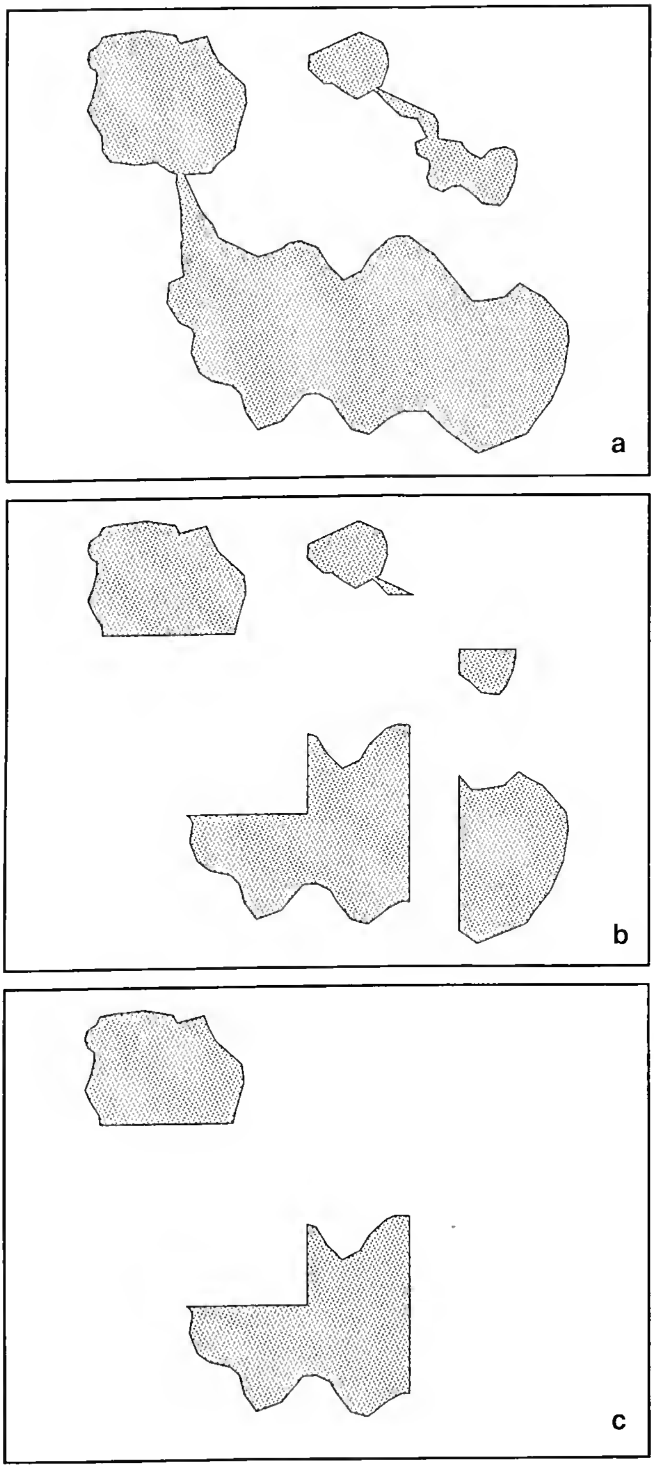

Fig. 4. Change in the number of remnants and the minimum remnant size with clearing. Initially there are two remnants (a). A clearing event leads to an increase in the number of remnants and a decrease in minimum remnant area (b). A further clearing event leads to a decrease in the number of remnants and an increase in minimum remnant area (c).

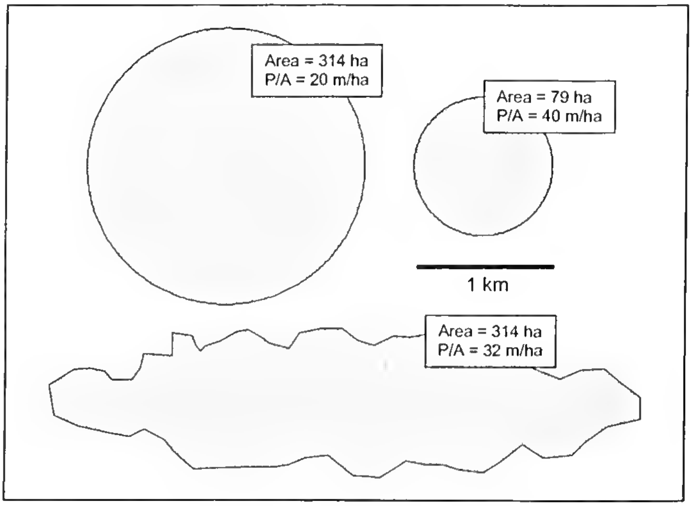

Fig. 5. Illustration of perimeter to area ratio (values are in metres per hectare). The large circle has the smallest ratio of perimeter to area (P/A) of the three features, i.e. it has the least proportion of its area near the edge. The irregular feature has the same area as the large circle but a higher P/A value due to its longer perimeter. The small circle has the highest P/A value, i.e. the most proportion of area near the edge.

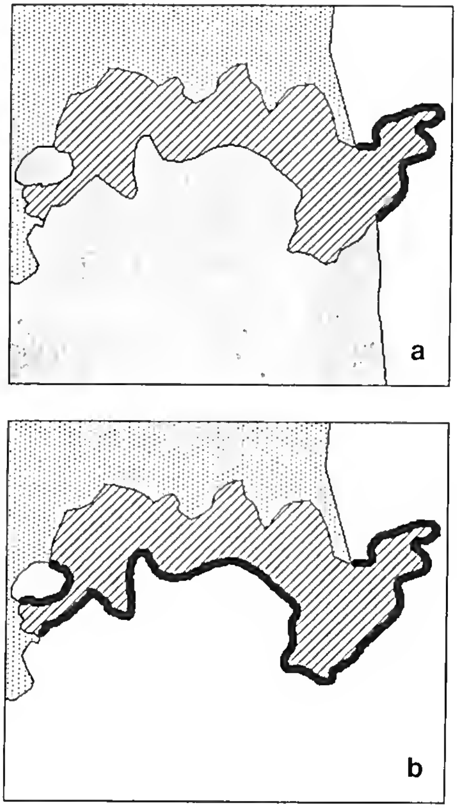

Fig. 6. The length of the exposed perimeter (bold line) for the cross-hatched vegetation type (a) increases after a clearing event (b).

Results

Accuracy and bias assessment

The comparison of 1996 satellite image interpretations and aerial photography for the Moree 1: 250 000 scale map sheet gave an overall accuracy of 96.8% (Table 2). For 1998 the same comparison gave an overall accuracy of 94.7% (Table 3). We conclude that our methods reliably and consistently distinguish recent clearing and areas of no change.

In the comparison of the uncertain category on the 1996 satellite imagery with aerial photographs (Table 4), 19 (32%) of the 60 validation points were in recently cleared vegetation. The uncertain category represents areas with very sparse vegetation at the lower end of resolution for our method. But our results indicate that the uncertain category is informative and, if resources were available, field or aerial inspections of areas in this category would detect further clearing. As stated previously, the uncertain category has been excluded from our analyses of the 1998 and 2000 interpretation. The total area mapped as uncertain was 17 822 ha for 1998 and 7531 ha for 2000.

Table 2. Accuracy assessment of 1996 satellite image interpretation for the Moree 1: 250 000 scale map sheet. Areas of recent clearing and no change were delineated on aerial photographs and randomly located points within these areas were compared to the satellite image interpretation.

	Aerial photography Cleared	No change
Total number of points	60	100
Number mapped as cleared from satellite imagery	56	1
Number mapped as no change from satellite imagery	4	99
% accuracy	93.3	99.0
Overall accuracy (total correct/total points) 96.8%		

Table 3. Accuracy assessment of 1998 satellite image interpretation for the Moree 1: 250 000 scale map sheet. Areas of recent clearing and no change were delineated on aerial photographs and randomly located points within these areas were compared to the satellite image interpretation.

	Aerial photography Cleared	No change
Total number of points	57	95
Number mapped as cleared from satellite imagery	54	5
Number mapped as no change from satellite imagery	3	90
% accuracy	94.7	94.7
Overall accuracy (total correct/total points) 94.7%		

Table 4. Examination of areas mapped as uncertain in the 1996 satellite image interpretation for the Moree 1: 250 000 scale map sheet. 60 random point locations within uncertain areas were checked for clearing on aerial photographs.

	Aerial photography Cleared	No change
Satellite image interpretation uncertain	19 (32%)	41 (68%)

Results for overall native woody vegetation

Figure 7 shows the extant native woody vegetation at the beginning of the study period in 1985. Its total area was 661 238 ha, representing 27.3% of the study area. There was a strong correlation between the distribution of the remaining vegetation and the bioregional provinces of Morgan and Terrey (1992) with the eastern provinces having already been very extensively cleared.

Clearing

Over 110 000 ha of native woody vegetation were cleared between 1985 and 2000 representing over 16% of the 1985 baseline vegetation mapping (Table 5). Average clearing rates differed markedly between the different measurement periods with the highest rate, in excess of 10 000 ha per year, recorded in the period ending 1998 (Fig. 8). The subsequent period, ending 2000, saw the clearing rate drop to approximately one third that of the preceding period. Figure 9 shows all clearing detected during the study period.

Fragmentation

In addition to the substantial reduction in area, the remaining native woody vegetation became increasingly fragmented over the study period. The number of remnants has steadily increased (Table 5) as formerly contiguous vegetation has been split by clearing. The effect of this creation of new remnants outweighed the complete clearing of other remnants which we observed. Note that the largest remnant size for all monitoring periods is over 200 000 hectares. A large proportion of the vegetation in the western part of the study area is inter-connected. Although some of the connections are very narrow, the whole of the connected portion is treated as a single remnant under our criterion of remnants being spatially distinct.

The results for median remnant area and perimeter to area ratio show that the vegetation is being successively reduced to smaller and more exposed fragments. The percentage of remnants with areas of 100 ha or less increased at the expense of remnants in larger size classes (Fig. 10).

Spatial patterns

In general the density of clearing across the study area reflects the density of vegetation at the beginning of the study period and most clearing occurred in the Castlereagh-Barwon province (Fig. 7 and Fig. 9). Particularly large areas were cleared to the east of Collarenebri and Mungindi. The major bioregional provinces in the eastern half of the study area, Northern Outwash and Northern Basalts, were extensively cleared during the 1970s and earlier. Table 6 shows the extent and percentage of native woody vegetation in these three provinces for each monitoring period.

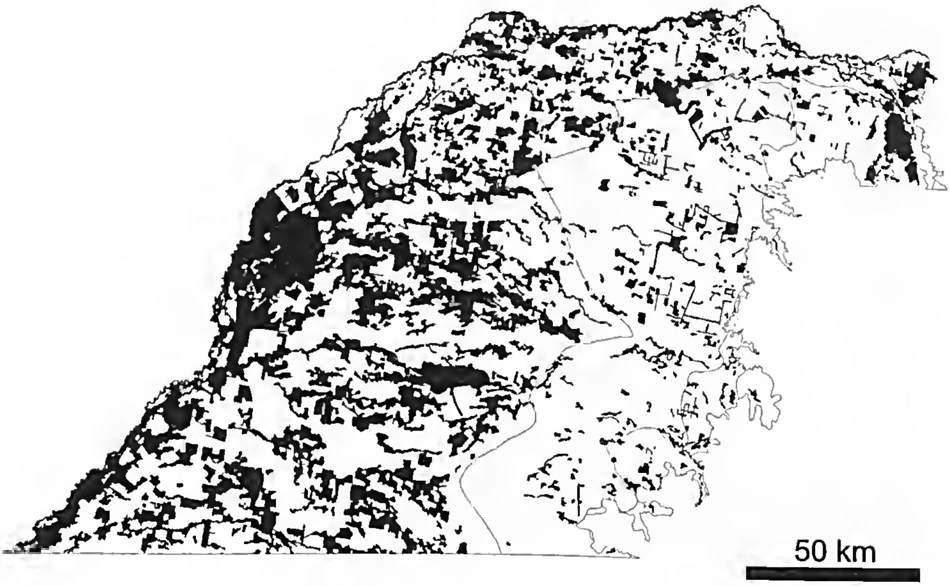

Fig. 7. The distribution of native woody vegetation at the start of the study period. Lines indicate the boundaries of bioregional provinces.

Table 5. Results for overall native woody vegetation

	1985	1994	1998	2000	Overall
Extant vegetation (ha) (% study area)	661 238 (27.3%)	600 721 (24.8%)	557 945 (23.1%)	550 911 (22.8%)	
Area cleared (ha)	-	60 517	42 776	7034	**110 327**
Area cleared (% 1985 vegetation)	-	9.2%	6.5%	1.1%	**16.7%**
Average annual clearing rate (ha/yr)	-	6724	10 694	3517	**7355**
Average annual clearing rate (as % 1985 vegetation)	-	1.02%	1.62%	0.59%	**1.1%**
Average annual clearing rate (as % previous area)	-	1.02%	1.78%	0.63%	
Number of patches	535	588	665	684	
Median patch area (ha) (min–max)	141 (11–281 564)	120 (10–242 030)	102 (10–214 617)	95 95(10–212 297)	
Median P/A ratio (m/ha)	55.5	60.0	64.1	66.3	

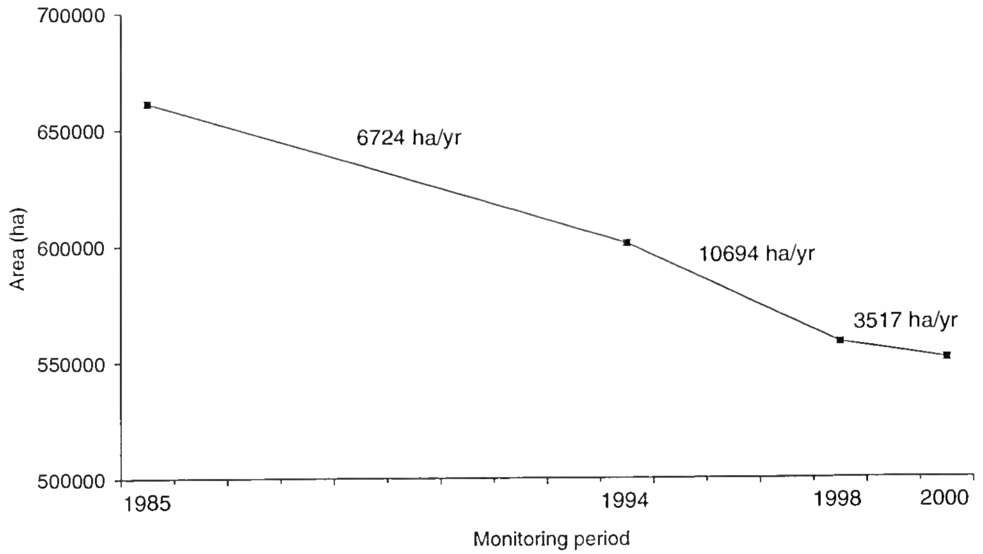

Fig. 8. Change in the area of native woody vegetation over the study period with average clearing rates shown for each monitoring interval.

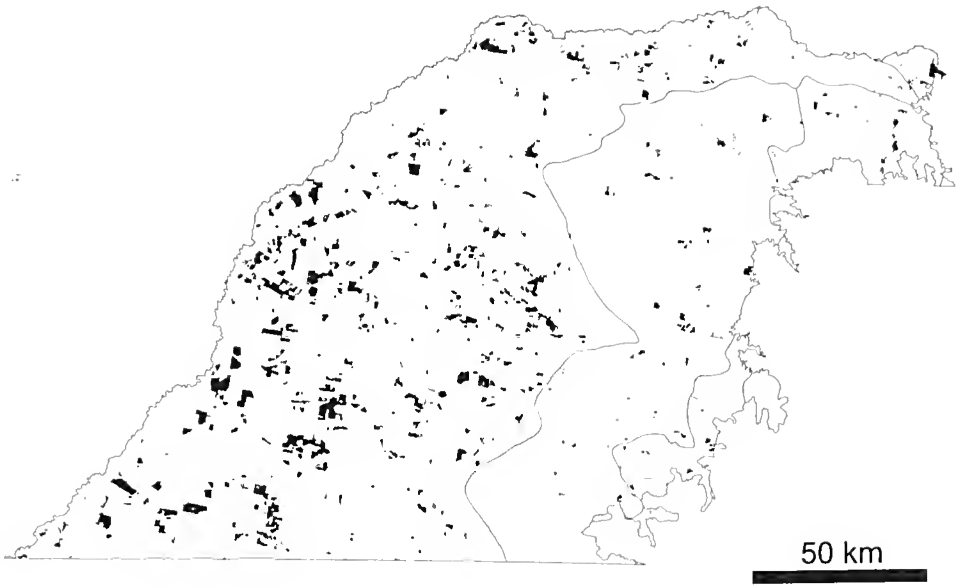

Fig. 9. The distribution of all clearing detected over the study period. Lines indicate the boundaries of bioregional provinces.

Table 6. The extent of native woody vegetation in the major bioregional provinces of Morgan and Terrey (1992).

	Area of native woody vegetation (ha and as % of province area)			
Province	**1985**	**1994**	**1998**	**2000**
Castlereagh-Barwon	579 390 (36.54%)	525 548 (33.14%)	484 654 (30.57%)	478 733 (30.19%)
Northern Outwash	50 813 (8.08%)	47 700 (7.59%)	45 811 (7.29%)	44 760 (7.12%)
Northern Basalts	31 779 (16.97%)	28 081 (15.00%)	27 501 (14.69%)	27 301 (14.58%)

Relative impacts

The pattern of relative clearing impacts is more complex than a simple east-west gradient as shown in Fig. 11. This map was derived from overlaying a regular 1 km grid of points onto the study area and calculating the percentage of native woody vegetation that was cleared throughout the study period within a 10km radius of each point. It highlights areas in the eastern portion of the study area where small clearing events have had a high relative impact. For example, north-east of Moree, where native woody vegetation was already highly depleted in 1985, further clearing resulted in losses of over 40%.

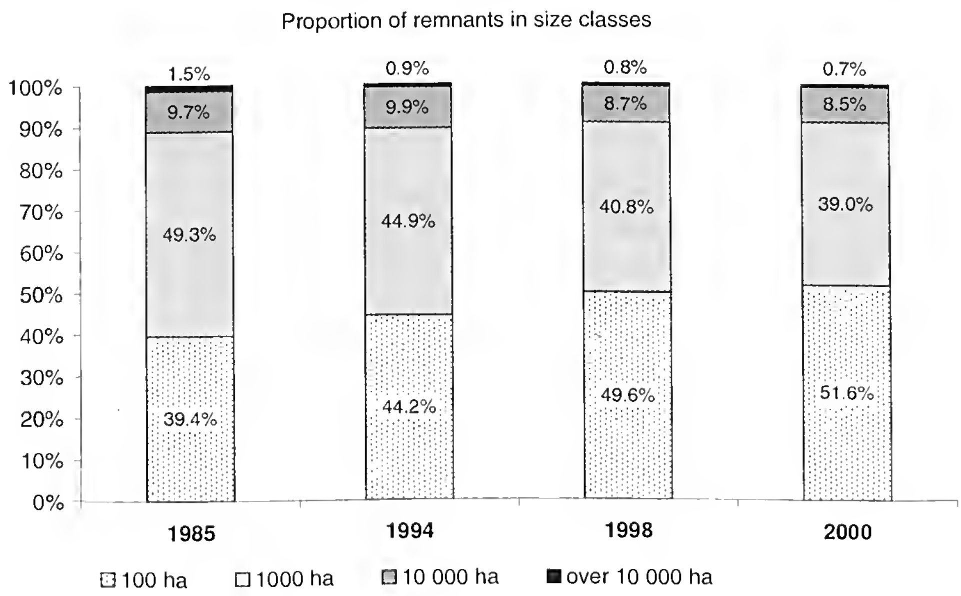

Fig. 10. Individual remnant areas over the study period expressed as the percentage of remnants in each of four size classes.

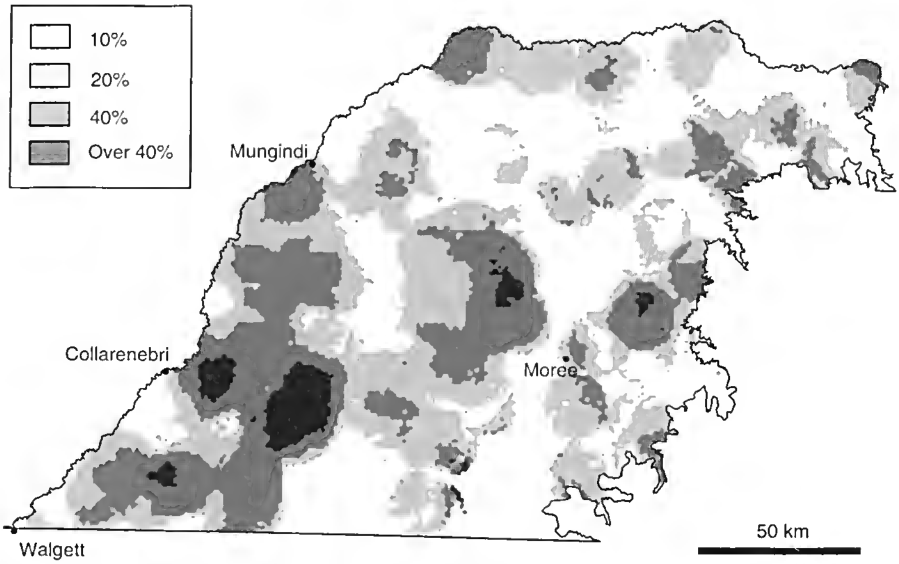

Fig. 11. The relative impact of clearing across the study area during the study period expressed as the percentage of native woody vegetation cleared within a 10 km radius.

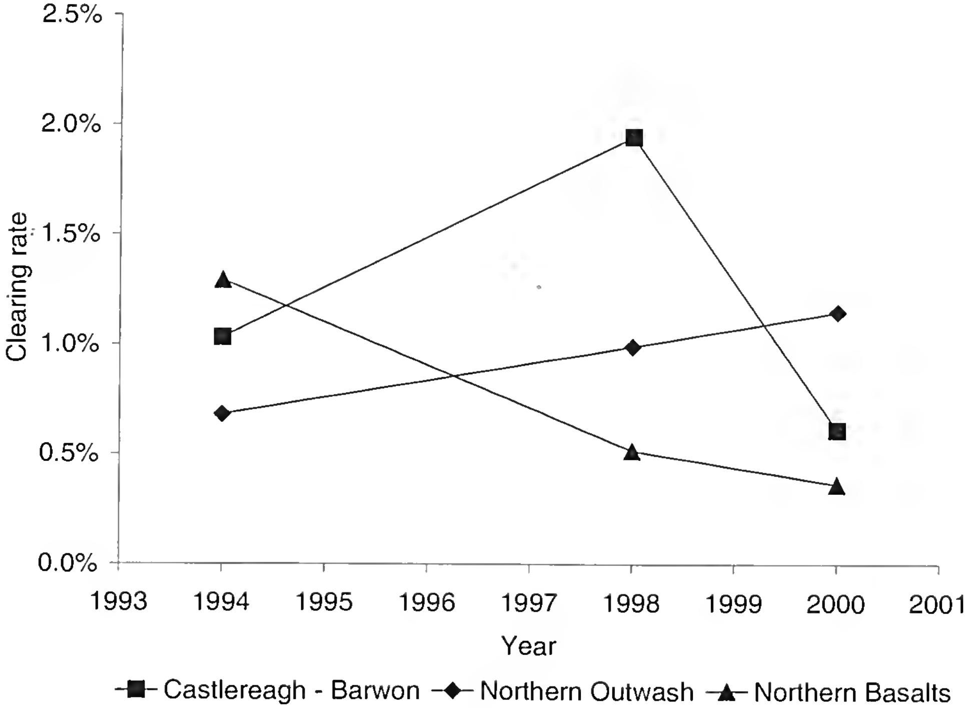

Fig. 12. Average annual clearing rates for native woody vegetation within bioregional provinces.

There were differing relative impacts for bioregional provinces, in terms of rates of percentage loss of vegetation (Fig. 12). The graph shows the average annual percentage of extant vegetation cleared during each monitoring period. Clearing rates in the western province, Castlereagh-Barwon, and eastern province, Northern Basalts, were at their lowest level in the last monitoring period ending 2000. In contrast, clearing rates for Northern Outwash province steadily increased over the study period.

Results for vegetation types

Descriptions and detailed results for each of the types of native woody vegetation mapped by Sivertsen and Metcalfe (unpublished) are listed in the Appendix.

Table 7 summarises the overall results by vegetation type ranked by the percentage of 1985 extent cleared. The greatest percentage loss occurred in Type R4: Lignum Shrublands, but given its small total extent and the difficulty in mapping this type (see Appendix) this is less significant than results for other types. The percentage loss for four extensive vegetation types exceeded the overall rate of vegetation loss for the study period. Only one vegetation type had no clearing detected during the study period.

The total percentage cleared versus 1985 extent for vegetation types is shown in Fig. 13. Vegetation types have been grouped on the basis of similar clearing versus extent values. Each of these groups is discussed below.

Group 1: Very extensive and heavily cleared

This group has one member, Type P9: Open Shrublands and Woodlands, which is defined by Sivertsen and Metcalfe (unpublished) as regrowth vegetation of various ages (see Appendix). Most of its distribution is in the Castlereagh-Barwon bioregional province. Fig. 14 shows the extant vegetation for 2000 together with vegetation that was cleared during the study period. Type P9 accounted for 28% of the native woody vegetation in the study area in 1985.

The open nature of Open Shrublands and Woodlands and large component of relatively young regrowth vegetation (see Appendix) probably makes it relatively easy and inexpensive to clear. It is also possible that there is a perception that, as regrowth vegetation with obvious signs of previous disturbance, it is of low value (Fig. 15).

The *NSW Native Vegetation Conservation Act* currently allows the clearing of regrowth vegetation that is up 10 years old without approval. However the definition of regrowth is open to interpretation since there are no definitions in the Act for the terms used in this particular exemption. Further the Act does not specify how to determine the age of vegetation or what components (trees, shrubs, grasses) should be considered. This and other exemptions for clearing under the Act are currently being reviewed by the New South Wales Government.

Group 2: Extensive and heavily cleared

Four vegetation types are in this group: R2: Floodplain Mosaic, R3: Coolabah Woodlands, R7: Coolabah-Poplar Box Woodlands, and R10: Open Coolabah

Table 7. Summary of the extent and rate of clearing for vegetation types arranged in decreasing order of proportional loss. The horizontal line indicates the general percentage rate of vegetation loss over the study period. The overall values (bottom row) are derived from the analysis of data for separate AMG map zones as described in the Methods and presented in Table 5. The values for vegetation types are derived from the analysis of data merged into AMG Zone 55.

Vegetation type	1985 area (ha)	Area cleared (ha) (ha/yr)	Percentage of 1985 area	Average clearing rate (ha/yr)	Average clearing rate (% 1985 area)
R4: Lignum Shrublands	1212	357	29.5%	24	1.96%
P9: Open Shrublands and Woodlands	186 604	41 875	22.4%	2792	1.50%
R2: Floodplain Mosaic	71 586	13 948	19.5%	930	1.30%
R10: Open Coolabah Woodlands	86 689	16 314	18.8%	1088	1.25%
P3: Open Poplar Box Woodlands	21 954	4085	18.6%	272	1.24%
P8: Belah Woodlands	12 172	1988	16.3%	133	1.09%
R3: Coolabah Woodlands	86 064	12 514	14.5%	834	0.97%
P10: Brigalow Woodlands	5792	823	14.2%	55	0.95%
H5: Yetman Hills Complex	17 201	2422	14.1%	161	0.94%
R7: Coolabah-Poplar Box Woodlands	93 935	11 679	12.4%	779	0.83%
R8: White Cypress Pine-Carbeen Woodlands	16 521	1970	11.9%	131	0.80%
R5: Myall Woodlands	8466	839	9.9%	56	0.66%
P4: Poplar Box Woodlands	11 205	1097	9.8%	73	0.65%
H8: Basalt Hills	1649	146	8.9%	10	0.59%
F4: Yetman Footslopes Complex	697	19	2.8%	1	0.19%
R1: River Red Gum-Coolabah Forests	39 415	455	1.2%	30	0.08%
P6: Iron Bark-White Cypress Pine Woodlands	132	0	0.0%	0	0.00%
Overall	**661 238**	**110 327**	**16.7%**	**7355**	**1.1%**

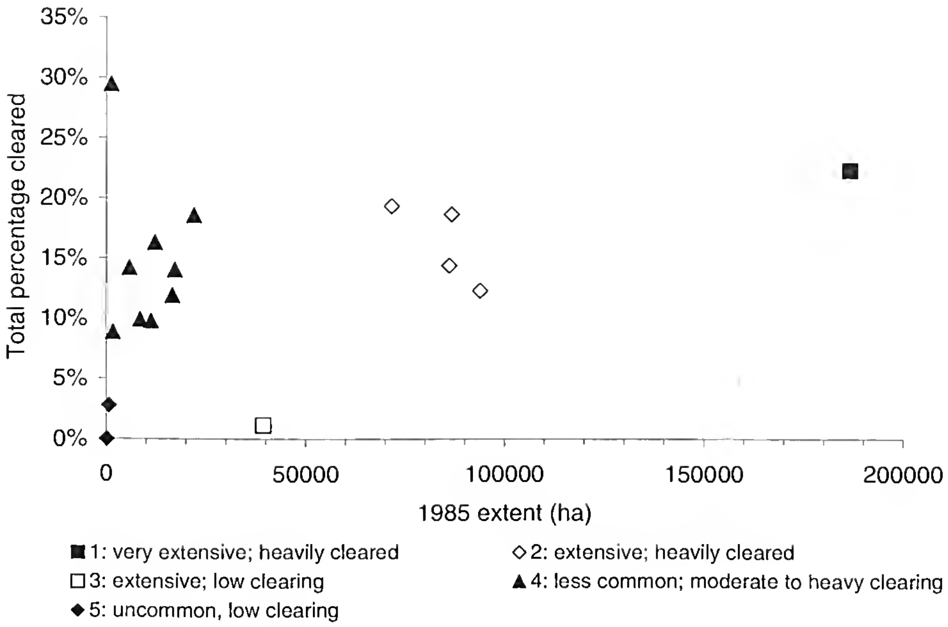

Fig. 13. Relationship between the percentage cleared and 1985 area for vegetation types. Groupings are referred to in the text.

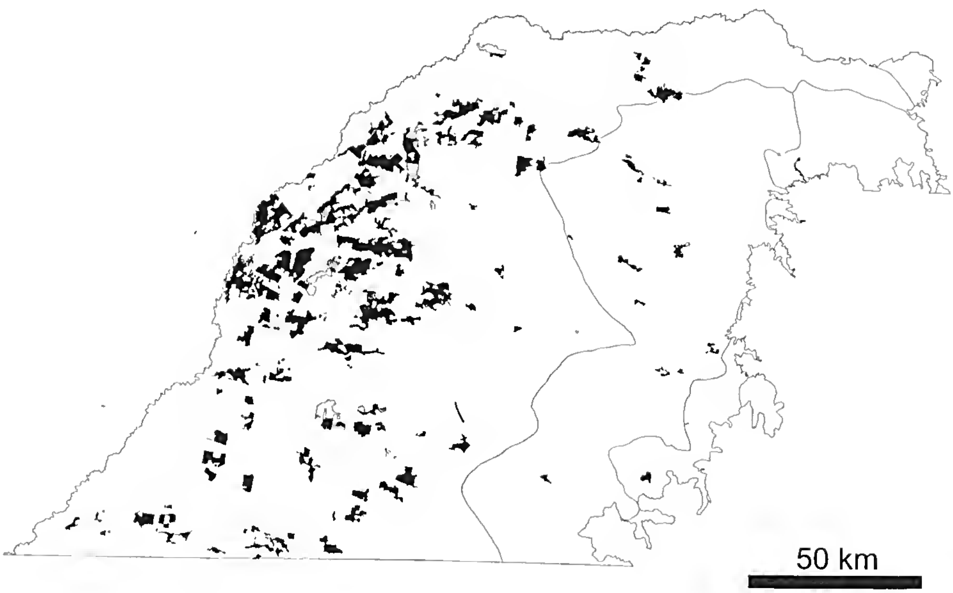

Fig. 14. Vegetation group 1: very extensive and heavily cleared (see text). Grey areas indicate clearing during the study period. Black areas indicate extant vegetation at the end of the study period. Lines indicate the boundaries of bioregional provinces (Fig. 3).

Fig. 15. Stand of vegetation type P9: Open Shrublands and Woodlands with young regeneration in the foreground.

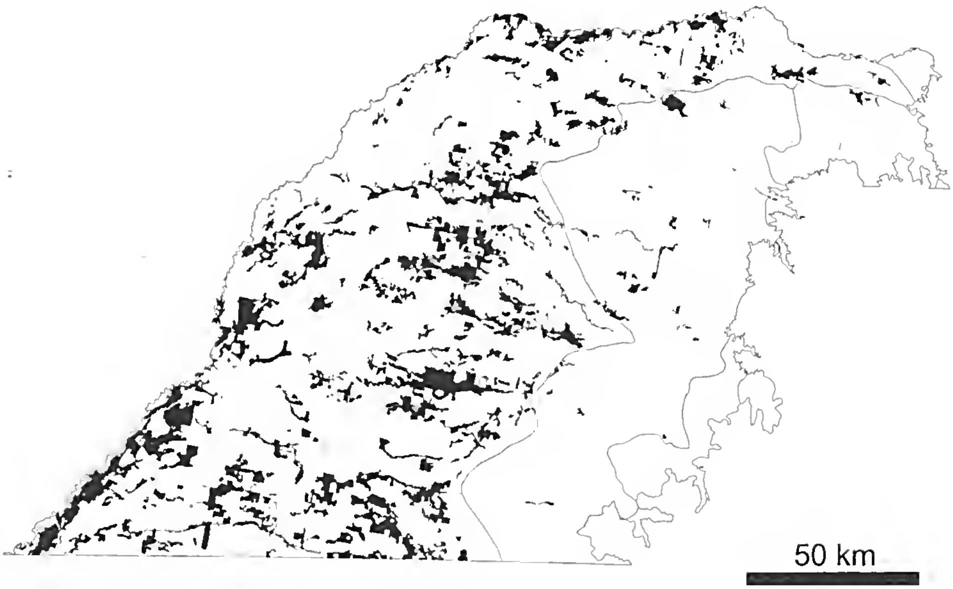

Fig. 16. Vegetation group 2: extensive and heavily cleared (see text). Grey areas indicate clearing during the study period. Black areas indicate extant vegetation at the end of the study period. Lines indicate the boundaries of bioregional provinces (Fig. 3).

Woodlands. They are mostly found in the Castlereagh-Barwon bioregional province (Fig. 16). This group accounted for 50% of the native woody vegetation in the study area in 1985. Coolabah (*Eucalyptus coolabah*) is the most common canopy species in these four vegetation types (Fig. 17).

The vegetation types in this group are found on grey clay soils that are suitable for cultivation and the low relief of the Castlereagh-Barwon province means that there are no physical constraints to prevent clearing. Substantial clearing of this group has occurred on and around the Gwydir Raft, west of the Moree township.

Group 3: Extensive with a low level of clearing

Only one extensive vegetation type, R1: River Red Gum-Coolabah Forests, experienced low levels of clearing during the study period. It is generally restricted to narrow bands in close proximity to rivers (Fig. 18) though in some areas its pre-European distribution would have included broader areas of adjacent floodplains.

Clearing within 20 metres of a watercourse has been prohibited since 1938 under the *Soil Conservation Act*, and continues to be prohibited under the *Native Vegetation Conservation Act*.

Group 4: Less common with a low to moderate level of clearing

Nine vegetation types are in this group: R4: Lignum Shrublands, R5: Myall Woodlands, R8: White Cypress Pine-Carbeen Woodlands, P3: Open Poplar Box Woodlands, P4: Poplar Box Woodlands, P8: Belah Woodlands, P10: Brigalow Woodlands, H5: Yetman Hills Complex, and H8: Basalt Hills. In general they occur in the eastern part of the study area which was very extensively cleared prior to 1985

Fig. 17. Stand of *Eucalyptus coolabah*.

(Fig. 19). Type R8 corresponds to Open Carbeen Forest which was listed as an Endangered Ecological Community under the auspices of the *NSW Threatened Species Conservation Act* in 1999.

This group typically occupies earthy loams and brown and grey clays which are suitable for agriculture. It is also found on sandy lenses which have only recently become suitable for cultivation with the development of new methods to seal the sandy soil with clay for flood irrigation.

Group 5: Uncommon and low level of clearing

This group is made up of two vegetation types, P6: Iron Bark-White Cypress Pine Woodlands and F4: Yetman Hills Complex. Both are very uncommon in the study area with a combined extent of less than 1000 ha in 1985.

Comparison with previously published results

Mapping undertaken by ERIC (1998) identified 2714 ha of clearing within the present study area for the period 1995 to 1997. Taking this as a 2-year period gives an average clearing rate of 1357 ha per year. In comparison, our mapping identified 42 776 ha of clearing for the period 1994 to 1998. Taking this as a 4-year period gives an average clearing rate of 10 694 ha per year, about 8 times the rate reported by ERIC (1998). Given the demonstrated accuracy of our visual interpretation methods, the extent, and hence the rate, of clearing reported by ERIC (1998) is clearly a significant underestimate for the study area.

Discussion

Native vegetation clearance is the single greatest threat to terrestrial biodiversity in New South Wales (EPA 2000). Continued clearing also threatens future agricultural production and incomes for farms and local communities through increased salinity, soil erosion, loss of insect pollinators, loss of native predators of agricultural pests, and disruption to other ecological services.

Our results show that substantial clearing of native woody vegetation is continuing in the northern New South Wales wheatbelt. Over the study period from 1985 to 2000 more than 110 000 ha of woody vegetation, 16.7% of the mapped 1985 extent, was cleared. Although the overall rate of clearing, and the rates for most individual vegetation types, were lower in the final 1998–2000 monitoring period than in the preceding period, clearing still exceeded 7000 ha (Table 5). In the most highly depleted bioregional province, Northern Outwash, the clearing rate steadily increased over the study period despite the province having only 8% native woody vegetation cover in 1985 (Fig. 12, Table 6).

Figure 20 shows simple projections of loss for native woody vegetation based on the overall average annual clearing rate and the rates for the last two monitoring periods.

These results are alarming, but we stress that they are conservative and the actual magnitude of loss and degradation of native vegetation in the study area is certainly greater than that presented here for a number of reasons.

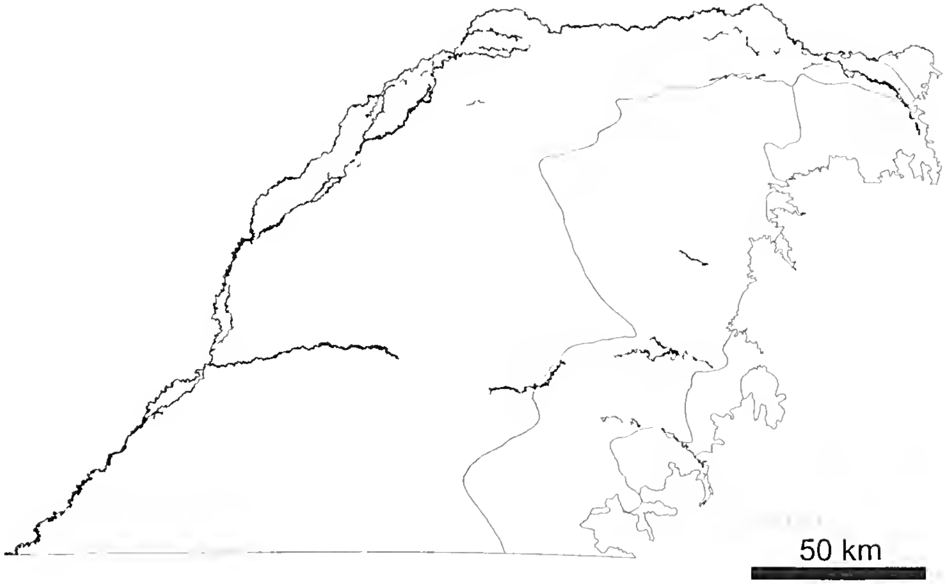

Fig. 18. Vegetation group 3: extensive with low level of clearing (see text). Lines indicate the boundaries of bioregional provinces (Fig. 3).

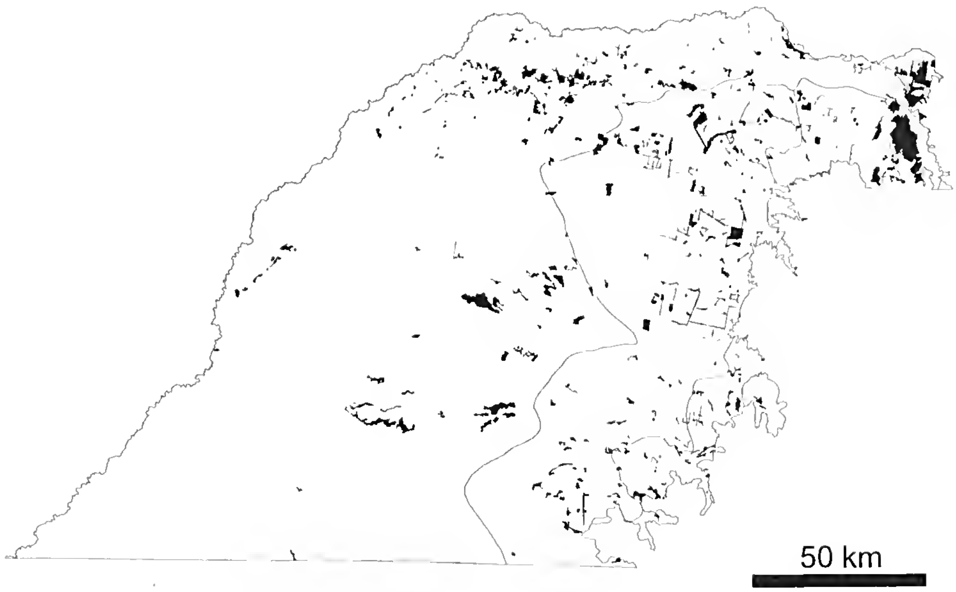

Fig. 19. Vegetation group 4: less common with moderate to heavy level of clearing (see text). Grey areas indicate clearing during the study period. Black areas indicate extant vegetation at the end of the study period. Lines indicate the boundaries of bioregional provinces (Fig. 3).

Firstly, our analysis is restricted to a subset of native vegetation within the study area. The baseline vegetation mapping of Sivertsen and Metcalfe (unpublished) delineates native woody vegetation with average canopy cover of at least 5%. Areas of scattered trees, treeless grasslands, other herbaceous communities and wetlands are not included. Yet all of these will have important conservation values and all are threatened by agricultural modification of the landscape and pressures such as irrigation and changed flooding regimes, inappropriate fire regimes, excessive grazing and weed infestation (Morrison & Bennet 1997, Benson 1999, EPA 2000).

Secondly, the limit of resolution in the baseline vegetation mapping and the Landsat satellite imagery used for this study set a lower limit of 10 ha on the size of remnants included in our analysis. This omits a large number of smaller remnants which, although only accounting for a small percentage of the total extent of native woody vegetation, will have important conservation values in terms of floristic composition, presence of rare plant and animal species, source of propagules and contribution to connectivity within the region. In the most highly depleted areas these small remnants may be the only link to the original native vegetation (Doherty 1998).

Thirdly, we omitted areas marked as uncertain during the interpretation of satellite imagery from the analysis presented here amounting to 17 822 ha for 1998 and 7531 ha for 2000. Our assessment of areas in the uncertain category presented in Table 4 shows that they include additional clearing of native woody vegetation. Ideally, a well-resourced monitoring program would use this category to guide further field or aerial checking.

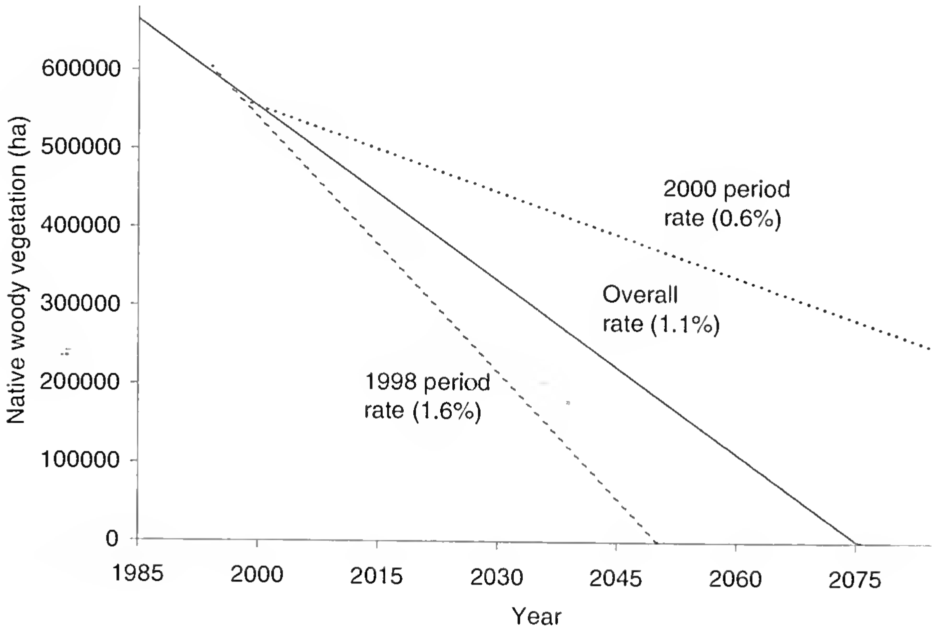

Fig. 20. Simple projection of vegetation losses based on maintaining average annual clearing rates.

Finally, we have reported only the loss of native woody vegetation characterised by the complete removal of the canopy layer or intensive cropping or pasture improvement beneath a sparse tree canopy. This omits thinning of tree cover, removal of very young saplings and degradation of the understorey through excessive grazing, burning or weed infestation, all of which are reportedly widespread in the study area. The effects of irrigation, landforming and changed water flows can also be profound. For example Morrison and Bennett (1997) describe irrigation-induced degradation and loss of Lignum shrublands and Coolabah woodlands in the Gwydir Valley.

Assessment and comparison of mapping methods

Visual interpretation of Landsat TM satellite imagery proved to be a practical and effective method for detecting change due to clearing in the study area including in areas of sparse native woody vegetation. Systematic validation of the technique indicated a high degree of accuracy. Comparison of our mapping with previous mapping largely derived from automated classification methods (ERIC 1998) showed that substantially more clearing was detected. The average annual clearing rate from our mapping was approximately eight times greater than that calculated from the ERIC mapping.

The ERIC study was intended for a broad-scale analysis of statewide clearing patterns. The techniques used allow a relatively rapid assessment of the gross pattern of clearing and trends in relative clearing rates between successive studies. At this level the statewide mapping is valuable but it cannot be used to calculate accurate absolute clearing rates.

Accurate data on vegetation change are essential for landuse planning. The use of methods that seriously underestimate the rate of clearing in sparse vegetation, such as the open woodlands of the study area, risks inappropriate decision making and unforseen negative consequences, both for nature conservation and for sustainable agricultural production. Though it is possible that future advances in digital analysis of satellite data will make automated methods feasible, this does not appear to be the case at present.

Another important limitation of previous studies is that they have only reported gross changes in vegetation cover. In contrast, the methods used in this study, together with baseline maps of extant native vegetation, allow us to report on change in the extent and distribution of individual vegetation types. This is a very considerable advantage for landuse, conservation and vegetation management planning. For statewide reporting of vegetation clearing we would suggest a combined approach that applies the methods used here for regions with adequate vegetation mapping and coarser methods where such mapping is not yet available.

General trends

Figure 8 summarises the general trend in overall clearing rates across monitoring periods. The highest average annual rate, approximately 10 700 ha per year cleared, was recorded for the 1994–1998 monitoring period, possibly in anticipation of the incoming *Native Vegetation Conservation Act*.

The results for the most recent monitoring period, 1998–2000, show a marked overall decline in the average annual clearing rate. However, a thorough validation of these results has yet to be carried out. Ideally, monitoring using similar methods to those used in this study will continue to determine if the rates of clearing remain at or below this lower level. Data on the location and boundaries of approvals granted for clearing, but not yet exercised, would also ideally be integrated into a comprehensive monitoring program. Clearing approvals granted by the NSW Department of Land and Water Conservation are valid for up to four years.

Trends for vegetation types

A number of points stand out from the results for individual vegetation types. Only one relatively common vegetation type, R1: River Red Gum-Coolabah Forests, was not heavily cleared during the study period. All other extensive types suffered substantial reductions from their mapped 1985 extent. Five types had percentage reductions in area that exceeded the general level of native woody vegetation loss.

Regrowth woody vegetation, mapped by Sivertsen and Metcalfe (unpublished) as P9: Open Shrublands and Woodlands was particularly heavily cleared. This could reflect ease of clearing as well as a perception that it is of lower value, in some sense, than other types of vegetation. Sivertsen and Metcalfe (unpublished) noted that many stands of this vegetation type showed obvious signs of disturbance and modification. Rapid clearing of Open Shrublands and Woodlands in the 1994–1998 monitoring period contributed to the high average annual clearing rate for overall vegetation. The *Native Vegetation Conservation Act* presently allows for clearing of regrowth vegetation that is up to ten years old. However, the stands of Shrublands and Woodlands mapped by Sivertsen and Metcalfe that remain will all now be older than this. Doherty (1998) points out that remnants of native vegetation that are secondary or even tertiary regrowth still represent a link to the original vegetation of a region and are of conservation value.

Coolabah (*Eucalyptus coolabah*) dominated woodlands were particularly heavily cleared during the study period. Large stands of Coolabah had been cleared prior to this study and others were apparently killed by altered flooding regimes in the Gwydir River valley (Morrison & Bennett 1997). The present rates of decline are thus of serious concern and, if maintained, would be expected to lead to population decline in a wide range of species.

Cumulative loss of vegetation

As the total area of native vegetation is reduced, the cumulative impact of each successive clearing event becomes greater. We found that an average of 7355 ha, or 1.1% of the total area of native woody vegetation mapped for 1985, was cleared during each year of the study period (Table 5). If this average rate was maintained then the actual percentage of vegetation lost in any given year would steadily increase (Fig. 21 lower curve). The upper curve (Fig. 21) shows what would result if the average annual clearing rate for the 1994–1998 period was maintained. These curves emphasise the need for frequent monitoring of vegetation clearing since apparently modest long term averages can mask high short-term losses.

The analysis of the proportion of native woody vegetation cleared within 10 km radius neighbourhoods across the study area illustrates another aspect of cumulative loss (Fig. 11). Areas to the east of Collarenebri and Mungindi are highlighted because of very large clearing events in these vicinities. But other areas, such as those to the north-east and north-west of Moree where the extent of clearing was much smaller, are also highlighted. In these areas there was very little native woody vegetation remaining by 1985 and so any clearing represents a large proportional loss.

Attempts to predict and mitigate the effects of vegetation clearing

Theoretical and empirical studies suggest that there can be a substantial time lag between habitat loss or modification and the onset of population declines and extinctions, an effect referred to as extinction debt (Saunders et al. 1991, Tilman et al. 1994). This implies that in an extensively cleared region predicting the implications of further habitat loss, or setting thresholds for maximum acceptable modification of the landscape, becomes increasingly precarious.

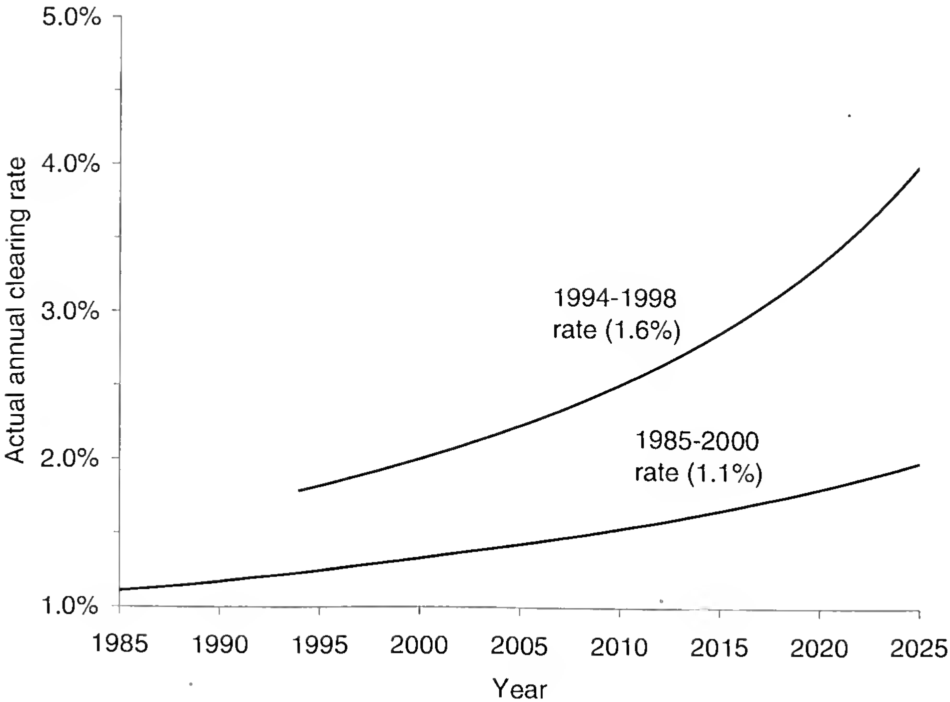

Fig. 21. Increase in the actual annual clearing rate over a 40 year period. The lower curve is based on the overall average clearing rate for 1985–2000. The upper curve is for the average rate for the monitoring period 1994–1998.

Other studies suggest that the relationship between habitat reduction and species loss in a region is likely to be highly non-linear and that there may be critical levels of habitat reduction beyond which the loss of species greatly accelerates (Andren 1994, Green 1994). One mechanism is the sudden decrease in spatial connectivity between vegetation remnants when the total vegetation cover is reduced below a certain point. Our ignorance on these issues is profound. It is difficult to say which groups of species will display population behaviour of the type seen in theoretical models or what the critical thresholds might be for different groups.

Various schemes for setting landuse limits within agricultural landscapes have been put forward (e.g. Freudenberger et al. 1997, McIntyre 2000, Reid 2000) that attempt to either prevent native vegetation cover falling below some critical point or, where it is already highly depleted, to restore the level of native vegetation to some level. Current vegetation management proposals include:

- setting targets for the retention or restoration of native vegetation cover;
- setting limits on the extent of overall vegetation or individual vegetation types that can be cleared;
- setting limits on the proportion of vegetation types that can be converted to intensive land uses such as cropping;
- increasing the area devoted to conservation through reserves, Voluntary Conservation Agreements or other mechanisms.

There is little science on which to base the setting of any such targets and limits, but values between 30–40% for retention of native woody vegetation cover have been widely advocated.

The mapping of Sivertsen and Metcalfe (unpublished) shows that the total cover of native woody vegetation in the study area had been reduced to 27.3% by 1985. Despite this, vegetation clearance has continued and at the end of our study period the figure had fallen to 22.8%. Levels of remaining cover vary between the three major bioregional provinces. In the Northern Outwash province total cover had fallen to 7.1% (Table 6). In terms of individual vegetation types precise pre-clearing areas are not available but many types, such as Brigalow Woodlands, have been reduced to a very small percentage of their former extent while others, such as the Coolabah dominated woodlands, have been subjected to recent extensive clearing. Any further clearing will narrow what options still remain to conserve a minimal level of native woody vegetation cover and attempt to expand remnants in the most depleted areas.

Implications for the *Native Vegetation Conservation Act* and regional vegetation management

With the implementation of the *NSW Native Vegetation Conservation Act* at the beginning of 1998, the management of native vegetation shifted to a regional model. The intention was to provide a framework for communication and cooperation between landholders, state and local government representatives, conservation groups, aboriginal representatives and scientists through Regional Vegetation Committees. Potentially, this could lead to an integrated consideration of sustainable agricultural production and conservation, but its success depends, in large measure, on our ability to provide the necessary high quality information required for decision making.

For native woody vegetation this information includes accurate vegetation mapping and monitoring of change. Comparison of the results of this study with data presented by ERIC (1998) shows that previous mapping of the location and extent of native woody vegetation clearance has seriously underestimated clearing rates. This is a result of the inability of automated classification methods to detect change in sparse woody vegetation that characterises much of the study area. As such, we conclude that this mapping is not a suitable basis for regional vegetation management.

A stated intention of the *Native Vegetation Conservation Act* is to prevent inappropriate clearing. Given very low total cover of native woody vegetation in the Northern Outwash bioregional province at the start of the study period, it could be assumed that any further clearing within the province would have been inappropriate. Instead, our analysis has shown that a high proportion of the remaining native woody vegetation was cleared in areas within the province (Fig. 11) and the average annual clearing rate steadily increased over the study period (Fig. 12). Thus far, the *Native Vegetation Conservation Act*, as well as *State Environmental Planning Policy No. 46* that preceded it, appear to have failed to prevent further decline in this very extensively cleared province.

Fragmentation effects

Our results show that for overall native woody vegetation, and most vegetation types, fragmentation has increased. Vegetation remnants, and patches of vegetation types, have become generally smaller as large remnants were reduced in size or separated into disjunct parts. The vulnerability to edge effects, as measured by exposed perimeter to area ratio, increased for almost all vegetation types. There are very few stands of any mapped vegetation type that are not adjacent to cleared land.

A comprehensive analysis of the effects of fragmentation on the biodiversity of the study area is beyond the scope of this study. The effects of the loss of vegetation cover through clearing, the spatial arrangement of vegetation remnants, condition and disturbance attributes, and the requirements and distribution of particular plant and animal taxa are all important and will interact in complex ways. There is a great need for further research. However, we agree with Reid (2000) that in the case of habitat loss on the massive scales seen in the New South Wales wheatbelt, attempting to separate the influence of habitat reduction from that of fragmentation on species extinctions is futile and irrelevant. Instead, there is a clear imperative to halt the present decline in native woody vegetation cover and enhance the size and quality of existing remnants.

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Apppendix: Detailed results for vegetation types.

The names and descriptions of vegetation types are taken from the unpublished data and mapping of Sivertsen and Metcalfe. Descriptions of vegetation structure follow the terminology of Walker and Hopkins (1984). Bioregional provinces referred to in the descriptions are those of Morgan and Terrey (1992) and are shown in Fig. 3.

Type R1: River Red Gum-Coolabah Forests

Description

This vegetation type is found along river banks, channels and back plains of the floodplain. Common canopy species are *Eucalyptus camaldulensis* and *Eucalyptus coolabah*. Typically it is restricted to narrow bands in close proximity to rivers on alluvial clays and grey cracking clays. It is found in all bioregional provinces within the study area.

Clearing within 20 metres of a watercourse has been prohibited since 1938 under the *Soil Conservation Act* and continues to be prohibited under the *Native Vegetation Conservation Act*.

Clearing

There was a relatively small amount of clearing in River Red Gum-Coolabah Forests over the study period, amounting to just over 1% of the area mapped in 1985 (Table 8).

Fragmentation

All mapped patches of River Red Gum-Coolabah Forests were adjacent to cleared areas. The number of patches and the range of patch sizes remained stable over the study period (Table 8, Fig. 22) though the median size decreased in the period ending 1998.

Table 8. Results for R1: River Red Gum-Coolabah Forests.

	1985	1994	1998	2000	Overall
Remaining extent (ha)	39 415	39 298	39 076	38 960	
Area cleared (ha)	-	117	222	116	**455**
Area cleared (% 1985 vegetation)	-	0.3%	0.6%	0.3%	**1.2%**
Average annual clearing rate (ha/yr)	-	13	56	58	**30**
Average annual clearing rate (as % 1985 vegetation)	-	0.03%	0.14%	0.15%	**0.08%**
Average annual clearing rate (as % previous area)	-	0.03%	0.14%	0.15%	
Number of patches	54	52	54	54	
Median patch area (ha) (min–max)	190 (18–11 877)	189 (18–11 879)	170 (18–11 875)	170 (18–11 875)	
Number of patches adjacent to clearing	54	52	54	54	
Median P/A ratio (m/ha) for patches adjacent to clearing	61.76	63.63	63.63	58.52	

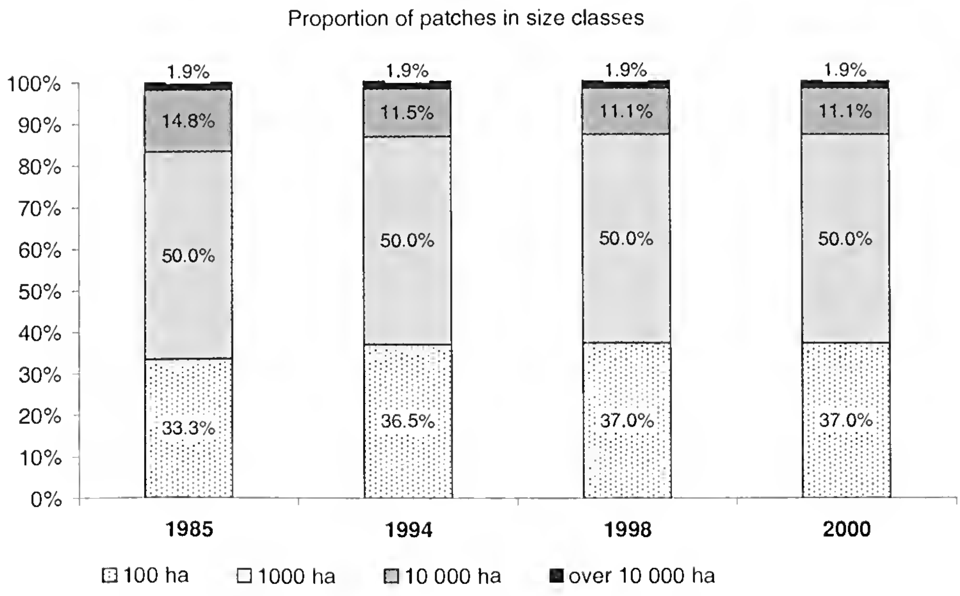

Fig. 22. The proportion of patches of R1: River Red Gum-Coolabah Forests in each of four size classes.

Type R2: Floodplain Mosaic

Description

This is a complex vegetation type with structure varying from tall open forests to low woodlands, sedgelands and grasslands. It is associated with grey cracking clays of floodplains and backplains. Common canopy species include *Eucalyptus coolabah*, *Eucalyptus largiflorens* and *Casuarina cristata*, with some *Eucalyptus camaldulensis* and *Eucalyptus populnea* subsp. *bimbil*. It is concentrated in two areas, the first in the northern-most part of the study area along the Macintyre, Boomi and Whalan Rivers, with a small patch on the Barwon River. The other occurrence is between Collarenebri, Moree and the southern boundary of the study area. Both areas are mostly within the Castlereagh-Barwon province.

Clearing

Floodplain Mosaic was heavily cleared during the study period, with a total loss of 13 900 ha amounting to 19% of the extent mapped for 1985 (Table 9). The overall average clearing rate, as a percentage of 1985 extent, was higher than the general rate of vegetation loss in the study area (cf. Table 7).

In the period ending 1994, there were a series of small to medium clearing events in the northern part of the study area. The following period, ending 1998, saw a doubling of the average clearing rate to about 1500 ha per year. There were large clearing events in the southern part of the study area near the confluence of the Gwydir and Barwon rivers. A particularly large series of clearing episodes occurred near Rowena on Thalaba Creek. The final 1998–2000 period saw a substantial reduction in the clearing rate.

Fragmentation

Compared to the beginning of the study period, stands of Floodplain Mosaic have become smaller and more prone to edge effects (Table 9, Fig. 23). There has been a steady increase in the proportion of patches of 1000 ha or less at the expense of the larger size classes. Median patch size decreased by 40% over the study period. The steady increase in patch perimeter to area ratio indicates increasing vulnerability to edge effects as previously large contiguous stands are reduced and sometimes subdivided by clearing.

Table 9. Results for R2: Floodplain Mosaic

	1985	1994	1998	2000	Overall
Remaining extent (ha)	71 586	64 674	58 514	57 639	
Area cleared (ha)	-	6912	6161	875	**13 948**
Area cleared (% 1985 vegetation)	-	9.7%	8.6%	1.2%	**19.5%**
Average annual clearing rate (ha/yr)	-	768	1540	437	**930**
Average annual clearing rate (as % 1985 vegetation)	-	1.07%	2.15%	0.61%	**1.30%**
Average annual clearing rate (as % previous area)	-	1.07%	2.38%	0.75%	
Number of patches	75	97	112	116	
Median patch area (ha) (min–max)	348 (9–11 494)	208 (1–10 200)	131 (1–9700)	117 (1–9700)	
Number of patches adjacent to clearing	74	96	111	115	
Median P/A ratio (m/ha) for patches adjacent to clearing	28.90	33.41	38.51	44.80	

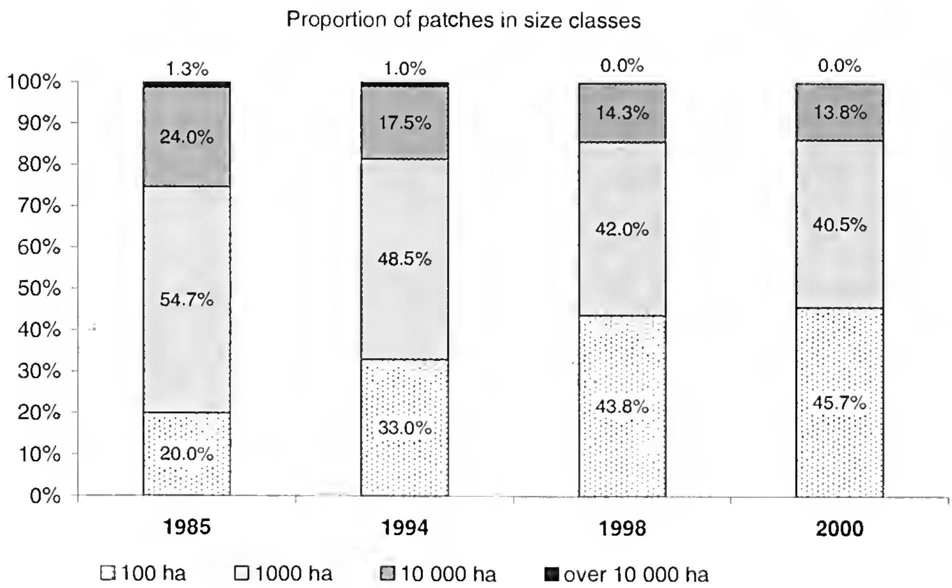

Fig. 23. The proportion of patches of R2: Floodplain Mosaic in each of four size classes.

Type R3: Coolabah Woodlands

Description

This vegetation type varies in structure from tall open forests through to open woodlands. The canopy is dominated by *Eucalyptus coolabah*, *Eucalyptus camaldulensis* and *Casuarina cristata*. It is usually associated with grey cracking clays on floodplains and closed depressions. Most occurrences are in the south west corner of the study area, along the Barwon River, Pian Creek, Thalaba Creek, Moomin, Mehi, and Gwydir Rivers, and Gingham watercourse. Further north, they occur on Croppa Creek, the Macintyre and Barwon Rivers. Most of the distribution is in the Castlereagh-Barwon province with some minor occurrences further east.

Clearing

Over 12 000 ha of Coolabah Woodlands, 14.5% of the mapped 1985 extent, were cleared during the study period (Table 10). The overall percentage rate of loss was slightly below the general rate of vegetation loss in the study area (cf. Table 7). The highest average annual clearing rate, over 1000 ha per year, was recorded for the period ending 1998. The rate decreased to about a quarter of this level in the period ending 2000.

Fragmentation

There was an increase in the number of patches over the study period while minimum, maximum and median patch sizes all decreased. The number of patches up to 100 ha in area steadily increased at the expense of the larger size classes (Table 10, Fig. 24). Almost all patches of Coolabah Woodlands are adjacent to clearing and there was an increased vulnerability to edge effects as indicated by increasing patch perimeter to area ratios.

Table 10. Results for R3: Coolabah Woodlands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	86 064	78 408	74 120	73 550	
Area cleared (ha)	-	7656	4288	570	**12 514**
Area cleared (% 1985 vegetation)	-	8.9%	5.0%	0.7%	**14.5%**
Average annual clearing rate (ha/yr)	-	851	1072	285	**834**
Average annual clearing rate (as % 1985 vegetation)	-	0.99%	1.25%	0.33%	**0.97%**
Average annual clearing rate (as % previous area)	-	0.99%	1.37%	0.38%	
Number of patches	98	109	123	126	
Median patch area (ha) (min–max)	182 (13–21 811)	154 (1–17 884)	137 (1–17 507)	135 (1–17 406)	
Number of patches adjacent to clearing	95	106	120	124	
Median P/A ratio (m/ha) for patches adjacent to clearing	32.32	35.31	42.56	42.97	

Type R4: Lignum Shrublands

Description

Lignum Shrublands are dominated by *Muehlenbeckia florulenta* and *Acacia stenophylla*. In the wheatbelt they are found on the grey cracking clays of banks, flats and swamps of the alluvial floodplains. In the present study area this vegetation type is restricted to four isolated stands along watercourses. However, it may be more extensive since it is difficult to identify from aerial photography.

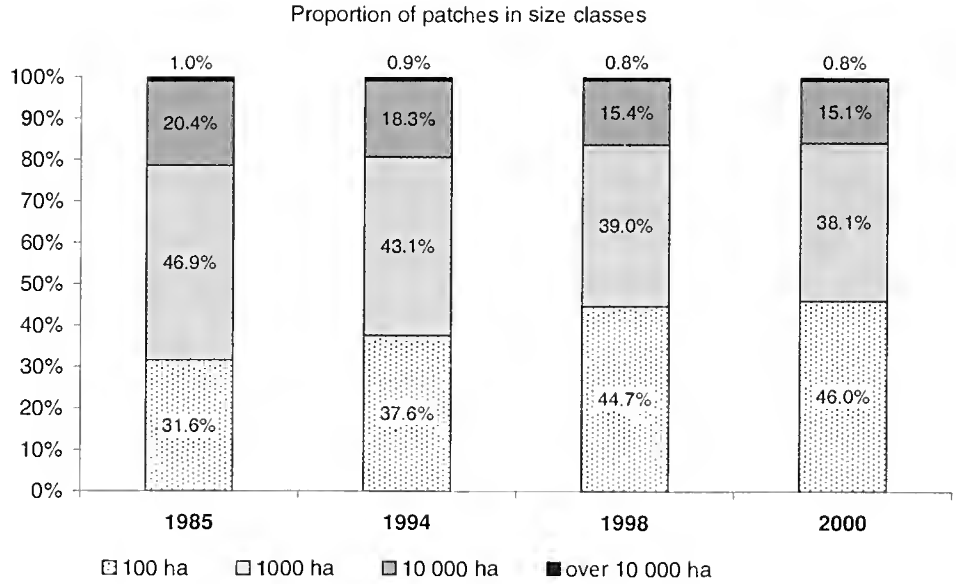

Fig. 24. The proportions of patches of R3: Coolabah Woodlands in each of four size classes.

Clearing

Of the 1212 ha of Lignum Shrublands mapped for 1985, 357 ha were cleared over the study period, a 29% reduction in the mapped 1985 extent (Table 11).

Fragmentation

Partial clearing of two of the original four patches is reflected in the increase in perimeter to area ratio. The distribution of patch sizes is not graphed for this small number of patches. All but one of the patches are adjacent to clearing.

Type R5: Myall Woodlands

Description

Myall Woodlands vary from mid-high to low open woodland. The canopy is dominated by *Acacia pendula*, with *Geijera parviflora, Alectryon oleifolius* and *Acacia farnesiana* present as occasional components. It is associated with gilgaied brown & grey cracking clays. Within the present study area it is mostly found in the Northern Outwash and Northern Basalts provinces.

This community is often difficult to distinguish on aerial photography and hence could have been more extensive than originally mapped in 1985.

Clearing

Nearly 10% of the mapped 1985 extent of Myall Woodlands was cleared during the study period (Table 12). The highest clearing rate was recorded for the period ending 1998 with much lower rates in the both the preceding and subsequent periods.

Fragmentation

There was a 30% decrease in the median size of patches over the study period. All patches are adjacent to cleared land and their vulnerability to edge effects, as measured by perimeter to area ratio, increased. The proportion of patches of up to 100 ha increased at the expense of the largest size class (Fig. 25).

Table 11. Results for R4: Lignum Shrublands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	1212	1207	1047	855	
Area cleared (ha)	-	5	159	192	**357**
Area cleared (% 1985 vegetation)	-	0.5%	13.1%	15.9%	**29.5%**
Average annual clearing rate (ha/yr)	-	1	40	96	**24**
Average annual clearing rate (as % 1985 vegetation)	-	0.05%	3.29%	7.94%	**1.96%**
Average annual clearing rate (as % previous area)	-	0.05%	3.30%	9.19%	
Number of patches	4	4	4	5	
Median patch area (ha) (min–max)	249 (129–586)	247 (129–585)	247 (129–426)	129 (42–426)	
Number of patches adjacent to clearing	3	3	3	4	
Median P/A ratio (m/ha) for patches adjacent to clearing	41.19	42.88	44.28	64.94	

Table 12. Results for R5: Myall Woodlands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	8466	8346	7675	7627	
Area cleared (ha)	-	120	671	48	**839**
Area cleared (% 1985 vegetation)	-	1.4%	7.9%	0.6%	**9.9%**
Average annual clearing rate (ha/yr)	-	13	168	24	**56**
Average annual clearing rate (as % 1985 vegetation)	-	0.16%	1.98%	0.28%	**0.66%**
Average annual clearing rate (as % previous area)	-	0.16%	2.01%	0.31%	
Number of patches	18	18	23	23	
Median patch area (ha) (min–max)	190 (11–2040)	190 (11–2038)	103 (1–1648)	103 (1–1623)	
Number of patches adjacent to clearing	18	18	23	23	
Median P/A ratio (m/ha) for patches adjacent to clearing	34.33	34.22	43.28	44.14	

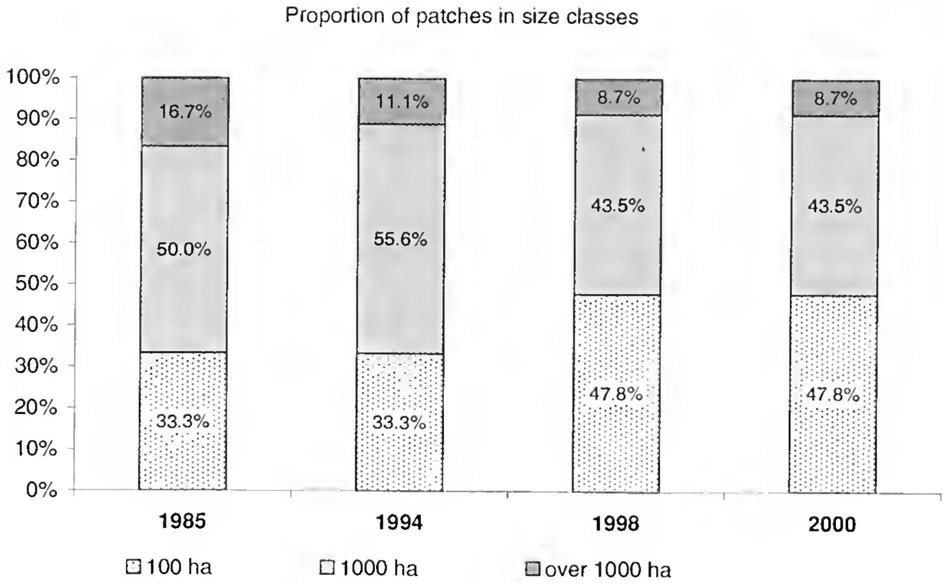

Fig. 25. The proportions of patches of R5: Myall Woodland in each of three size classes.

Type R7: Coolabah-Poplar Box Woodlands

Description

This vegetation type ranges in structure from woodlands to tall open woodlands with some grassland inclusions. Characteristic canopy species are *Eucalyptus populnea* subsp. *bimbil*, *Eucalyptus coolabah*, and *Casuarina cristata*. It occurs on the interzone between the black soil dominated alluvial plain and the more elevated earthy soil of the peneplain. This interzone comprises elements of both soil types in a complex mosaic. Within the mosaic, areas of treeless grassland occur in sinuous bands which follow relict, in-filled watercourses. Most occurrences are in the Castlereagh-Barwon province with some relatively isolated remnants in the Northern Outwash province north of Moree.

Clearing

11679 ha of Coolabah-Poplar Box Woodlands, 12.4% of the mapped 1985 extent, were cleared over the study period (Table 13). The highest clearing rate was in the period ending 1998. Clearing during this period mainly occurred close to watercourses, with clearing events between Moomin and Mehi watercourses, along the Gingham watercourse, and along the Barwon, Boomi & Macintyre Rivers. The clearing rate in the subsequent period decreased by more than 50%.

Fragmentation

Over the study period, patches of Coolabah-Poplar Box Woodlands have become smaller, more numerous and more prone to edge effects (Table 13, Fig. 26). The median size of patches decreased by 30% and the number of patches in the up to 100 ha category increased by nearly three times at the expense of the larger size classes. Almost all patches are adjacent to cleared land and became generally more vulnerable to edge effects as measured by perimeter to area ratio.

Table 13. Results for R7: Coolabah-Poplar Box Woodlands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	93 935	87 050	83 103	82 256	
Area cleared (ha)	-	6885	3947	847	**11 679**
Area cleared (% 1985 vegetation)	-	7.3%	4.2%	0.9%	**12.4%**
Average annual clearing rate (ha/yr)	-	765	987	424	**779**
Average annual clearing rate (as % 1985 vegetation)	-	0.81%	1.05%	0.45%	**0.83%**
Average annual clearing rate (as % previous area)	-	0.81%	1.13%	0.51%	
Number of patches	116	150	166	170	
Median patch area (ha) (min–max)	334 (41–9212)	194 (1–8802)	184 (1–7766)	174 (1–7658)	
Number of patches adjacent to clearing	114	148	164	169	
Median P/A ratio (m/ha) for patches adjacent to clearing	32.89	44.11	47.53	47.53	

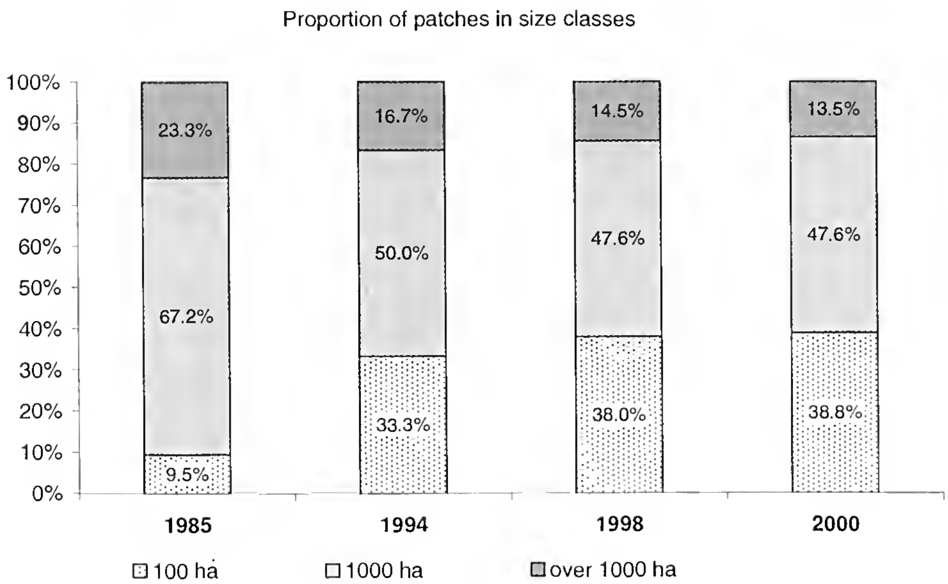

Fig. 26. The proportion of patches of R7: Coolabah-Poplar Box Woodlands in each of three size classes.

Type R8: White Cypress Pine-Carbeen Woodlands

Description

This vegetation type varies from tall open forests to tall open woodlands. A number of temperate dry rainforest taxa are found in the canopy and understorey. Characteristic canopy species include *Callitris glaucophylla, Corymbia tessellaris, Eucalyptus populnea* subsp. *bimbil, Corymbia dolichocarpa, Eucalyptus camaldulensis, Casuarina cristata and Allocasuarina luehmannii.* It occurs on siliceous sands and minor earthy sands on flats and gentle rises of the alluvial plain and is concentrated in the northern part of the Castlereagh-Barwon province north of Whalan creek.

This type corresponds to Carbeen Open Forest which was listed as a Endangered Ecological Community under the New South Wales Threatened Species Conservation Act in 1999.

Clearing

1970 ha of White Cypress Pine-Carbeen woodlands, 11.9% of the mapped 1985 extent, were cleared over the study period (Table 14). The highest clearing rate was in the period ending 1998. Most clearing took place in the northern part of the study area as well as on the Gwydir raft near Moree, where this type is present as scattered stands. About 250 ha were cleared between Mungindi and Collarenebri in a narrow band of remnants parallel to the Barwon River. The clearing rate decrease substantially in the final period ending 2000.

Fragmentation

Median patch area fell substantially over the study period, especially in the period ending 1998 (Table 14). The distribution of patch sizes was more stable than for some other vegetation types though there was an increase in the proportion of patches in the smallest (up to 100 ha) size class (Fig. 27). Nearly all patches are adjacent to cleared areas and their vulnerability to edge effects, as measured by perimeter to area ratio, increased.

Table 14. Results for R8: White Cypress Pine-Carbeen Woodlands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	16 521	15 660	14 644	14 551	
Area cleared (ha)	-	861	1016	93	**1970**
Area cleared (% 1985 vegetation)	-	5.2%	6.1%	0.6%	**11.9%**
Average annual clearing rate (ha/yr)	-	96	254	47	**131**
Average annual clearing rate (as % 1985 vegetation)	-	0.58%	1.54%	0.28%	**0.80%**
Average annual clearing rate (as % previous area)	-	0.58%	1.62%	0.32%	
Number of patches	58	63	67	67	
Median patch area (ha) (min–max)	172 (12–1518)	136 (1–1517)	100 (1–1517)	100 (1–1424)	
Number of patches adjacent to clearing	55	60	64	64	
Median P/A ratio (m/ha) for patches adjacent to clearing	44.38	49.56	54.64	54.64	

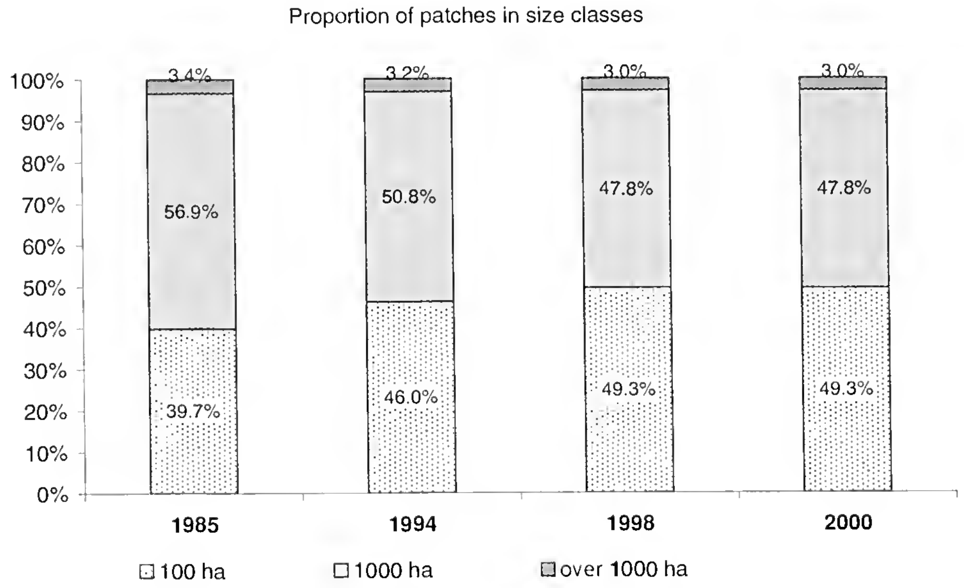

Fig. 27. The proportion of patches of R8: White Cypress Pine-Carbeen Woodlands in each of three size classes.

Type R10: Open Coolabah Woodlands

Description

This vegetation type varies from mid-high to tall woodlands and open woodlands. *Eucalyptus coolabah* dominates the canopy with *Casuarina cristata* and *Acacia stenophylla* also present. It occurs on the grey cracking clays of the banks and floodplains of Gill Gill Creek, the Gwydir River and Pian Creek in the Castlereagh-Barwon province.

Clearing

Open Coolabah Woodlands were one of the most heavily cleared vegetation types. The overall clearing rate of 1.25% of 1985 extent per year is greater than the overall rate of vegetation loss in the study area (cf. Table 7). 16 314 ha, more than 18% of the mapped 1985 extent, was cleared during the study period (Table 15). The highest clearing rate was in the period ending 1998. Most clearing occurred in the vicinities of Rowena and Collarenebri as well as along the Mehi River, about 50 km west of Moree. The clearing rate fell substantially in the final period ending 2000.

Fragmentation

Open Coolabah Woodlands became substantially more fragmented as measured by all summary statistics (Table 15). Minimum and maximum patch sizes decreased and there was a very marked decrease in median size from 1265 ha to 81 ha. This is also indicated by the changing distribution of patch sizes (Fig. 28) with the proportion of patches in the smallest size class, up to 100 ha, increasing by more than 8 times over the study period at the expense of the large size classes. All patches are adjacent to clearing and their overall vulnerability to edge effects, as measured by perimeter to area ratio, increased markedly.

Table 15. Results for R10: Open Coolabah Woodlands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	86 689	77 409	71 449	70 375	
Area cleared (ha)	-	9280	5961	1073	**16 314**
Area cleared (% 1985 vegetation)	-	10.7%	6.9%	1.2%	**18.8%**
Average annual clearing rate (ha/yr)	-	1031	1490	537	**1088**
Average annual clearing rate (as % 1985 vegetation)	-	1.19%	1.72%	0.62%	**1.25%**
Average annual clearing rate (as % previous area)	-	1.19%	1.93%	0.75%	
Number of patches	23	44	57	64	
Median patch area (ha) (min–max)	1265 (72–17 772)	227 (1–15 203)	101 (1–13 249)	81 (1–13 245)	
Number of patches adjacent to clearing	23	44	57	64	
Median P/A ratio (m/ha) for patches adjacent to clearing	17.32	39.08	51.73	59.18	

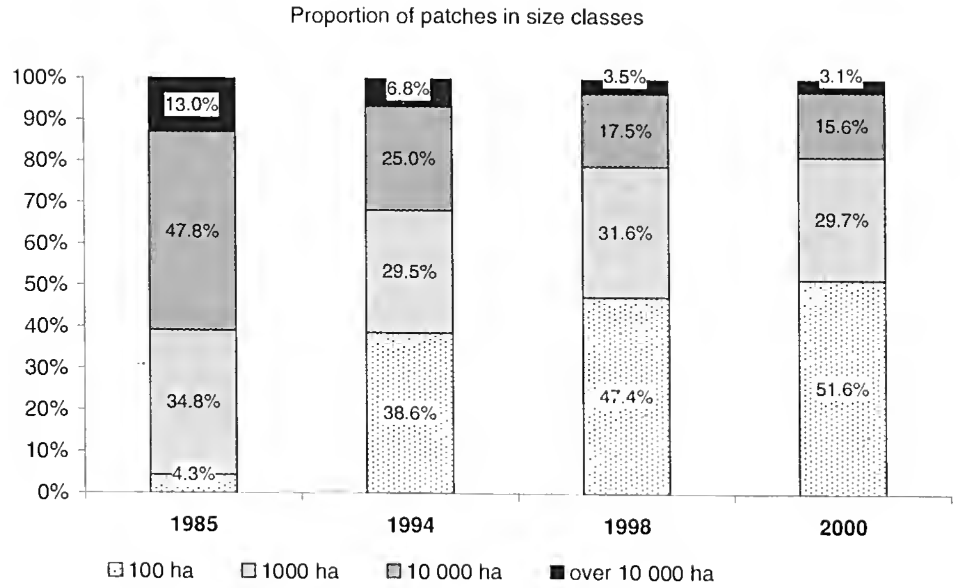

Fig. 28. The proportion of patches of R10: Open Coolabah Woodlands in each of four size classes.

Type P3: Open Poplar Box Woodlands

Description

This vegetation type varies in structure from mid-high to tall open woodlands. *Eucalyptus populnea* subsp. *bimbil* is the most common canopy species with *Casuarina cristata, Acacia harpophylla* and *Eucalyptus melanophloia* also present. It is mostly found on loamy red earths of flats, gentle slopes and low crests. The distribution takes in the eastern two thirds of the study area with occurrences in the Castlereagh-Barwon, Northern Outwash and Northern Basalts provinces.

Clearing

Open Poplar Box Woodlands were among the most heavily cleared vegetation types. The overall clearing rate of 1.24% of 1985 extent was higher than the overall rate of vegetation loss in the study area (cf. Table 7). 4085 ha, or 18.6% of the mapped 1985 extent, were cleared over the study period (Table 16). The highest clearing rate was in the period ending 1998. The subsequent period saw the rate drop by about two thirds.

Fragmentation

Median patch size decreased by about 25% (Table 16). All patches are adjacent to clearing and their vulnerability to edge effects, as measured by perimeter to area ratio, increased. The proportion of patches in size classes remained relatively stable over the study period (Fig. 29).

Table 16. Results for P3: Open Poplar Box Woodlands

	1985	**1994**	**1998**	**2000**	**Overall**
Remaining extent (ha)	21 954	19 587	18 083	17 869	
Area cleared (ha)	-	2367	1504	214	**4085**
Area cleared (% 1985 vegetation)	-	10.8%	6.9%	1.0%	**18.6%**
Average annual clearing rate (ha/yr)	-	263	376	107	**272**
Average annual clearing rate (as % 1985 vegetation)	-	1.20%	1.71%	0.49%	**1.24%**
Average annual clearing rate (as % previous area)	-	1.20%	1.92%	0.59%	
Number of patches	79	82	88	89	
Median patch area (ha) (min–max)	175 (12–1607)	145 (12–1607)	124 (2–1470)	117 (2–1470)	
Number of patches adjacent to clearing	79	82	88	89	
Median P/A ratio (m/ha) for patches adjacent to clearing	46.55	52.63	60.44	60.88	

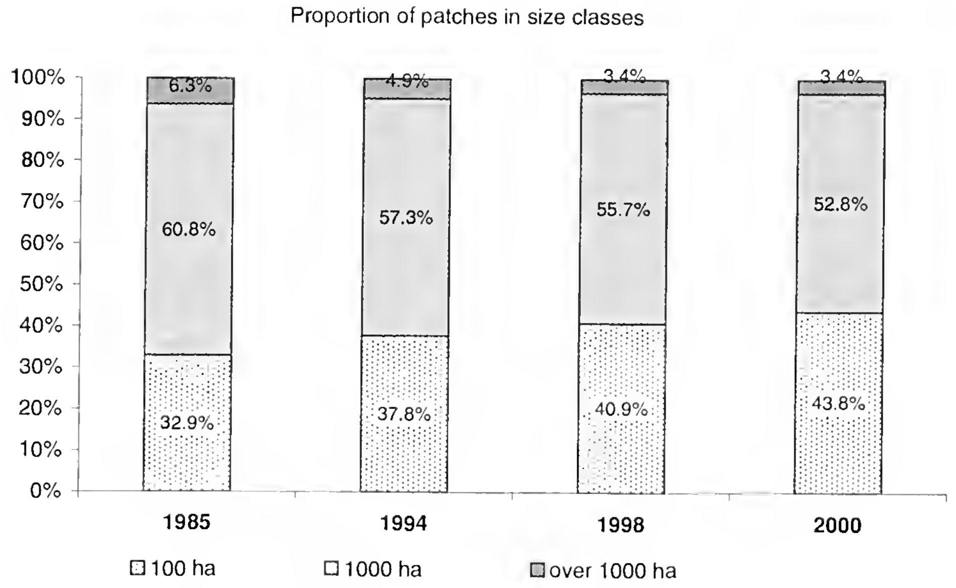

Fig. 29. The proportion of patches of P3: Open Poplar Box Woodlands in each of three size classes.

Type P4: Poplar Box Woodlands

Description

This vegetation type is very similar in composition to P3: Open Poplar Box Woodlands and is distinguished by its more continuous canopy cover. Common canopy species include *Eucalyptus populnea* subsp. *bimbil*, *Eucalyptus melanophloia*, *Casuarina cristata* and *Callitris glaucophylla*. Both habitat and distribution are similar to P3: Open Poplar Box Woodlands.

Clearing

This was one of the less cleared vegetation types with 1097 ha, or 9.8% of the mapped 1985 extent, being cleared during the study period (Table 17). The highest clearing rate was recorded in the period ending 2000.

Fragmentation

Median patch size decreased by about 25% over the study period. Almost all patches are adjacent to clearing and their vulnerability to edge effects, as measured by exposed perimeter to area ratio, increased (Table 17). The proportion of remnants across size classes remained relatively stable over the study period (Fig. 30).

Table 17. Results for P4: Poplar Box Woodlands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	11 205	10 586	10 449	10 107	
Area cleared (ha)	-	618	137	342	**1097**
Area cleared (% 1985 vegetation)	-	5.5%	1.2%	3.0%	**9.8%**
Average annual clearing rate (ha/yr)	-	69	34	171	**73**
Average annual clearing rate (as % 1985 vegetation)	-	0.61%	0.31%	1.52%	**0.65%**
Average annual clearing rate (as % previous area)	-	0.61%	0.32%	1.64%	
Number of patches	58	60	59	61	
Median patch area (ha) (min–max)	94 (17–2369)	69 (17–2275)	67 (17–2275)	67 (12–2275)	
Number of patches adjacent to clearing	57	59	58	60	
Median P/A ratio (m/ha) for patches adjacent to clearing	59.63	63.69	67.62	67.62	

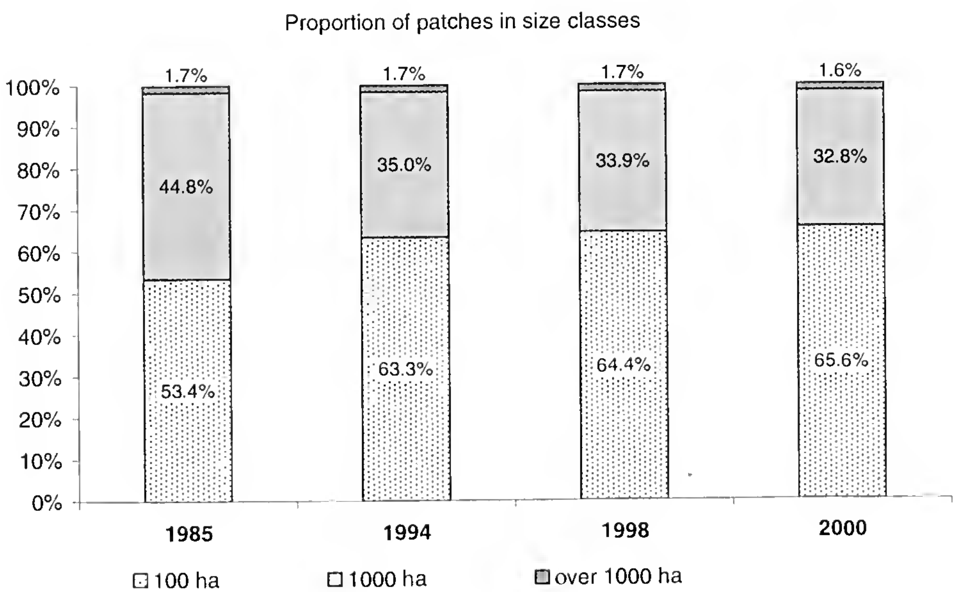

Fig. 30. The proportion of patches of P4: Poplar Box Woodlands in each of three size classes.

Type P6: Iron Bark-White Cypress Pine Woodlands

Description

This vegetation type forms a mid-high open forest with *Eucalyptus melanophloia*, *Callitris glaucophylla* and *Eucalyptus populnea* subsp. *bimbil* as the dominant canopy species. It is found on red earths on flats. Within the study area two small remnants were mapped by Sivertsen and Metcalfe (unpublished), one in the Northern Outwash province and the other in the Northern Basalt province.

Clearing

No clearing was recorded in the 132 ha of Iron Bark-White Cypress Pine Woodlands mapped in the study area (Table 18).

Table 18. Results for P6: Iron Bark-White Cypress Pine Woodlands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	132	132	132	132	
Area cleared (ha)	-	0	0	0	**0**
Area cleared (% 1985 vegetation)	-	-	-	-	-
Average annual clearing rate (ha/yr)	-	-	-	-	-
Average annual clearing rate (as % 1985 vegetation)	-	-	-	-	-
Average annual clearing rate (as % previous area)	-	-	-	-	
Number of patches	2	-	-	-	
Median patch area (ha) (min–max)	66 (27–105)	- -	- -	- -	
Number of patches adjacent to clearing	2	-	-	-	
Median P/A ratio (m/ha) for patches adjacent to clearing	60.85	-	-	-	

Type P8: Belah Woodlands

Description

This vegetation type varies in structure from mid-high to tall woodlands through to open woodlands. *Casuarina cristata* is the dominant canopy species with *Acacia harpophylla, Eucalyptus populnea* subsp. *bimbil*, and *Eucalyptus microcarpa* also present. It occurs on brown and grey clays of flats, very gentle slopes and minor streamlines. Within the present study area much of the distribution is in the Northern Outwash province as roadside remnants, windbreaks and riparian verges. Some larger remnants exist in the north of the study area in the Castlereagh Barwon province. There are also a small number of occurrences in the Northern Basalts province.

Clearing

The rate of loss for Belah Woodlands was about equal to the overall rate of vegetation loss for the study period. 1988 ha, or 16.3% of the mapped 1985 extent, were cleared (Table 19). The rate of clearing remained stable for the periods ending 1994 and 1998 with small clearing events scattered quite evenly throughout the distribution. Some patches were completely removed but most clearing appeared to be 'tidying up' of small areas leaving linear remnants. The final period saw the clearing rate drop by about 60%.

Fragmentation

At the start of the study period Belah Woodlands were already highly vulnerable to edge effects. There were no patches greater than 1000 ha and 59% were less than 100 ha. During the study period the median patch area decreased by about 20% (Table 19) and the proportion of patches in the smallest size class increased (Fig. 31). All patches are adjacent to clearing and their vulnerability to edge effects, as measured by perimeter to area ratio, increased.

Table 19. Results for P8: Belah Woodlands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	12 172	10 897	10 291	10 184	
Area cleared (ha)	-	1275	606	107	**1988**
Area cleared (% 1985 vegetation)	-	10.5%	5.0%	0.9%	**16.3%**
Average annual clearing rate (ha/yr)	-	142	152	54	**133**
Average annual clearing rate (as % 1985 vegetation)	-	1.16%	1.24%	0.44%	**1.09%**
Average annual clearing rate (as % previous area)	-	1.16%	1.39%	0.52%	
Number of patches	93	93	98	97	
Median patch area (ha) (min–max)	82 (12–777)	77 (1–563)	56 (1–563)	58 (1–563)	
Number of patches adjacent to clearing	93	93	98	97	
Median P/A ratio (m/ha) for patches adjacent to clearing	74.22	80.68	87.06	86.37	

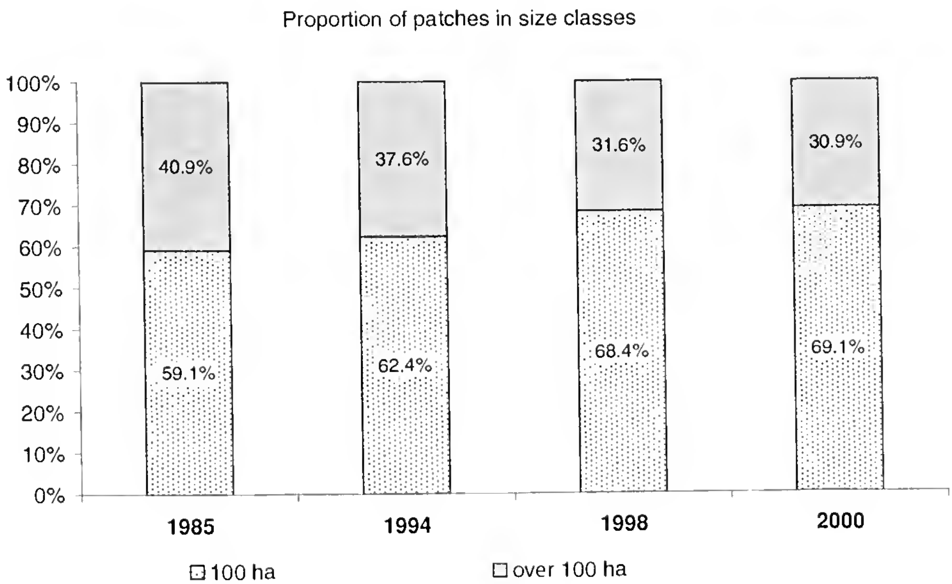

Fig. 31. The proportion of patches of P8: Belah Woodlands in each of two size classes.

Type P9: Open Shrublands and Woodlands

Description

This vegetation type occurs as open shrublands and woodlands which are typically very open and patchy. Canopy species include *Casuarina cristata, Eucalyptus coolabah, Eucalyptus largiflorens* and *Eucalyptus populnea* subsp. *bimbil*. It is found on grey clays on flats, open depressions, and gentle rises. The distribution of Open Shrublands and Woodlands is concentrated in the western third of the study area in the Castlereagh-Barwon province with lesser occurrences in the Northern Outwash and Northern Basalts provinces.

Stands of P9: Open Shrublands and Woodlands exhibit evidence of previous disturbance including thinning using a variety of techniques, ring-barking, poisoning and tree felling. The woody vegetation observed during field surveys for vegetation mapping was frequently young regrowth (Sivertsen & Metcalfe unpublished data). Remaining stands will now be over 13 years old with some in excess of 20 years old.

Clearing

Open Shrublands and Woodlands was the most heavily cleared of the extensive vegetation types in the study area and its rate of loss exceeded the overall rate of vegetation loss for the study period. 41 875 ha, or 22.4% of the mapped 1985 extent, were cleared (Table 20). The highest clearing rate was in the period ending 1998 while the rate fell by about 70% in the subsequent period.

Fragmentation

Patches of Open Shrublands and Woodlands became more numerous, smaller and more prone to edge effects over the study period. Minimum and maximum patch sizes decreased and there was a very marked reduction in the median size (Table 20). The proportion of patches in the smallest size class of up 100 ha increased by about ten times over the study period (Fig. 32) at the expense of the largest size classes. By the end of the study all patches were adjacent to clearing and their vulnerability to edge effects, as measured by perimeter to area ratio, had increased.

Table 20. Results for P9: Open Shrublands and Woodlands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	186 604	164 875	147 219	144 729	
Area cleared (ha)	-	21 729	17 656	2490	**41 875**
Area cleared (% 1985 vegetation)	-	11.6%	9.5%	1.3%	**22.4%**
Average annual clearing rate (ha/yr)	-	2414	4414	1245	**2792**
Average annual clearing rate (as % 1985 vegetation)	-	1.29%	2.37%	0.67%	**1.50%**
Average annual clearing rate (as % previous area)	-	1.29%	2.68%	0.85%	
Number of patches	105	156	213	223	
Median patch area (ha) (min–max)	1054 (41–14 011)	362 (1–11 573)	127 (1–7899)	95 (1–7899)	
Number of patches adjacent to clearing	103	156	213	223	
Median P/A ratio (m/ha) for patches adjacent to clearing	17.25	28.19	55.52	64.02	

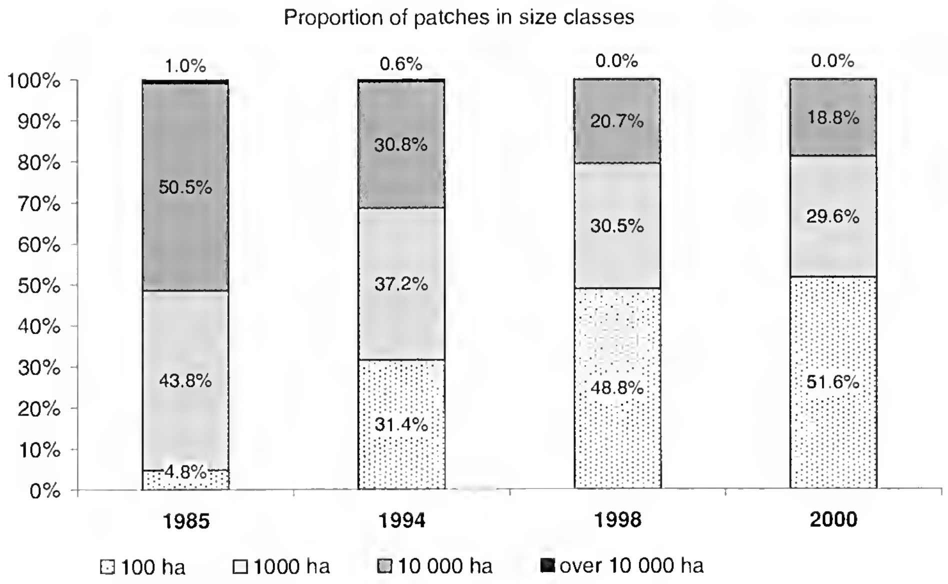

Fig. 32. The proportion of patches of P9: Open Shrublands and Woodlands in each of four size classes.

Type P10: Brigalow Woodlands

Description

This vegetation type varies in structure from mid-high woodlands to tall open forests. Canopy species include *Acacia harpophylla* with pockets of *Casuarina cristata*, and *Eucalyptus populnea* subsp. *bimbil*. It is found on brown clays of flats that are shallowly gilgaied. Most occurrences are in the northern half of the study area in the Northern Outwash and Northern Basalts Provinces with minor occurrences in the Castlereagh-Barwon Province.

Once extensive through what was known as the Brigalow Belt, Brigalow Woodlands were substantially cleared from the 1960s onwards. From an estimated extent of 250 000 ha (Pulsford 1984 cited in Benson 1999) only 5790 ha were present in 1985 (Sivertsen & Metcalfe unpublished).

Clearing

There was further clearing of Brigalow Woodlands during the study period with 823 ha, or 14.2% of the mapped 1985 distribution, being cleared (Table 21). The highest clearing rate occurred in period ending 1998 with a substantial reduction in the rate for the subsequent period.

Fragmentation

All remaining patches of Brigalow Woodlands are small. No patches are over 700 ha and half are less than 100 ha. The period ending 1994 saw a decrease in median patch size (Table 21) and an increase in proportion of patches in the smallest size class (Fig. 33). The very high perimeter to area ratios for all periods are a result of the generally small patches and indicate a high vulnerability to edge effects.

Table 21. Results for P10: Brigalow Woodlands

	1985	1994	1998	2000	Overall
Remaining extent (ha)	5792	5276	4994	4969	
Area cleared (ha)	-	516	282	25	**823**
Area cleared (% 1985 vegetation)	-	8.9%	4.9%	0.4%	**14.2%**
Average annual clearing rate (ha/yr)	-	57	70	13	**55**
Average annual clearing rate (as % 1985 vegetation)	-	0.99%	1.22%	0.22%	**0.95%**
Average annual clearing rate (as % previous area)	-	0.99%	1.34%	0.25%	
Number of patches	37	39	40	41	
Median patch area (ha) (min–max)	119 (11–682)	83 (11–618)	81 (11–606)	78 (11–606)	
Number of patches adjacent to clearing	37	39	40	41	
Median P/A ratio (m/ha) for patches adjacent to clearing	103.20	110.68	109.98	109.29	

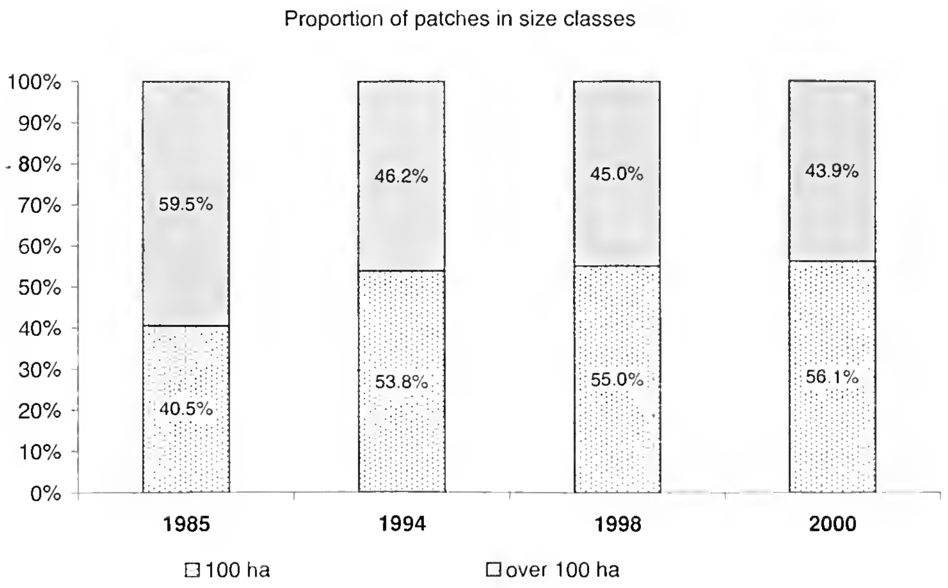

Fig. 33. The proportion of patches of P10: Brigalow Woodlands in each of two size classes.

Type F4: Yetman Footslopes Complex

Description

This is a complex type with sub-units too small to map at the 1: 250 000 scale used by Sivertsen and Metcalfe (unpublished). It varies in structure from tall to very tall woodlands and open forests. Canopy species include *Angophora costata*, *Eucalyptus chloroclada* and *Eucalyptus blakelyi* with some *Eucalyptus melanophloia* and *Callitris glaucophylla* also present. It occurs on siliceous and earthy sands associated with sandy streamlines and flats in the extreme east of the study area in the Northern Outwash and Northern Basalts provinces.

Clearing

The only clearing recorded for Yetman Footslopes Complex was 19 ha, or 2.8% of the 1985 mapped extent, in the period ending 1994 (Table 22).

Fragmentation

The number and size of patches remained stable throughout the study period.

Table 22. Results for F4: Yetman Footslopes Complex

	1985	1994	1998	2000	Overall
Remaining extent (ha)	697	677	677	677	
Area cleared (ha)		19	0	0	**19**
Area cleared (% 1985 vegetation)	-	2.8%	-	-	**2.8%**
Average annual clearing rate (ha/yr)		2	-	-	**1**
Average annual clearing rate (as % 1985 vegetation)		0.31%	-	-	**0.19%**
Average annual clearing rate (as % previous area)		0.31%	-	-	
Number of patches	8	8	8	8	
Median patch area (ha) (min–max)	42 (13–364)	41 (13–364)	41 (13–364)	41(13–364)	
Number of patches adjacent to clearing	8	8	8	8	
Median P/A ratio (m/ha) for patches adjacent to clearing	75.64	75.64	75.64	75.64	

Type H5: Yetman Hills Complex

Description

This is a complex type with sub-units too small to map at the 1: 250 000 scale used by Sivertsen and Metcalfe (unpublished). Its structure varies from mid-high open woodlands to open forests. A variety of canopy species are present including *Callitris glaucophylla, Allocasuarina luehmannii, Angophora costata, Eucalyptus crebra, Corymbia dolichocarpa, Eucalyptus dealbata* and *Eucalyptus melanophloia*. It grows predominantly on sandy red and yellow earths and siliceous sands on crests, slopes and flats. Most of its remaining extent is in Northern Basalts province in the far north- east of the study area with lesser occurrences in the Northern Outwash and Peel provinces.

Clearing

2422 ha of Yetman Hills Complex, or 14% of the 1985 mapped extent, were cleared over the study period (Table 23). Most clearing occurred in the period ending 1994.

Fragmentation

Patch sizes were relatively stable over the study period (Table 23, Fig. 34). All patches were adjacent to clearing and there was a modest increase in perimeter to area ratio.

Table 23. Results for H5: Yetman Hills Complex

	1985	1994	1998	2000	Overall
Remaining extent (ha)	17 201	15 030	14 892	14 779	
Area cleared (ha)	-	2172	137	113	**2422**
Area cleared (% 1985 vegetation)	-	12.6%	0.8%	0.7%	**14.1%**
Average annual clearing rate (ha/yr)	-	241	34	57	**161**
Average annual clearing rate (as % 1985 vegetation)	-	1.40%	0.20%	0.33%	**0.94%**
Average annual clearing rate (as % previous area)	-	1.40%	0.23%	0.38%	
Number of patches	12	15	15	15	
Median patch area (ha) (min–max)	157 (30–9598)	145 (26–8550)	145 (26–8550)	145 (26–8550)	
Number of patches adjacent to clearing	12	15	15	15	
Median P/A ratio (m/ha) for patches adjacent to clearing	35.20	39.65	39.65	39.65	

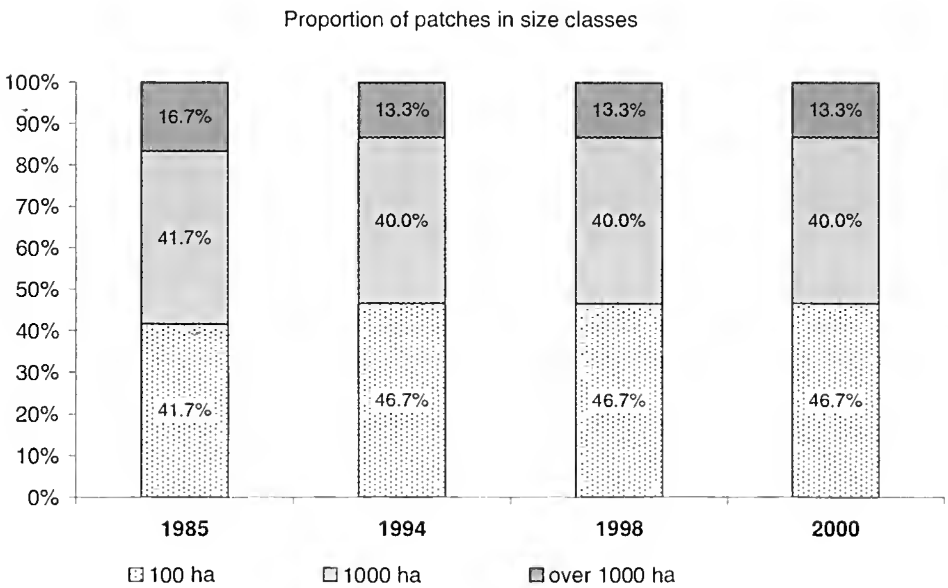

Fig. 34. The proportion of patches of H5: Yetman Hills Complex in each of three size classes.

Type H8: Basalt Hills

Description

This vegetation type forms mid-high open woodland and shrubland. Canopy species include *Casuarina cristata, Eucalyptus populnea* subsp. *bimbil, Callitris glaucophylla, Corymbia dolichocarpa*, and *Brachychiton populneus*. Seven small remnants were mapped on basalt hills by Sivertsen and Metcalfe (unpublished) on the eastern margin of the study area in the Northern Basalts province.

Clearing

The only clearing recorded for Basalt Hills was in the period ending 1998 with 146 ha, or 8.9% of the 1985 mapped extent, being cleared (Table 24).

Fragmentation

The size of the largest patch decreased in the period ending 1998 but otherwise patch sizes remained stable as did the median perimeter to area ratio.

Table 24. Results for H8: Basalt Hills

	1985	**1994**	**1998**	**2000**	**Overall**
Remaining extent (ha)	1649	1649	1503	1503	
Area cleared (ha)	-	0	146	0	**146**
Area cleared (% 1985 vegetation)	-	-	8.9%	-	**8.9%**
Average annual clearing rate (ha/yr)	-	-	36	-	**10**
Average annual clearing rate (as % 1985 vegetation)	-	-	2.21%	-	**0.59%**
Average annual clearing rate (as % previous area)	-	-	2.21%	-	
Number of patches	7	7	7	7	
Median patch area (ha) (min–max)	127 (28–702	127 (28–702)	127 (28–556)	127 (28–556)	
Number of patches adjacent to clearing	7	7	7	7	
Median P/A ratio (m/ha) for patches adjacent to clearing	43.95	43.95	43.95	43.95	

Information for Authors

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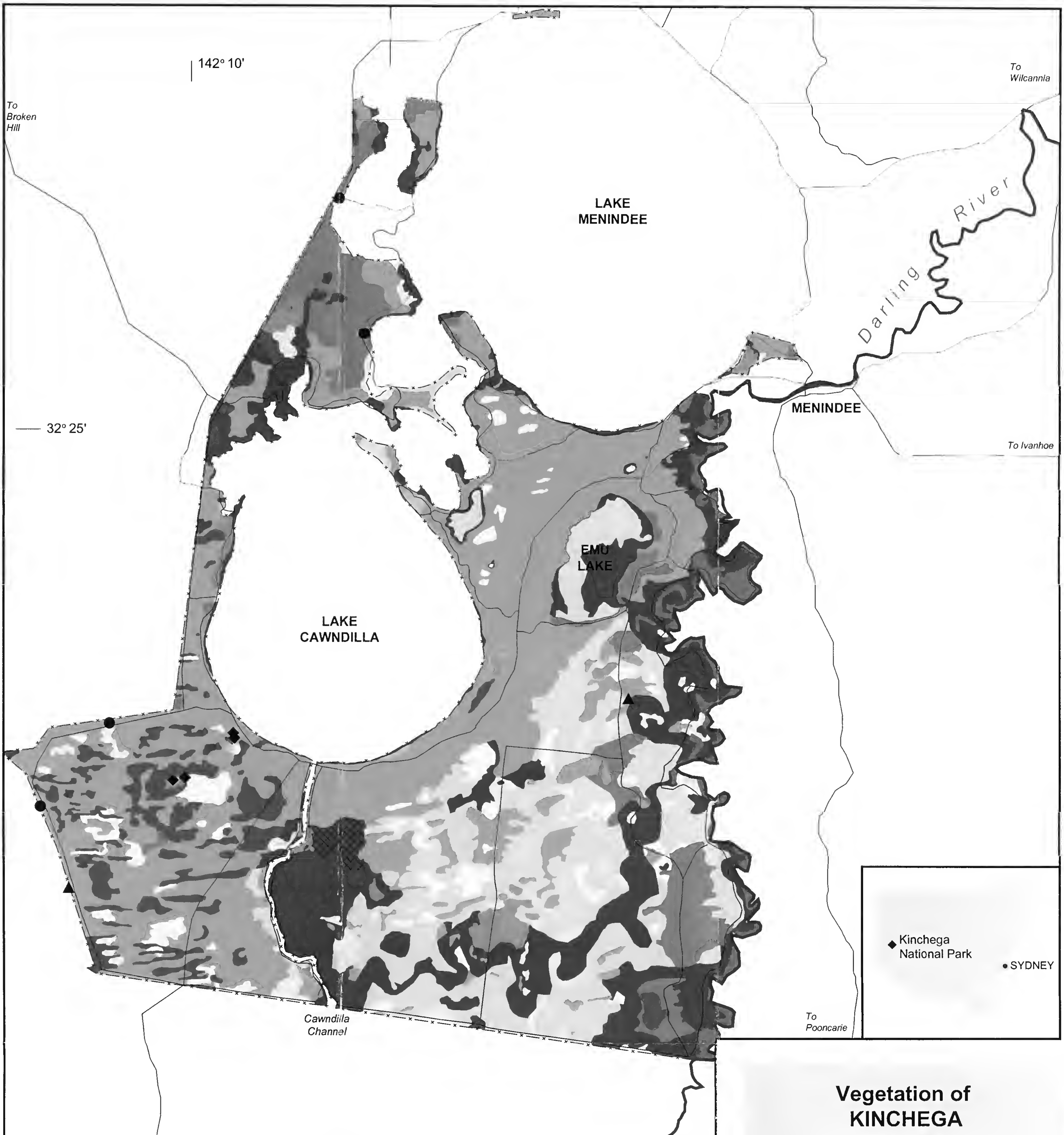

- *Eucalyptus camaldulensis* open-woodland
- *Eucalyptus largiflorens* woodland
- *Eucalyptus largiflorens* open-woodland
- *Casuarina pauper*/*Alectryon oleifolius* woodland/open-woodland
- *Acacia victoriae* subsp. *victoriae* open-shrubland
- *Acacia ligulata* open-shrubland
- ● *Acacia loderi* open-shrubland
- ◆ *Acacia carnei* open-shrubland
- ▲ *Acacia aneura* tall open-shrubland
- *Dodonaea viscosa* subsp. *angustissima*/*Senna artemisioides* subspecies/*Eremophila sturtii* shrubland
- *Maireana pyramidata*/*M. sedifolia* low open-shrubland
- *Atriplex nummularia* low open-shrubland
- *Chenopodium nitrariaceum* low open-shrubland
- *Sclerolaena* spp./*Atriplex* spp. low-open shrubland
- *Zygochloa paradoxa* hummock grassland
- Lakebed herbland
- Unvegetated/Scald
- Area of dead *Eucalyptus largiflorens* woodland
- Darling River
- Road or track
- Kinchega National Park boundary
- Lake boundary

N

Scale 1: 140 000

0 2.5 5 km

Australian Map Grid Zone 54

Vegetation of KINCHEGA NATIONAL PARK Western New South Wales

M.E. Westbrooke, M.K.C. Kerr & J.R. Leversha

University of Ballarat

Centre for Environmental Management

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